Collective Dynamics

Glossary for Research on Human Crowd Dynamics - 2nd Edition

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Abstract Pedestrian and crowd dynamics involves multiple disciplines, including computer science, engineering, mathematics, physics, bio-mechanics, psychology, social science and more. For effective collaboration between disciplines, researchers need a com-

mon understanding of key concepts. To address this challenge, *A Glossary for Human and Crowd Dynamics* was published six years ago, providing researchers with a valuable reference for cross-disciplinary communication.

We now present the second version, which includes 53 new concepts and 12 revisions from the first glossary, collaboratively developed by 65 contributors from various disciplines and regions around the world through a multi-stage process. This process involved identifying new concepts not covered in the first glossary and suggesting revisions to existing entries, voting on proposed additions and modifications, writing definitions for the selected concepts, and collaboratively revising and editing the entries.

By introducing new terms and refining existing definitions, this glossary aims to facilitate clearer communication, improve conceptual consistency, and support collaboration among researchers working within the field of human and crowd dynamics from diverse perspectives.

Keywords Anticipation · Behaviour · Behavioural repertoire · Behavioural uncertainty · Behaviour (Collective) · Behaviour (Operational/Tactical/Strategic) · Behaviour (Rational) · Behaviour (Non-rational) · Behaviour (Irrational) · Behaviour detection · Pushing behaviour · Bottleneck · Cognition · Cognitive maps · Competitiveness · Crush · Crowd composition · Crowd incident · Crowding · Density · Distance · Egress · Egressibility · Emergent phenomena · Evacuation · Evacuation guidance · Experiment · Falling · Falls · Field study · Flow · Flow rate · Fundamental diagram · Gait analysis · Gathering (Crowd/Mass/Religious) · Group · Groupthink · In-group · Social group · Prototypical group member · Headway · Ingress · Interaction · Leader · Level of service · Model (Hybrid) · Model (Machine learning) · Movement direction · Heading · Motivation · Navigation · Objective · Target · Purpose · Goal · Panic · Pedestrian · People counting · Perception · Risk perception · Personal space · Response time · Single-file · Single-file motion · Stampede · Trajectory · Velocity · Observed velocity · Free velocity · Desired velocity · Waiting · Zipper effect

1. Concepts

The concepts presented in the glossary are arranged alphabetically. If a concept has subconcepts, they are listed below the respective concept, also in alphabetical order. Revised concepts from the first glossary [1] are marked with a [Revised] label in their title.

Anticipation

Anticipation refers to actions taken in relation to an event that has not occurred yet. In the context of locomotion modelling, anticipation may be based on the prediction in time of the relative motion of other pedestrians with respect to the observer, leading to the adaptation of the observer's movement to avoid potential collisions. In many agent-based models, agents anticipate only up to the next most threatening collision, predicted from current velocities. Other approaches like game theory can describe anticipation over larger time

scales, such as the passage of a mobile obstacle, or the evacuation of a room. In psychology, in the context of perception and cognition, the term may be related to a broader range of prospective events. Their nuances may lead to distinct actions; for example, collision avoidance may differ depending on whether the collision is with an adult or a child.

Behaviour [Revised]

Actions or reactions by individuals in response to internal and external stimuli, including inaction. In the field of pedestrian dynamics, the concept is often extended to groups of people, in which case it is referred to as collective behaviour. Behaviour can be overt (observable) or covert (internal or private).

Behavioural repertoire

Behavioural repertoires are socially meaningful behaviours such as queuing, pushing or walking that can be seen in crowds. Some actions, such as walking, can be done solo or in groups of varying sizes, while others, such as racing or queuing, require the participation of others. Certain behaviours, such as dancing in a mosh pit or doing the "wave", can only be performed by many people. Furthermore, behavioural repertoires require specific spatial conditions (e.g. a queue cannot be formed in an already crowded space, a mosh pit requires an open space) and, conversely, can be physically characterised by a specific pattern of density, velocity and spatial orientation. Behavioural repertoires (e.g. queuing or running) are typically collections of movement operations that are bound together by cultural understandings and social scripts that describe not only what movements to make, but also how to feel, relate to each other, and so on. Some of these behaviours may be part of highly organised rituals.

Behavioural uncertainty

Behavioural uncertainty refers to the variability inherent in human behaviour due to its stochastic nature, meaning that human actions are inherently unpredictable and governed by probabilistic patterns. Evacuating the same building with the same individuals starting from the same locations on consecutive days could yield significantly different outcomes. On the other hand, human nature is not random, but it can appear stochastic because it is influenced by numerous complex and interacting factors that are not fully known. These factors make behaviour difficult to predict with precision, generating uncertainty. In the context of pedestrian motion, behavioural uncertainty arises due to individual motivation, past behavioural patterns, external environments (such as crowd density and perceived danger), and random perturbation.

Behaviour (Collective) [Revised]

Collective behaviours are responses of groups to internal and external stimuli that arise from interactions between group members and interactions with their surroundings. Col-

lective behaviour comprises the spatial or temporal synchronisation or coordination of group/crowd behaviour (signaling their common goal). In contrast, aggregate behaviour lacks synchronisation across individuals even if interactions between individuals may occur (e.g., to avoid collisions). For example, collective behaviours may occur within a crowd where people support each other attempting to approach a shared or overlapping goal (e.g., an exit) and aggregate behaviour may be observed in a crowd in a shopping centre where individuals separately try to get to different shops. Other relevant terms defined in this and the previous glossary are social group, collective emotions, and collective actions.

Behaviour (Operational/Tactical/Strategic)

Pedestrian behaviour can be considered as a three-level hierarchy: strategic, tactical and operational. At the strategic level, pedestrians make high-level decisions towards their long-term goal, such as selecting a destination and a schedule of activities. At the tactical level, they decide on specific actions, like selecting a route towards their destination. At the operational level, they make short-term, or local, movement decisions in response to their immediate surroundings. Local behaviour may be affected by the pedestrian's interaction with other pedestrians and the physical environment. Local behaviour may influence the pedestrian's operational-level and strategic-level behaviour and thus their long-term goal. For instance, if they consider local conditions too crowded, they could change the routes and exits they were originally planning to take.

Behaviour (Rational)

Decisions and actions resulting from analytic and possibly pre-planned processes that are guided by information perceived from the surrounding environment, authority figures, or others, intended to lead to appropriate outcomes. For instance, during an emergency, a person who observes a fire may rationally respond by raising the alarm and leaving via the nearest available exit.

Note that the term "rational" typically refers to an externally evaluated judgement of optimality or appropriateness. However, accurately assessing the adaptiveness of individuals' actions can be difficult. Individuals involved in an emergency may perceive their actions as rational even if the outcomes differ from their intended goals. This discrepancy often arises because their behaviour is strongly influenced by situational awareness, available information, and instructions received during the emergency.

Behaviour (Non-rational)

Decisions and actions taken that are the result of rapid thought processes, reduced or erroneous information, while not being privy to all viable options. The actor (e.g., the person showing non-rational behaviour) may consider their behaviour as rational based on the information at hand, their familiarity with their surroundings, or their level of expertise. For an external observer, however, their behaviour may (wrongly) be perceived

as irrational, which is common among such observers or those reporting on human behaviour during emergencies (e.g., the media and the attribution of behaviours or outcomes as "panic"). Examples of non-rational behaviours include people evacuating via their familiar exit rather than a closer emergency exit (due to lack of familiarity or lack of trust) or futile attempts when trying to put out a large fire with completely inappropriate and inadequate means. These types of behaviours are often observed during emergencies.

Behaviour (Irrational)

Decisions and actions that are impulsive, non-adaptive and emotionally driven, deviating from both rational and non-rational behaviour. These behaviours may be selfish, self-destructive or destructive to the group. Inaction in the face of danger is part of irrational behaviour. A key misconception is to label behaviours that are rational (or at least not irrational) from the perspective of the individuals involved in the emergency, such as pushing others in a crowd, as irrational because they appear so from the perspective of an outside observer or those reporting on the incident. The labelling of behaviour as irrational could therefore be considered an attribution error by external observers, when the intentions and actions of those responding to the danger are misinterpreted. Irrational behaviour is very rarely observed in emergencies and is atypical of human behaviour in hazardous situations - perhaps it is only observed when there is an imminent threat to life.

Behaviour detection

The act of identifying, detecting and categorising individual, group or collective behaviour in a crowd. Behaviour detection can be carried out in the context of field studies, experiments, everyday situations or crowd incidents. For incidents, behaviour detection can be achieved through various means, including firsthand observation, analysis of accounts and survey responses from those involved, or examination of any available video footage. For experiments, field studies, or the observation of everyday situations, video data often forms the basis for a systematic and reconstructable behaviour detection method. If not available, behaviour can also be recorded through participatory observations and the use of coding schemes. Some behaviour can also be directly detected with sensors. We expect that artificial intelligence will become able to detect crowd behaviour in the future.

Pushing behaviour

Pushing behaviour in crowds occurs when individuals exert physical force on others within the crowd. This can take different forms, such as using hands for traditional pushing, shoulders for applying pressure, or forearms to create personal space. The behaviour is often driven by individual motivations, such as the desire to reach a specific location, maintain one's position in a standing crowd, or escape the pressure of a densely populated area. Varying levels of motivation and physical attributes influence the intensity of force applied, so pushing behaviour can be categorized by its intensity. The direction of the push is also crucial, as it directly impacts the step and posture of the person being pushed.

