Towards Behavioral Objects: A Twofold Approach for a System of Notation to Design and Implement Behaviors in Non-anthropomorphic Robotic Artifacts

Samuel Bianchini, Florent Levillain, Armando Menicacci, Emanuele Quinz and Elisabetta Zibetti

Abstract Among robots, non-anthropomorphic robotic artifacts are in an interesting position: the fact that they do not resemble living beings, yet impart a sense of agency through the way they move, motivates to consider motion as a source of expressivity in itself, independently of any morphological cues. This problematic is considered in parallel to the question of movement notation and the different levels

---

This publication is part of a research program ("The Behavior of Things") that is supported, through the Labex Arts-H2H, by Investissements d'Avenir (ANR-10-LABX-80-01) of The French National Research Agency (ANR).

S. Bianchini (✉)
The École nationale supérieure des Arts Décoratifs, Ensadlab/Reflective Interaction,
31 rue d'Ulm, 75240 Paris Cedex 05, France
e-mail: samuel.bianchini@ensad.fr

F. Levillain · E. Quinz · E. Zibetti
University of Paris 8 Vincennes-Saint-Denis, 2 rue de La Liberté,
93526 Saint-Denis Cedex, France
e-mail: florent.levillain@userlab.fr

E. Quinz
e-mail: equinz@univ-paris8.fr

E. Zibetti
e-mail: ezibetti@univ-paris8.fr

F. Levillain · E. Zibetti
The École pratique des hautes études (EPHE), 4-14 rue Ferrus, 75014 Paris, France

F. Levillain · E. Zibetti
The Cité des sciences et de l'industrie, 30 Avenue Corentin Cariou, 75019 Paris, France

A. Menicacci
Dance Department, The Université du Québec à Montréal (UQAM), Case Postale 8888,
succursale Centre-ville, Montréal (Québec) H3C 3P8, Canada
e-mail: menicacci.armando@uqam.ca

E. Quinz
The École nationale supérieure des Arts Décoratifs, Ensadlab-Reflective Interaction,
31 rue D'Ulm, 75240 Paris Cedex 05, France

J.-P. Laumond and N. Abe (eds.), *Dance Notations and Robot Motion*,
Springer Tracts in Advanced Robotics 111,
DOI 10.1007/978-3-319-25739-6_1

of abstraction that one may consider when reflecting on movement and its relation to a spatial, temporal and social context. This is through a twofold perspective, drawing on both dance notation and cognitive psychology, that we consider the question of movement notation, and its relation to expressive gestures and psychological attributes. To progress in the direction of a system of notation that could integrate the qualitative, relational, and behavioral aspects of movement, we propose different typologies and a model of constraints to analyze, conceive and implement behaviors in robotic artifacts.

1 Introduction: Analyzing, Designing, and Implementing Behaviors for Non-anthropomorphic Objects?

In light of new forms of domestic and social robotics, many objects in our daily lives could be endowed with the capacity to move autonomously, to act and react, even to adapt flexibly to their environment. These robotic artifacts would be able to carry out actions that, though partially scripted, could give the impression of being motivated by and executed in pursuit of goals, and might even be considered intelligent [5, 6]. Because these objects would not resemble humans or other animal forms, their expressive potential would emerge mostly from dynamic and contextual cues: the way they move, the way they engage with the environment, the way they react to social agents.[1] From this behavioral specificity arise two interesting questions. The first is related to the “disembodied” aspect of their movement: if we consider motion to be a source of expressivity in itself, we need to find a way to extract expressive movements that apply as much as possible independently of the physical structure of the object. The second question has to do with the way human observers spontaneously interpret motion: to convey emotions and other psychological attributes, we ought to determine which motion cues need to be considered, and how those cues interact with the context of a particular behavior.

How can we annotate the movement of robotic artifacts, and how can we implement expressive behaviors in these non-anthropomorphic (and non-zoomorphic) structures? How can we dispense with the human body as a system of reference, while still maintaining a movement quality, suggestive enough to recall a living being, even to evoke a personality? These questions are approached within a project both practical and theoretical, bringing together several disciplines. It is through a twofold perspective, drawing on both dance notation and cognitive psychology, that we consider possible responses to the question of movement notation at different levels of abstraction and related to psychological properties. Our project has only just gotten

[1]We call “behavioral objects” the moving artifacts that a human observer perceives as acting in a meaningful way