Additionally, pushing behaviour is dynamic; an individual pushing in one moment may change their behaviour in the next as social and physical conditions change. Though usually observed as individual actions, groups of people may collectively engage in pushing behaviour. Pushing poses significant safety risks, as it increases crowd density and can lead to injuries, falls, or even life-threatening situations such as crowd crushes. Even when it doesn't cause immediate harm, it is often seen as an inappropriate behaviour. As a phenomenon within human and crowd dynamics, it is advised to study pushing behaviour and its effects from both psychological and physical perspectives.

Bottleneck [Revised]

A bottleneck is an area with reduced throughput capacity (e.g., a corridor narrowing) compared to its surroundings, causing congestion and higher pedestrian density upstream when the incoming flow exceeds that reduced capacity.

Cognition

Cognition is the set of mental processes that enable an individual to perceive, process, understand, and prepare to respond to their environment. Cognitive functions include perception, attention, memory, decision-making, reasoning, and problem solving. In pedestrian research, examples of such cognitive functions are the processing of perceptual information (vision, hearing, taste/smell, touch) from the human and built environment as well as social information from other people, the creation of an internal representation of the world, and the decisions about what stimuli to focus on and what action to take next.

Cognitive maps [Revised]

Cognitive maps are mental representations of space that help individuals navigate and understand their environment. Rather than being literal maps, they are abstract and flexible frameworks that encode, store, and recall information about locations and spatial arrangements. They include a person's spatial, environmental, and social knowledge.

There are different perspectives on how cognitive maps function – for example, whether they operate as a Euclidean-based representation of space (where landmarks are positioned using reasonably accurate spatial coordinates), as a connection-based representation (a topological map), as a network of topological connections between places labeled with local metric information, or as a combination of all three.

Competitiveness

Competitiveness refers to the behavioural tendency of individuals to compete or assert dominance in pedestrian spaces, such as sidewalks, entrances, crosswalks, or public transport stations. It can be quantified by how people navigate and position themselves relative to others, with some individuals seeking to move faster, claim more space, or reach destinations more efficiently than others. Sometimes it involves moving while disregarding

physical contact or potential collisions. In dense environments, such actions may escalate into pushing and, in extreme cases, lead to life-threatening situations.

Competitiveness can sometimes lead to friction or tension in crowded spaces, it can also be a natural response to the need to get to a destination efficiently and it can be part of playful forms of trying to be the first.

Crush

Crowd crushes are disasters in which excessive crowd density leads to a series of mechanisms that create enormous pressure on bodies, resulting in injuries or death. Critical density is exceeded when there is no longer space between individuals, causing them to lose control of their movements. This can lead to shoving, pushing, and mass instability, ultimately resulting in falls, injuries, or death due to asphyxia or physical trauma.

Crowd crushes often stem from organizational failures in crowd safety management, such as allowing overcrowding and exceeding critical density thresholds. These failures are sometimes compounded by poor infrastructure and ineffective communication. However, media reports often misattribute such incidents to "mass panic," portraying them as the result of individuals overreacting, lacking behavioural control, or thinking irrationally. They are also incorrectly labeled as "stampedes". These explanations wrongly place blame on crowd members and may not accurately reflect their actual behaviours.

Crowd composition

Crowd composition refers to the (physiological or psychological) characteristics and attributes of individuals within a crowd, including demographic, group identity, and situational factors, collectively influencing the crowd's dynamics and response. It involves both individual and group-level elements that shape how a crowd behaves.

A crowd is considered homogeneous if the attributes of interest among individuals within the crowd are identical or sufficiently similar. In contrast, a crowd composed of individuals with significantly different attributes is referred to as heterogeneous. Deciding whether the crowd is homogeneous or heterogeneous is especially important for simulations, where individuals are represented by agents with given parameters. Heterogeneity of agents is usually represented by multiple agent profiles (each defined by different set of parameters, goals or similar) or by wide distribution of the parameters representing heterogeneity (as e.g. desired velocity).

Crowd incident

Situations in places that are attended by many people, where accidents, increased safety risks, or unusual events occur as a result of interactions between individuals. Understanding the frequency and nature of these incidents can help develop targeted interventions to address the most prevalent safety concerns and enhance overall pedestrian safety and comfort. Often mistakenly used as a synonymous of "Crush", "Panic", and "Stampede".

Crowding

Crowding is the subjective psychological experience of spatial limitation, discomfort, or stress that individuals may perceive in crowd conditions due to restricted space. Perceptions of crowding can be influenced by personal and social factors, including task coordination, competition among crowd members, interpersonal relationships, or the nature of crowd members' social identities.

In contrast, crowd density refers to the objective, physical measurement of available space per individual, focusing solely on spatial limitations without considering individual perception or personal space. Therefore, density alone does not cause crowding; rather, social and personal factors play a key role in shaping the crowding experience.

Density

Density is a measure of the degree of occupancy of a given area. Fundamentally, density is a macroscopic measure, meaning it is well-defined for large, homogeneously distributed crowds. However, in practice, pedestrian flows often involve relatively few agents in confined spaces – compared to interpersonal distances. In such cases, density is still measured but should be interpreted as perceived density or as an observable influencing pedestrian dynamics.

Various methods exist for measuring density, with the most common unit being pedestrians per square meter. Methods range from direct pedestrian counts within a specified area to approaches using Gaussian smoothing, nearest-neighbor distance estimates, and Voronoi decomposition. The latter provides a direct measure of the area available to each pedestrian.

Distance

Distance is a measure of the spatial relationship between individuals or objects, typically measured in meters. This metric plays a crucial role in understanding crowd movement, including interactions between individuals and collision avoidance. For the inter-person distance, see the definition of headway.

Mathematically, distance can be defined in various ways depending on the type of model. For instance, in continuous space models, the Euclidean distance is commonly applied due to its straightforward geometric interpretation. In contrast, in discrete space models, the Manhattan distance can also be implemented, offering a suitable alternative in grid-based systems.

This spatial concept of distance can also be expanded for time relations, where time distance refers to temporal aspects such as time to collision, clearance times, or time gaps between individuals or objects. Additionally, in evacuation maps, not only the physical distance but also time distance is sometimes used as an indication of the approximate distance to the evacuation site.

Egress/Egressibility

Egress refers to the phase during which people leave or exit a space. It includes both routine and emergency situations, with emergency egress often referred to as evacuation. Considering human movement during egress is a critical aspect of architectural and urban design, ensuring that buildings and public areas provide adequate means for people to exit safely and efficiently.

Egressibility considers the accessibility to means of evacuation. For example, whether a given route is possible for a person, depending on their own personal and physical needs. This includes ensuring that exits are navigable and usable for all individuals, including those with functional limitations. It is essential that design and operations enable the safe and effective exit of all users during the egress phase, in both routine and emergency situations.

Emergent phenomena

A concept from complex systems theory referring to system properties that emerge exclusively through interactions between its parts. An essential characteristic of emergent phenomena is that they are not inherent in the individual elements, but only emerge from dynamic interplay between them. In crowd dynamics, global patterns of motion can arise at the crowd level from local interactions between individuals or from interactions between individuals and their physical environment. Consequently, these motion patterns cannot be easily predicted from observing the actions of individuals in isolation. Examples include collective motion effects, such as lane formation, that arise from interactions within a crowd in a static environment.

Evacuation [Revised]

The movement of individuals or a crowd to a safer location in response to a threat, warning, or safety concerns. Evacuation processes are often described as a timeline with several phases: detection, decision, alarm, reaction, and movement. The terms “evacuation” and “egress” are often used interchangeably, though “egress” more specifically refers to the phase during which people leave or exit a space.

Different types of evacuation include:

- Self-evacuation: This category involves individuals taking initiative to evacuate based on personal judgment or situational awareness, rather than waiting for instructions.
- Controlled evacuation: This term can be used for scenarios where evacuation is tightly managed and could include predetermined routes, checkpoints, or assembly points to avoid congestion or to maintain safety and/or security.
- Phased evacuation: Involves sequential evacuation of people in specific areas, e.g. floors in a high-rise building or seating areas in a sports ground.

- Community evacuation: Involves the large-scale evacuation and relocation of people from their residences over extended distances, often coordinated across various modes of transportation, including cars, buses, trains, boats, and even aircraft.
- Assisted evacuation: Involves the process of an individual or a group helping the evacuation of other individuals or groups that are unable to evacuate independently due to physical or cognitive impairments.

Evacuation guidance

Refers to the strategies, tools, and systems designed to direct people safely and efficiently during an evacuation. This may include:

- Fixed signage and markers indicating exits, assembly points, or safe routes. Information can be static or can be dynamically updated through electronic means.
- Specialized support systems for individuals with specific needs, including mobility impairments, sensory disabilities, medical conditions, or language barriers.
- Authority-led instructions provided by security personnel, emergency responders, or designated evacuation leaders, helping to manage crowd behaviour and ensure adherence to safe routes.

Experiment

Experiments (or experimental studies) are investigative approaches designed to formulate or test scientific hypotheses or models based on pedestrian dynamics measurements. Unlike observational (field) studies, experiments involve collecting measurements under controlled or semi-controlled conditions.

These controlled conditions represent simplified versions of real-world systems and can include demographic factors (e.g., student participants), physical settings (e.g., virtual reality environments), and tasks (e.g., navigating through a maze). Typically, experimental conditions are systematically varied to determine cause-and-effect relationships, such as analyzing how changes in exit widths affect egress times. Natural experiments make use of known changes taking place within actual systems to investigate these relationships — for instance, examining the impact of newly installed signage.

Experimental measurements of pedestrian dynamics employ various techniques capable of gathering data across different scales: involving large groups (macroscopic), individual pedestrians (microscopic), or specific body parts of individuals (sub-microscopic).

Key concerns in experimental studies include validity, robustness, and reproducibility of findings. The abstraction inherent in experimental designs can limit their ecological validity; however, carefully planned experiments can produce results that generalize beyond specific contexts, differentiating them from field observations. Robustness can be achieved through repeated measurements — for example, conducting multiple consecutive trials or runs within a given experimental setup involving different participant groups

drawn from the same population. Reproducibility, linked closely to the level of control maintained over experimental conditions, remains challenging due to inherent variability in pedestrian behaviour, ranging from individual differences to factors such as physical fitness, demographics, and social norms.

Falling/Falls

To come down onto the ground as a result of uncontrolled loss of balance, which can be caused by either internal perturbations (e.g., disease-related impairments, fainting, attempting sharp turns) or external perturbations (e.g., physical interactions such as being pushed, tripping over obstacles or slippery surfaces). Falling is one of the main causes of serious injuries reported in crowd incidents. Falls can result in individuals lying on the ground and being trampled by others. This may also trigger balance recovery actions involving physical interactions, which can set other individuals off balance and cause a chain reaction of falls.

Field study

Refers to the collection of data in the actual setting where the phenomena occur "naturally". Field experiments manipulate independent variables in the real world. In contrast to laboratory experiments, there is no perfect control of conditions, but the response of subjects to varying conditions is measured. In observational studies, there is no intervention by the researchers. Typically, subjects are unaware that they are being observed in order to avoid altering their natural behaviour.

Field studies usually have high ecological validity (realistic setting) but low internal validity (ability to attribute an effect to a factor or condition). Technological advances, such as improved sensors, have recently improved the quality of data in pedestrian research, making field studies increasingly popular.

Flow [Revised]

Flow represents the global movement of a set of pedestrians, who usually share the same goal, at least at the same moment. "Global" here refers to an averaged sense, where individual variations are not considered. Several flows may coexist, such as bidirectional flows in a corridor or crossing flows in an open space or at an intersection.

Flows can also be local, for example, when pedestrians react to a local perturbation, or global, as in the case of the evacuation of a building. A flow can be characterized by the composition of the crowd (age, gender, disabilities, luggage carriage, etc.), the average speed of the crowd members, their eagerness to move through (whether the situation is normal or if there is awareness of danger), and the homogeneity of the target direction.

Flow rate

The intensity of the ensemble movement of a set of pedestrians can be characterized by the flow rate. It is usually measured by counting the number of persons passing through either a virtual line more or less perpendicular to the main direction of the flow, or through a specific device through which pedestrians must go (e.g., a gate or door). The flow rate is obtained by dividing this number by the observation time. Flow can then be expressed in ped/s, or in ped/(m·s) if it is also divided by the width of the line crossed (such as the width of a corridor or gate). Other time or distance units may also be used. For a locally homogeneous crowd, flow rate can also be defined in the spirit of fluid mechanics as the product of the density and the mean velocity of pedestrians. In particular, the figure depicting the relationship between density and flow rate is one type of fundamental diagram. The obtained "specific flow" is the one appearing in the macroscopic mass conservation law and is defined as the number of pedestrians per unit time per unit distance.

Fundamental diagram [Revised]

The fundamental diagram describes the transport properties of crowds by illustrating the relationships between density, speed, and flow. Qualitatively, it shows that walking speed decreases as density increases. The flow–density relationship initially rises with increasing density, reaches a peak, and then declines as density continues to increase. The position of the peak separates density levels in which the movement is free from density level associated with congestion. Quantitative relationships vary across contexts due to differences in crowd composition, individual behaviour, cultural norms, the physical environment, and data collection practices.

Interpretation and modelling considerations: The fundamental diagram, often together with the continuity equation, is used in many mathematical models to ensure consistency with empirical transport properties of pedestrian flows. Agent-based models that aim to reflect these properties should qualitatively reproduce the shape of the fundamental diagram, especially to demonstrate their capacity to represent congested states. However, it is important to recognize that exact quantitative agreement with empirical data is not always expected. The specific form of the diagram is highly context-dependent. Imposing an empirical curve on a model without considering demographic, procedural, geometric, or cultural differences may lead to misleading or inappropriate conclusions.

Gait analysis

Gait analysis is a method for studying human locomotion, particularly movement patterns during walking or running, through kinematics, kinetics, and/or neuro-muscular assessments. This includes analyzing of the following parameters:

- Spatio-temporal parameters of gait such as: cadence (number of steps taken per unit of time), step length (distance between feet in the walking direction), step width (distance between feet perpendicular to walking direction), stride length (distance between successive placements of the same foot),

- Trajectory and derived quantities, e.g., velocity, speed, acceleration, jerk,
- Foot clearance: Distance between the foot and the ground during the swing phase (foot height),
- Joint angles and their coordination: Relative positions and movements of hips, knees, and ankles during gait cycle,
- Weight distribution: How body weight distribution shifts, e.g., Center of Mass or Center of Pressure,
- Base of Support: Area containing all contact points between an individual and its support surfaces,
- Muscle activity: Intensity and timing of muscle activation.

As such, gait analysis can provide valuable insights into mobility, balance, and potential fall risks, especially for older adults and populations with impairments. Further, it can help guide the design of safer staircases and evacuation procedures.

Gathering - Crowd/Mass/Religious

Mass gatherings can be inferred from trajectory pattern mining that allows spatial clusters (stable over time and space) to be identified. These physical gatherings can take different forms. They may involve people coming together for a specific social purpose, such as a religious celebration, a music festival, or a demonstration. These gatherings differ from scenarios in which large numbers of people are co-present (e.g., very busy railway stations) because they often feature a sense of shared group membership, even among individuals who do not personally know each other. Such a sense of shared group membership is not guaranteed, but when it emerges, it transforms a physical aggregate of individuals (acting in terms of their individuality) into a psychological collective with important consequences for behaviour.

First, crowd members' behaviour is shaped by their understanding of shared values and norms. Second, social relations between crowd members become closer, such that others' physical proximity is less likely to be experienced as aversive, and participants are more likely to provide mutual social support. Third, the emotional experience of crowd membership is often highly positive. These features of mass gatherings illustrate the importance of recognizing that crowd behaviour (including people's movement) is not reducible to the characteristics of the individuals gathered together. Rather, we must consider how people psychologically define themselves and those around them.

Additionally, mass gatherings often involve a certain degree of organization or structure, reflecting a common purpose or idea shared by participants. This organizational aspect does not necessarily require professional event management but indicates a level of coordination or intent that distinguishes these gatherings from spontaneous or incidental crowds.

Group [Revised]

1. A group of people or items is a set of people or items which are connected or linked for some period of time by some measure (e.g. spatially or psychologically).

2. In self-categorization theory (psychological terms), a group is defined as people who think of themselves as a group (as a theoretical definition).

3. Discussion:

   a) In crowd science, the term "pedestrian group" is often used to refer to a group of pedestrians, e.g., a group of people moving together. This definition does not specify the nature (or absence) of the social relationship between the group members. The label "group" may be assigned either by the individuals themselves or by an external observer. It would be beneficial to more clearly specify the nature of the group and to agree on sub-categories (e.g., social pedestrian groups defined as groups with persistent social relationships that extend beyond the immediate crowd context, such as family, friends, colleagues and similar; socially interacting pedestrian groups defined as groups whose members are socially interacting, such as conversation while walking together; a pedestrian group can also be a group of people carrying out the same activity, for example a group of visitors accompanying a guide in a museum).

   b) In models or simulations of crowd dynamics, often only groups of two (dyads) or three (triads) individuals are introduced, as these are reported to be the most frequently occurring. Furthermore, larger groups often break into smaller subgroups of two or three people, which tend to be more dynamically stable and present characteristic shapes (abreast, file, V or Lambda formations). Moreover, the question of an upper limit to the size of groups merits consideration. For example, small group research usually agrees that a team or a small group generally consist of no more than 7-10 persons.

Groupthink

For pedestrian dynamics groupthink may for instance refer to homogenous behaviour in the case of evacuation. However, empirical reviews suggest there is no evidence for the psychological state of groupthink. Alternative analyses of the situations upon which groupthink was based suggest that dissent among group members was more common than originally thought, and some experimental work has shown that highly identified group members can actually dissent more.

In-group

An in-group is a collection of individuals within a group (including in crowd contexts) who share a social identity based on common characteristics, beliefs or affiliations (e.g. students, believers, card-carrying members).

In social identity theory and self-categorisation theory, the in-group is contrasted with one or multiple out-group(s), who do not share the attribute that defines the in-group (e.g., non-students, infidels, non-members).

Social group

A social group is a collection of individuals who feel connected to one another and recognize themselves as part of the group, potentially leading to a sense of shared social identity. Social groups can be composed of familiar individuals (e.g., families, colleagues, friends), strangers who share a salient social identity (e.g., political protesters, concert attendees, football fans), or strangers who interact and form new connections in the crowd (e.g., people who interact about events in the crowd or respond to them in similar ways).

Prototypical group member

A prototypical group member refers to an individual who has the typical characteristics and behaviour of a specific group within a crowd. This member serves as a representative or standard for the group's identity.

In the social identity approach to leadership, prototypicality refers to a leader who most effectively distinguishes the in-group from the out-group.

Headway

Headway refers to the temporal or spatial distance between two consecutive pedestrians. It is often seen as a determining cue for the behaviour of the follower. It is intimately linked with the notion of leader-follower, and thus is well defined mainly for one-dimensional flows, though following behaviour can also be relevant, for example, for flows in corridors. When moving in 2D, the determination of the preceding person can be done by taking the field of vision and the potential probability of collision into account. In high-density flows, the signal may be filtered to take out the step oscillations, as it may not be negligible anymore in front of the headway itself.

Spatial headway refers to the Euclidean distance between two consecutive pedestrians, typically measured from the center of their heads, sometimes restricted to the component in the main movement direction. The headway is sometimes just named distance. Headway can be considered as a proxy for inverse density in single-file configurations. In certain cases, headway could be measured differently, for example, from the center of mass of the individuals, when wheelchair users are considered or the influence of swaying should be reduced.

Temporal headway refers to the time interval between passings of two consecutive pedestrians through a given check-point, usually an exit line or an artificial line in a corridor perpendicular to the expected direction of motion. In case of unidirectional flow through the checkpoint, the mean temporal headway can be considered as a proxy for inverse flow.

Ingress

Ingress refers to the phase during which people arrive at and enter a space or venue (e.g., a building, an event site, or a stadium). In crowd management, planning for safe and efficient ingress means restricting congestion and maintaining acceptable density levels essential for a steady and thus comfortable flow of people. This may include balancing the flow of people during managed entry processes such as ticket checks and security screening procedures. Depending on the context, ingress can range from routine, everyday entrance situations to those involving special crowd management measures, such as queuing systems for large events.

Interaction

Direct exchange between or involvement with someone or something. In the context of human behaviour and crowd dynamics, different types of interactions can be observed. These are dynamic patterns of people-people (e.g., moving as a group, informing others of danger, etc.) or people-environment interactions (e.g., interactions with transient and static features, lighting, interaction with signage, etc.). In particular, research may also refer to people-hazardous environment interactions (e.g., avoiding a smoke-filled area, crawling to avoid a smoke layer, moving to higher ground as a result of floodwaters, etc.). This specific type of interaction may, in other fields, be referred to as a response to the environment.

Interactions can be symmetric or non-symmetric, such as mutual maintenance of personal space and leader-follower dynamics, respectively. Interactions can be one-to-one, one-to-many, and many-to-many (between groups such as different protestors, between police and protestors). Interactions can be synchronous or sequential in time and/or space, as well as conscious or unconscious. Finally, interactions can be social and/or physical. Physical interactions refer to physical contact between individuals and can be voluntary (e.g., walking arm-in-arm, dancing, etc.) or involuntary (e.g., due to a high crowd density or during recovery motion to avoid falling).

Interactions are the mechanism that activates collective behaviour. Interaction is often used as a prerequisite for identifying or defining groups (or social groups) of pedestrians.

Leader

When individuals interact with one another, a leader can be identified as someone who effectively influences others, while those replicating such behaviour are considered followers. The dynamics of leader-follower interactions may be observed in several aspects of pedestrian movement, such as the initiation of movement, change in direction, and impacts on walking speed. Social factors — including shared identity, body size, individual personality, authority or knowledge — along with flocking behaviours such as heading and positioning within a crowd, play a crucial role in determining leadership influences. In some contexts, there may be a general agreement on who should be followed, while

in other cases, leadership can be more distributed among sub-groups. Leadership can either evolve over time through dynamic interactions or remain static, for example, within a hierarchical structure.

Level of service

A measure of the overall quality of traffic flow. The Pedestrian Level of Service (PLOS) more specifically categorizes the quality of pedestrian infrastructure into six different levels (A–F). In this PLOS, "A" represents unrestricted walking (e.g., the main hall of a station in the early morning), and "F" represents walking conditions on the verge of a full stop (e.g., a station where train service has stopped and large crowds are staying).

In the classical PLOS framework, the main criteria are flow rate, density, and the freedom to choose walking direction and speed. It is therefore best suited for pedestrian infrastructure designed primarily for walking. The classical PLOS was later expanded to queuing areas. However, areas or situations where pedestrians neither move nor queue (e.g., waiting in city centers or public transport facilities) are not covered. Subjective or objective measurements of the experiences of pedestrians and their evaluation are also not included in the definition of PLOS, but have been increasingly studied in the last decade by researchers in the field of pedestrian dynamics.

Models (Hybrid) [Revised]

Hybrid Models in pedestrian dynamics refer to computational frameworks that integrate at least two distinct modelling approaches, which may differ in their representation of scale (e.g., micro vs. macro), time (discrete vs. continuous), space (grid-based vs. continuous), environment, movement mechanisms, or other crowd characteristics. The concept of hybrid models can also refer to models that combine empirical data with theoretical model approaches.

Models (Machine learning) [Revised]

Machine learning is the process of training computer models with data, and using algorithms and statistical models to identify patterns and relationships. This allows computer models to perform tasks and generate predictions without relying solely on explicit, rule-based programming. A key aspect of this is the ability to learn functions directly from data, and the mapping of input data to corresponding outputs. In the context of crowd dynamics, machine learning has been applied to trajectory prediction, data-driven simulation (including integration with traditional physics-based models), evacuation planning and optimization, and crowd flow analysis from video data.

Movement direction/Heading

Movement direction is the continuously adjusted route that individuals or groups take as they navigate through space. It reflects not only the pursuit of a destination along the path

of least resistance but also incorporates the adaptive, real-time modifications made in response to environmental cues, visual guidance, and social interactions. This definition covers the multi-directional nature of crowd movement (being uni-, bi-, or multidirectional) depending on factors such as pedestrian density, spatial constraints, and individual decision-making processes. The posture of pedestrians and the movement direction are related. When density is low, pedestrian posture often aligns with heading direction which is similar to the movement direction. In high density scenarios, such alignment becomes less apparent due to the need for more complex spatial adjustments.

Motivation

Psychological concept that describes the driving force of behaviour. Due to theoretical differences within psychology, multiple and diverse conceptualisations of motivation coexist. Most approaches distinguish between general motives (e.g. achievement, security, needs, affiliation motives, however, the lists of human motives vary by psychological school), and the concrete motivation of an action. This concrete motivation is the result of a process in which the subjective significance of the goal (depending on the underlying motive) plays a central role, along with the perceived feasibility and control over achieving it.

In the field of pedestrian dynamics, motivation is usually relevant in relation to the movement towards a goal. Diverse motives can drive the movement - ranging from safety motives in an emergency situation to affiliation motives in helping situations or achievement motives when the goal is to be the first (in a marathon, at a concert, etc). High motivation can be observed when individuals perceive the goal as highly valuable and attainable, whereas low motivation occurs when the goal, despite its value, seems out of reach.

The strength of motivation can be reflected in speed, density, flow, or the behavioural repertoire chosen (e.g. pushing versus letting someone go first). Importantly, motivation is highly heterogeneous within a crowd, even when social norms promote a certain level of motivation. Additionally, motivation is dynamic, not static — it fluctuates due to environmental factors (e.g., unexpected interruptions) or internal decisions.

Navigation

Navigation is the process and strategy by which pedestrians move through their environment. Navigation involves both the decision-making and physical movement aspects of how individuals and groups choose paths, avoid obstacles, and reach specific destinations. It encompasses how people plan their routes (choosing the most efficient or preferred paths) and adjust them (wayfinding as a cognitive process), including collision avoidance) in response to spatial layout and signage (such as hallways, exits, or intersections), environmental obstacles (like walls, furniture, or barriers), crowd density (observing the distribution of people or congestion), and social interactions (maintaining personal space, forming lanes).

Objective/Target/Purpose/Goal

A desired end state or overall outcome that an agent or group of agents is attempting to accomplish within a given spatio-temporal context (e.g., at a particular time and place). Achieving this objective may require completing one or several tasks, which are specific actions guided by the agent's motivation, that contribute to progress toward the objective. The objective can influence locomotor trajectories and the regulation of interpersonal distances, as agents dynamically adapt their movements and spatial relationships to accomplish the necessary tasks.

Panic

The term "panic" can refer to a feeling (sudden fear, racing pulse), and/or a cognition (disproportionate belief about threat), and/or behaviours (flight, uncontrolled, abandoning norms, selfish, competitive). The term is often used as a vague catch-all for a range of phenomena. The idea of crowd "panic" has been employed as part of attempts to blame the psychology and behaviour of the public for crowd disasters which might better be explained in terms of negligence and mismanagement.

There is the problem of determining whether evacuees' beliefs and behaviours are disproportionate within an event, where there is often limited information available to them. For decades, social scientists have argued that the concept of "panic" is not appropriate or useful to describe or explain most behaviour in emergencies. A problem is that it involves unnecessary speculation on motivations/ feelings/ cognition. Most evacuation behaviour could be described more neutrally as "flight". The repeated finding of evidence of cooperation and helping among strangers in emergency evacuations problemises the assumption that people necessarily lose control, abandon norms, and become competitive in emergencies.

Modellers of crowd behaviour have long used the term "panic" when characterizing evacuations. If they simply mean flight, then ideally this term should be substituted. If they mean flight behaviour that involves competition – pushing and trampling – then it would be useful to (1) state the behaviours; (2) become more familiar with the evidence on the conditions under which emergency evacuations are associated with pushing and trampling.

The media plays a significant role in perpetuating the use of the term "panic," often sensationalising crowd behaviour and reinforcing misconceptions about loss of control and irrationality. This contributes to the continued use of an imprecise term, which should be avoided when more accurate and specific concepts are available.

Pedestrian [Revised]

A pedestrian is a person whose mode of locomotion includes walking, running or crawling or, for the mobility impaired, using assistive devices or being assisted by another pedestrian. People who are waiting, stopping or queuing are considered to be pedestrians.

Pedestrians can be further divided into specific categories such as pedestrian-commuters, pedestrian-shoppers, pedestrian-travellers, etc.

People counting

People counting (also referred to as pedestrian counting or crowd counting) is the process of counting distinct individuals within a specified area at a specific time, or counting the number of individuals passing a defined line over a given time interval. It differs from crowd size estimation, which is typically used when precise counting methods are not available.

Perception

Perception is a biological process whereby an organism detects available information (e.g. visual, acoustic, tactile, olfactory) and becomes aware of their environment. For humans, this includes recovering properties such as 3D shape, size, distance, surface properties and materials, self-motion, object motion, the actions of other people, and recognizing objects. The brain uses this information to control action and as input to other cognitive processes.

Risk perception

The impact of accidents, disasters as well as intentional risky behaviours on people changes and accumulates with their development. Risk perception refers to the ability of pedestrians to perceive environmental risks by assessing the likelihood and severity of potential dangers, such as casualties and injuries. It is influenced by various factors, including pedestrian demographics, event characteristics, and environmental conditions as well as the temporal development of the risks in their walking environment. This perception significantly impacts pedestrians' immediate intentions and behaviour during disasters, and is always along with potential risk-avoidance behaviours they may adopt.

Personal space

According to proxemics, the study of how humans use the surrounding space while performing activities, personal space describes different distances between people that influence human perception, communication, emotions, and behaviour. The commonly used order of magnitude of these distances is:

1. **Intimate distance** (up to about 0.5m),
2. **Personal distance** (about 0.5m - 1.2m),
3. **Social distance** (about 1.2m - 3.5m),
4. **Public distance** (more than 3.5m).

Despite these specified distances, personal space is malleable depending on a number of factors. Notably, various factors such as cultural norms, individual preferences, demographic characteristics (e.g., age, gender), relationship dynamics, and situational context can influence the extent of personal space (e.g., jostling vs. walking in an almost empty park). Of particular relevance to crowds, the experience of others' physical proximity is shaped by the degree to which an individual defines themselves and proximal others as sharing a common group membership. In such situations, the close proximity of other people is accepted (and judged pleasurable) in a way that it is not in the absence of such a psychologically shared group membership.

In contrast, peripersonal space is a term used in neuroscience to describe the area surrounding an individual that allows for physical interactions with the environment (e.g., grasping objects), while interpersonal space is the physical distance between an individual and their neighbor.

Response time

Response time refers to the time interval between a specific stimulus or event and a consequential action. Both the stimulus/event and action need to be specified. The response time may be as small as a fraction of a second, in the case of someone detecting a person (the stimulus) in front and modifying their trajectory or movement speed (the consequential action). However, when perceiving an emergency alarm signal, starting evacuation movement (generally referred to as pre-movement time or pre-evacuation time) may take several minutes or longer. Response time involves perception, cognition and the beginning of an action.

Mathematical tools to model response time include second order formulations and delay terms. In second order models (Newton's second Law) the inertia effect causes higher response times. Delay terms allow to account for response times also in first order models. A further advantage of delay terms is that the response time can be explicitly encoded in the model.

Single-file/Single-file motion

Single-file motion refers to the unidirectional movement of individuals along an imaginary or idealized line, where they do not pass each other. This type of movement is characterized by a reduced degree of freedom and the absence of route choices. It is commonly observed when individuals move along narrow aisles, segregated pathways, or in organized contexts such as queues. Single-file motion under laboratory conditions is mostly investigated by having participants move in circular or oval settings, limiting interactions to mainly longitudinal ones.

Stampede

A mass movement of individuals, typically – but not exclusively – in response to an external stimulus or perceived threat. Originally, the term described animal behaviour in

the wild (e.g., wildebeest herds fleeing from predators). It is often used in the context of crowd disasters, though frequently in a misleading or inaccurate manner.

Stampede is usually characterized by several features:

1. sudden, uncontrolled movement at the same time, often in the same direction,
2. a large number of individuals, generally motivated by
3. strong emotional triggers such as fear, e.g., of a threat or desire, e.g., to acquire objects in a sale or promotion.

In reports of crowd disasters, stampede is often associated with the word "panic", with the implication that victims are "trampled" underfoot by fleeing participants. In reality, the vast majority of crowd disasters that are described as "stampedes" are better characterized as "crowd crushes", in which deaths are caused by high density inducing asphyxiation. To clarify the distinction between "stampede" and "crowd crushes", popular media organizations (e.g. The Guardian) have modified their style guides to emphasize that the former term is to be associated only with animal, rather than human, behaviour.

The term stampede originates from the American Spanish "estampida" in connection with "estampido" (crack or bang noise) and "estampar" (to stamp). This later form originates from the German "stampfen" also meaning "to stamp".

Trajectory [Revised]

A trajectory describes the path of a pedestrian through space as it evolves over time. Although actual motion is physically continuous, trajectories are often measured or modeled as discrete sequences of time-stamped positions (e.g., frame by frame). In pedestrian dynamics, trajectories commonly track a person's head or a central reference point, ignoring minor body motions. When data from various sources are integrated, trajectories can be enriched with additional attributes such as gaze direction.

Velocity

Velocity is the speed and direction at which a person is moving. In practice, velocity can be affected by both environmental, physical or internal factors. In science, speed is measured in meters per second.

Observed velocity

A vector variable that refers to the measurement of actual velocity. Actual velocity expresses the rate of change of an object's position in time (in continuous models it is represented by the first derivative of the position). The observed velocity is often understood as the average velocity over a measurement time period, e.g. the distance vector between the positions at the start and end of the measurement time period divided by its duration. The magnitude of the velocity vector is speed, which is measured in space units per time units, usually meters per second.

Free velocity

Free velocity, or free-flow velocity or free-flow speed, represents the velocity or speed at which an individual can move when they are not impeded by others or environmental constraints. It is typically the highest speed a person can achieve under ideal conditions, such as moving in an uncrowded space. The direction associated with this speed is typically not investigated explicitly.

Desired velocity

The term "desired velocity" derives its origins from numerical models of pedestrian dynamics where it sets the ideal reference state that drives an individual's motion. In a general context, it represents the ideal speed and direction a pedestrian would choose in the absence of external influences, reflecting their intrinsic goal and motivation. Originating from early force-based models, where it serves as the reference state toward which self-propulsion forces drive the actual velocity, the concept has since been adopted and adapted in a variety of modelling frameworks — including velocity-based and rule-based models — each specifying different mechanisms for how this target is approached. Importantly, the desired velocity is dynamic, being continually modulated by situational contexts, personal intentions (for example, whether one is hurrying or moving leisurely), perceived safety, and social norms. In some cases, the term is used in a narrower sense to refer only to its magnitude, known as the desired speed or preferred speed.

Waiting

Waiting refers to the actions exhibited by individuals or groups when they pause or remain stationary. It can be observed in many daily situations such as in public transportation facilities. Additionally pedestrians can wait due to physical constraints (e.g. local density in a crowded environment), due to behavioural intentions (e.g. failing to evacuate when following the behaviour of others) or due to instructions (e.g. waiting for a green light or a venue to open gates).

Zipper effect

This phenomenon occurs in a crowded situation whereby two or more pedestrians form lanes in a bottleneck and merge together, because the bottleneck width does not allow pedestrians from different lanes to stand shoulder by shoulder. Pedestrians in the lanes are intercalated like a zipper, although not necessarily one-by-one, reducing the number of lanes. As this happens the pedestrians in one lane use up some space in the other lane with their shoulders due to swaying. Within each lane, the headway that pedestrians maintain with respect to the walker just in front of them imposes a finite minimal distance between the pedestrians. When the zipper effect occurs, each pedestrian adjusts their walking speed and distance to secure this space in front of them.

2. Discussion

First and foremost, this glossary is specific to the context of human crowd dynamics research. The concepts presented here have been defined with reference to crowds, pedestrian and collective dynamics, and related disciplines. While these definitions may not differ fundamentally from those used in other fields, it is important to note that alternative versions (some more comprehensive, others more general) may exist in different disciplinary contexts.

The first glossary's discussion begins with the statement: "We do not view this glossary as a collection of finalized and formal definitions, but as a starting point for a discussion on more consistent use of terminology in research on crowd dynamics." [1]. We continue to value this perspective and have adopted it in shaping the new concept definitions. Given the interdisciplinary nature of our field, clear communication is essential, and updating the terminology is especially important given the rapid developments in the field (e.g., Artificial Intelligence).

Over the past few years, we have also observed the evolution of the disciplines focused on crowd research, which now include emerging areas and, consequently, newly integrated concepts. Additional entries have been included in this second glossary because these terms have gained greater relevance and frequency of use in recent years.

At the same time, several concepts from the original glossary have been revisited. The suggested revisions do not imply that the earlier definitions were incorrect or incomplete, but rather reflect the need for updated context and additional information.

The first glossary's discussion also included a list of concepts that had not yet been developed at the time [1]. When all authors were invited to suggest concepts to be added to the second glossary, some of the items from this earlier list were proposed once more and subsequently voted on. For all concepts, we set a threshold and selected those that received more than 25 votes, corresponding to approximately half of the suggested items. Several of the selected concepts also appeared in the "future direction" list from the first glossary. A detailed breakdown of the voted concepts is shown in Fig. 1.

The concepts that received fewer than 25 votes remain part of the extended list and might be added in a future third version of the glossary.

The extended list of concepts (ordered from most to least voted) is as follows: *Validation, Accessibility, Follower, Tracking, Viable exit, Pedestrian sensing, Phase transitions, Floor field, Event management, Warnings/Signs, Full-body motion, Riot, Footfall, Demographics, Verification, Crowd rush, Milling, Deindividuation, Geometry, Luggage-laden pedestrian, Collective memory, Anonymous crowd, Last mile, Universal design, Collectivization, View cone, Effervescence, Energy/Entropy, Ethics, Body, Kettling, Identity fusion, Persona, Empowerment, Lidar, Entrainment, Hooliganism, Observatories, Rare event, Dataset, Audience, Long-time asymptotics, Indistinguishability, Serpentine group, Open street maps*.

More details about the creation process of this second edition can be found in the appendix of this work.

Overall, this glossary is intended to support both newcomers and experienced researchers engaged in interdisciplinary work on human crowd dynamics. We hope it serves not only

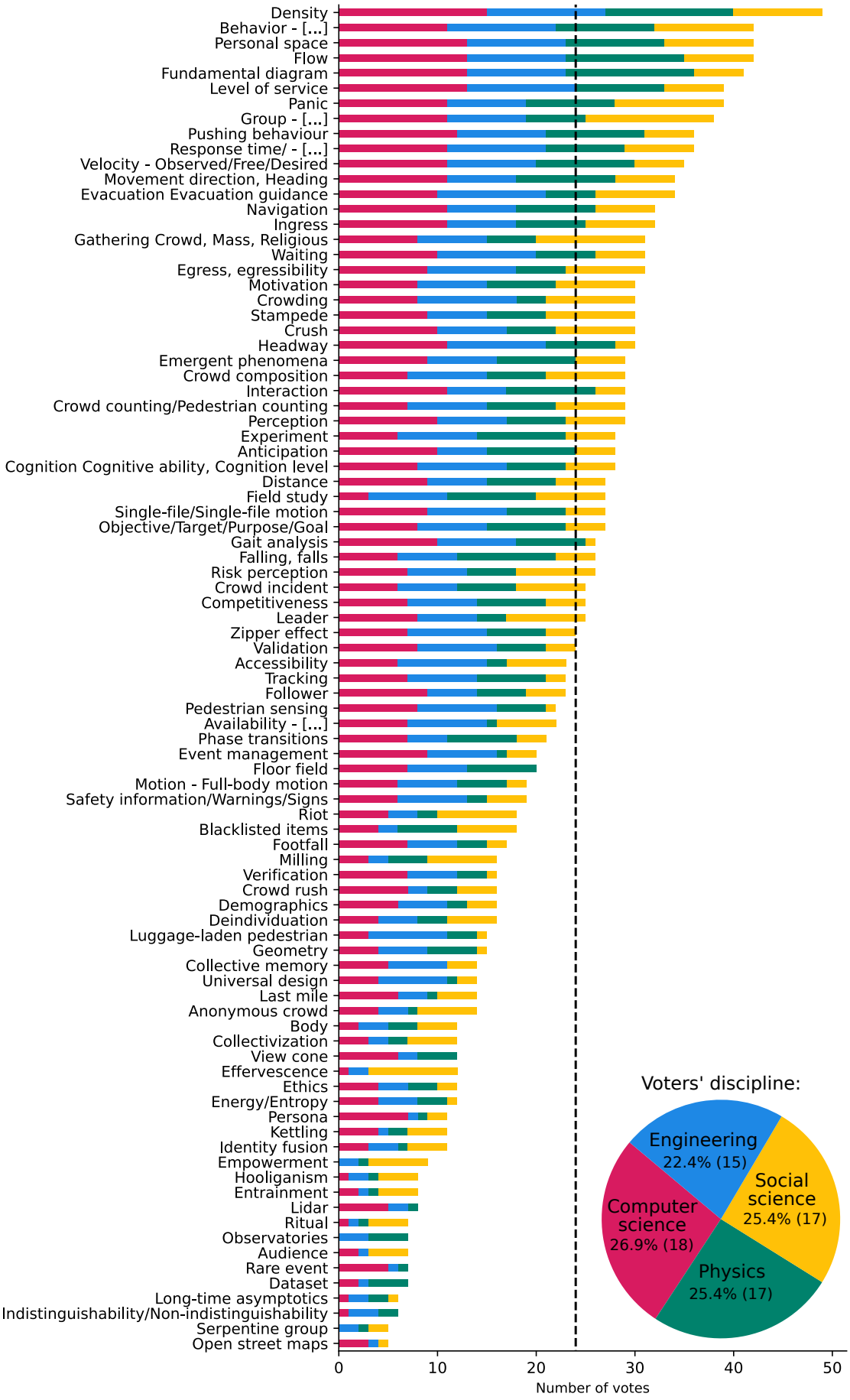


Figure 1 **Results of the voting process.** Each author could vote for as many concepts as they wished. The black dashed line indicates the threshold of 25 votes, which was used to select the final concepts. Voters were broadly grouped into four main research disciplines. The pie chart shows the number of voters in each discipline. The disciplines are represented by a different color to indicate which concepts received the most votes within each group.

as a shared reference point but also as an invitation to contribute to the ongoing development of terminology in the field. Ultimately, this edition should be seen as a snapshot of some of the most relevant concepts currently shaping our research community. As new technologies, applications, and theoretical perspectives continue to emerge, both the definitions and the significance of these concepts are likely to evolve. For this reason, future editions of the Glossary for Research on Human Crowd Dynamics are to be expected.

Author Contributions All authors contributed to the project by suggesting concepts, voting on them, writing definitions, and revising the written entries. Authors are listed in alphabetical order. The organizers were responsible for coordinating and overseeing the project, including process design, internal coordination, and communication with all contributors. Corresponding authors from the organizational committee may be contacted for any inquiries.

References

[1] Adrian, J., Bode, N., Amos, M., Baratchi, M., Beermann, M., Boltes, M., Corbetta, A., Dezecache, G., Dezecache, G., Drury, J., et al.: A glossary for research on human crowd dynamics. Collective Dynamics **4**, 1–13 (2019). doi:10.17815/CD.2019.19

A. Appendix

Organisational report: Protocol adopted for the creation of the Glossary for Research on Human Crowd Dynamics – 2nd Edition

1. Initial gatherings
2. Author invitations
3. New concept suggestions
4. Voting for the concepts
5. Drafting concept definitions
6. Revising concept definitions
7. Editing concept definitions

A.0.1. Initial gatherings

- The organizational committee was formed, consisting of some members from the first glossary and additional members who initially proposed creating a second version.

- It was decided to adopt a flexible approach, allowing the possibility of adding more members if needed or someone wishes to join.

- A shared folder was set up, including:
  - A file listing all former and newly suggested authors, along with their disciplines, country of work, and contact information.
  - An organizational plan draft.
  - Meeting notes.

- Further phases established: invitation, concept suggestions, voting, drafting, revision, editing, submission.

- A central email address (ped-glossary@fz-juelich.de) was created for future communication with authors throughout the phases.

A.0.2. Author invitations

Duration: Two weeks

- Author invitations were divided among the organizational committee.
  - All former glossary authors were invited.
  - New authors were selected and invited based on personal suggestions.
    * New authors were required to have experience in the field of pedestrian dynamics, ideally at the postdoc level.
    * When selecting additional authors, disciplinary diversity was prioritized to ensure a broad range of expertise.
    * A global perspective was also emphasized by including authors from various countries and continents (see Fig. 2).
      · *Note*: The predominance of authors based in Europe, particularly Germany, reflects the project's origins at the Jülich Research Center and the fact that early invitations were circulated internally.

- A deadline of two weeks was set for acceptance. If an invited author did not respond within this timeframe, they were not followed up further.

- Once all responses were received, the complete author list was shared with everyone, allowing authors to suggest additional participants if someone crucial was missing.

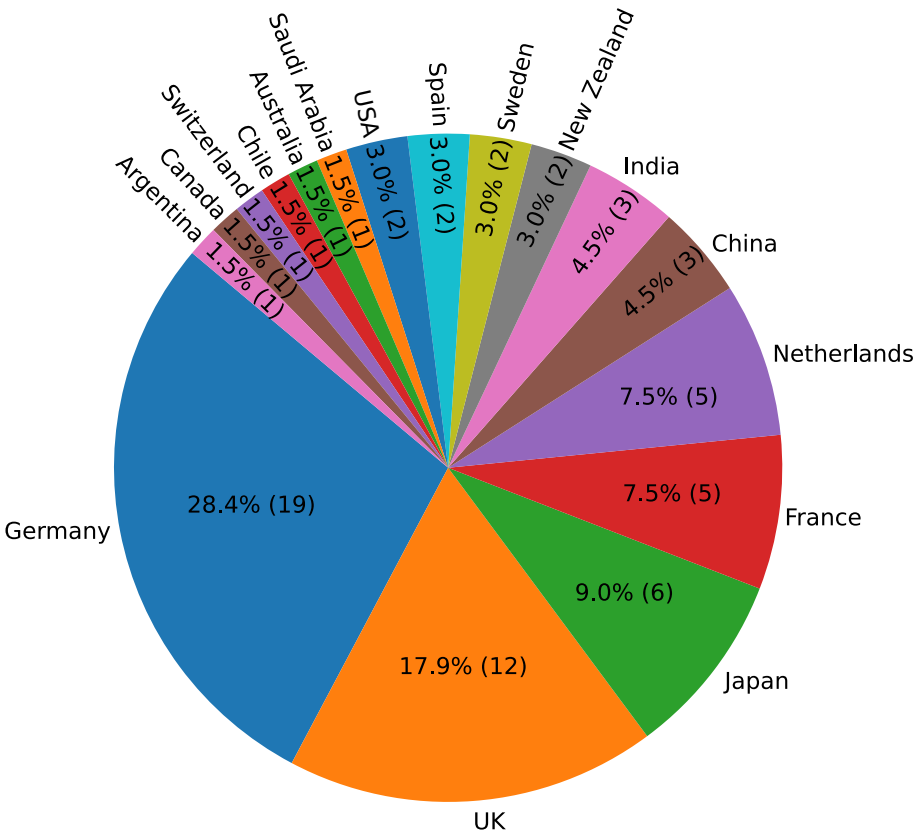


Figure 2 **Country of work of the voting authors.** This pie chart shows the distribution of the 67 voting authors by country of professional affiliation at the time of the voting process.

A.0.3. New concept suggestions

Duration: Four weeks

- A dedicated website was created to allow authors to suggest the concepts they would like to see in the second glossary.
  - The website enabled authors to submit their concepts in text boxes.
  - To prevent accidental deletions or modifications, no edit or delete options were provided after a concept was submitted.
- All authors had the option to contribute an unlimited number of concepts/terms for further voting.
- Authors could also propose revisions to existing concepts/terms from the original glossary.
- This stage was conducted anonymously, without recording contributor names.

A.0.4. Voting for the concepts

Duration: Six weeks

- All suggested concepts were grouped where applicable. Similar concepts were merged, and subconcepts were created.
- A Google Forms poll was created and sent to all authors.
- Authors were encouraged to vote based on which concepts would be most beneficial to the community to avoid mass voting but no upper limit was imposed on the number of concepts an author could vote for.
- Names were collected in the poll to track who suggested each concept for later stages.
- A cutoff threshold was applied: Only concepts with more than 25 votes (above the average) moved to the next phase (see Fig. 1).

A.0.5. Drafting concept definitions

Duration: Six weeks

- Authors were categorized by discipline: computer science, engineering, physics, and social science.
- The organizational committee formed subgroups.
  - Each group was interdisciplinary, mixing authors from different fields.
  - Groups consisted of 5–6 authors.
  - A pre-appointed group leader was assigned to each group, either from the organizational committee or selected randomly from the authors.
    - Group leaders were responsible for overseeing the writing process, distributing, or arranging the concepts if needed.
  - Authors who had not participated in the previous voting phase were evenly distributed across all groups to minimize the risk of inactive groups.
- Each group was assigned 3–4 concepts, distributed equally, starting from the most voted concept.
  - Concept definitions were limited to 200 words, though this was a recommendation rather than a strict rule.
  - References were not allowed.
  - A catalog of advice points was shared as a guideline for structuring concept definitions (procedure, suggestions, guideline).
- A general email was sent to all authors, followed by group-specific emails containing: group member details; assigned concepts; suggestions, notes, and remarks from previous stages regarding those concepts.

- A Latex document was created to allow group leaders to post the concepts developed by their groups. It was sent out before the deadline as a reminder.

Conference participation:

- The organizational committee decided to create a poster for the upcoming Traffic and Granular Flow (TGF24) conference. This poster can be seen in Fig. 3.
- Authors were informed that if their drafts were finalized one week before the deadline, they could be included in the poster.
- More than half of the drafted concepts were included in the poster presentation.
- The presentation of the poster to the conference audience provided an opportunity for preliminary discussion regarding the revision process and served as a means of outreach to potential contributors (resulting in the addition of three new authors in the later phases of the project).

A.0.6. Revising concept definitions

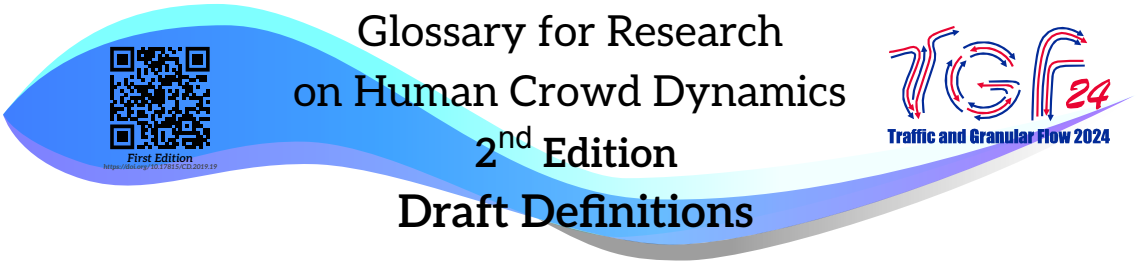
Duration: Six weeks

- All drafts were compiled into a Google Document, utilizing the tabs feature.
  - Each concept or subconcept was placed in a separate tab, allowing for both a general overview and focused revisions on preferred concepts.
- A pre-structured revision box was added to each concept page, including author's name, reason for the revision, and the proposed revision (with changes highlighted). Authors were instructed to copy this box and submit their revisions in their chosen concept tab.
- An overview and an example tab were added to outline the general rules and provide sample revisions.
- The document was view-only for direct edits; authors could only suggest revisions using track changes. Appointed editors monitored the process, ensuring revisions followed the structured format and rejecting unintended modifications if necessary.
- Each author was responsible for at least two revisions, with no upper limit.
- References were not allowed, as in the previous stage.
- Authors were encouraged to consider previous revisions and build upon them rather than revising from scratch.
- The email explaining the revision procedure included a call for volunteers for the next stage, "Editing," particularly for concepts with multiple suggested revisions.

A.0.7. Editing concept definitions

Duration: Two weeks

- The concepts was decided to be distributed among the organizational committee members and additional volunteers.
- Editors were advised to ensure consistency across concepts, paying attention to potential hyperlinks between related entries.
- Editors were advised to report any conflicts on revised concepts to the organizing committee, who would arrange a conflict resolution meeting if needed.
- A Latex document was created to allow the editors to post the finalized concepts.



Anticipation:

In the context of locomotion modelling, anticipation is a synonym for prediction in time based on motion. For example, pedestrians observe the paths and speeds of other pedestrians and anticipate potential collisions. Based on this prediction, the observer adapts his or her movement.

Behaviour:

Behaviour (collective):

1. Behaviour is the response of individuals or groups to internal and external stimuli.
2.Collective behaviours are responses of groups to internal and external stimuli that arise from interactions between group members and interactions with their surroundings. Collective behaviour comprises the spatial or temporal synchronisation of group/crowd dynamics, and self-organisation that may be emergent behaviours. In contrast, aggregate behaviour lacks synchronisation across individuals even if interactions between individuals may occur (e.g. to avoid collisions). For example, collective behaviour may occur in a crowd that attempts to approach a common goal (e.g., an exit) and aggregate behaviour may be observed in a crowd in a shopping centre where individuals separately try to get to different shops. Other relevant terms defined in this glossary are collective emotions, collective actions.

Will also be considered: Behavioural repertoire, Behaviour ((operational/tactical/strategic), Behaviour (rational/ non-rational/irrational).

Cognition:

Cognition is the set of mental processes that enable an individual to perceive, process, understand, and prepare to respond to their environment. Cognitive functions include perception, attention, decision-making, and problem solving. In pedestrian research, examples of such cognitive functions are the active processing of sensory input (vision, hearing, taste/smell, touch) from the human and built environment, the use of an internal representation of the world, and the decision of where to put attention to or what the next action will be.

Crowding:

Crowding is the psychological experience in a crowd that might lead to perceived spatial limitations, discomfort, or stress due to limited space. Crowding is influenced by social and personal factors, such as task coordination, competition, or interpersonal relationships.
In contrast, crowd density is the physical measurement of available space per individual, focusing purely on spatial limitations without considering individual perception or personal space. Therefore, density alone does not cause crowding, however the social and personal factors do.

Distance:

Distance in locomotion modelling is a measure of the spatial relationship between individuals or objects, typically measured in metres. This metric plays a crucial role in understanding crowd movement, including interactions between individuals and collision avoidance.
Mathematically, distance can be defined in various ways depending on the type of model. For instance, in continuous space models, the Euclidean distance is commonly applied due to its straightforward geometric interpretation. In contrast, in discrete space models, the Manhattan distance can also be implemented, offering a suitable alternative in grid-based systems. Moreover, distance is closely related to density, especially the inverse of the distance corresponds to the local density for the one-dimensional case.
This spatial concept of distance can also be expanded for time relations, where time distance is used to indicate temporal aspects such as time to collision, clearance times, or time gaps between individuals or objects. In addition, in evacuation maps, not only the physical distance but also this time distance is sometimes used as an indication of the approximate distance to the evacuation site.

Flow:

The number of agents (according to the definition given in the 1st edition of the glossary) crossing a given set of coordinates as a function of time (the coordinates may be associated with a door, opening, or other physical characteristic of a building). Flow can be expressed as a 'rate', i.e., the count of agents crossing the coordinates per unit time. Mathematically, the "specific flow" is defined as number of agents per unit time per unit distance (e.g. per minute per metre). Specific flow can be thus derived from a given crowd density multiplied by its mean velocity.

Egress, Egressibility:

Egress refers to the phase during which people leave or exit a space. It includes both routine and emergency situations, with emergency egress often referred to as evacuation. Considering human movement during egress is a critical aspect of architectural and urban design, ensuring that buildings and public areas provide adequate means for people to exit safely and efficiently.

Egressability considers the accessibility and usability of these exit routes, focusing on factors such as clarity, capacity, and safety. This includes ensuring that exits are navigable and usable for all individuals, including those with disabilities and cognitive pr physical impairments. It is essential that design and operations enable the safe and effective exit of all users during the egress phase, in both routine and emergency situations.

Evacuation:

The process of moving individuals or a crowd to a safe location in response to a threat, warning, or safety concerns. This process typically consists of several phases: detection, decision, alarm, reaction, and movement (also referred to as "egress"). The terms "evacuation" and "egress" are often used interchangeably, though "egress" more specifically refers to the physical act or route of exiting a building or area.
Different types of evacuation include:
1. Self-evacuation: This category involves individuals taking initiative to evacuate based on personal judgment or situational awareness, rather than waiting for official instructions.
2. Controlled Evacuation: This term can be used for scenarios where evacuation is tightly managed by authorities, with predetermined routes, checkpoints, or assembly points to avoid congestion or maintain safety.
3. Cooperative vs. Competitive Evacuation: Behavior during an emergency can range from cooperative to competitive, influenced by the perceived urgency and time constraints for leaving a building.
4. Shelter-in-Place (SIP): Although distinct from evacuation, shelter-in-place protocols may be relevant. This involves guiding occupants to stay in a secure area within a building, usually for protection against external threats like hazardous materials or severe weather.
5. Phased evacuation: Involves sequential evacuation of specific areas (e.g., floors in a high-rise building) or groups of occupants.
6. City Evacuation: Involves the large-scale relocation of residents over extended distances, often coordinated across various modes of transportation, including cars, buses, trains, boats, and even aircraft.

Will also be considered: Evacuation guidance.

Group:

1. A group of people or items is a number of people or items which are connected or linked for some time by some measure (e.g. spatially or psychologically).
2. In self-categorization theory (psychological) terms, a group is people who think of themselves as a group (this a theoretical definition).

Will also be considered: Groupthink, In-group, Social group, Prototypical group member.

Interaction:

Direct exchanges between, involvement with someone or something.
In the context of human behaviour and crowd dynamics different types of interactions can be observed. These are dynamic patterns of people-people (e.g., moving as a group, informing others of danger, etc) or people-environment interactions (e.g., interactions with transient and static features, lighting, movement within corridors, interaction with obstacles, lifts, escalators or signage, etc).
Sometimes, crowd dynamics research also refers to people-hazardous environment interactions (e.g., avoiding a smoke-filled area, crawling to avoid smoke layer, moving to higher ground as a result of floodwaters, or responding actively to slow-onset natural hazards) that may in other fields be referred to as responses to the environment.
Interactions can be symmetric or non-symmetric, such as mutual maintenance of personal space, and leader-follower dynamics, respectively. Interactions can be one-to-one, one-to-many, and many-to-many (between groups such as different protestors, between police and protestors). Interactions can be synchronous or sequential in time and/or space. Interactions can be physical, or not.
Interactions are the mechanism to achieve collective behaviour. Interaction is often used as a prerequisite for identifying or defining groups (or social groups) of pedestrians.

Objective/Target/Purpose/Goal:

Single task or collection of tasks that an agent or group of agents (according to the definition given in the 1st edition of the glossary), is attempting to accomplish within a given spatio-temporal context (i.e., at a particular time and place).

Panic:

The term *panic* can refer to a feeling (sudden fear, racing pulse), and/or a cognition (disproportionate belief about threat), and/or behaviours (flight, uncontrolled, abandoning norms, selfish, competitive). The idea of crowd 'panic' has been employed as part of attempts to blame the psychology and behaviour of the public for crowd disasters which might better be explained in terms of negligence and mismanagement.
There is the problem of determining whether evacuees' beliefs and behaviours are disproportionate within an event where there is often limited information available to them. For decades, social scientists have argued that the concept of 'panic' is not appropriate or useful to describe or explain most behaviour in emergencies. A problem is that it involves unnecessary speculation on motivations/ feelings/ cognition. Most evacuation behaviour could be described more neutrally as 'flight'. The repeated finding of evidence of cooperation and helping among strangers in emergency evacuations problemizes the assumption that people necessarily lose control, abandon norms, and become competitive in emergencies.
Modellers of crowd behaviour have long used the term 'panic' when characterizing evacuations. If they simply mean flight, then ideally this term should be substituted. If they mean flight behaviour that involves competition – pushing and trampling – then it would be useful to (1) state the behaviours; (2) become more familiar with the evidence on the conditions under which emergency evacuations are associated with pushing and trampling.

Perception:

In humans, a reconstructive process by which a piece of sensory information is represented by the brain. This reconstructive process is shaped by the brain's immediate context (i.e., the specific situation and how it is appraised by the brain) and the socialization of the agent (the set of contexts in which the brain has developed). Perception of the same stimulus or context can vary for one individual over time, or from one individual to another. This may be due to differences in bodily characteristics (e.g., eyesight, hearing), situational and contextual differences (e.g., group membership), or cultural differences which may lead to different interpretations of the same sensory input. For simulations, perception of sensory information can be modelled as the inspection of the environment of each agent with deriving (individual) actions from these incoming information.

Single-file/Single-file motion:

Single-file motion refers to the unidirectional movement of individuals along an imaginary or idealized line, where they do not pass each other. It is characterized by a reduced degree of freedom and the absence of route choice, and is commonly observed when individuals move along narrow aisles or segregated pathways, or in organized contexts such as queues.
Single-file motion under laboratory conditions is mostly investigated by letting participants move in circular or oval settings, limiting the interaction to a mainly longitudinal one.

Response time/Reaction time/Pre-movement time:

Response time refers to the time interval between a specific stimulus or event and a consequential action. Both the stimulus/event and action need to be specified. The response time may be as small as a fraction of a second, in the case of detecting the movement of a person (the stimulus) in front and modifying your own trajectory or walking speed (the consequential action). However, when perceiving a fire (alarm), starting evacuation movement (often referred to as pre-movement time for evacuation) may take minutes or hours. Moreover, response time involves perception, cognition and the beginning of an action.

Velocity:

Velocity is the speed and direction at which a person is moving. In practice, velocity can be affected by both environmental, physical or internal factors.

Will also be considered: Free Velocity, Observed Velocity, Desired Velocity.

Waiting:

Waiting refers to the actions exhibited by individuals or groups when they pause or remain stationary in a crowded environment. This can be either due to physical constraints (e.g. local density), due to behavioural intentions (e.g. failing to evacuate when following the behaviour of others) or due to instructions (e.g. waiting for a green light or a venue to open gates).

Concepts also present is the 2nd edition of the glossary:
Crush, Crowd composition, Crowd counting, Density, Emergent phenomena, Experiment, Falling, Field study, Gait analysis, Gathering, Headway, Ingress, Leader, Level of service, Heading, Motivation, Navigation, Personal space, Pushing behaviour, Risk perception, Stampede.

Figure 3 Poster presenting draft definitions of selected concepts at the *Traffic and Granular Flow (TGF24)* conference, December 2024.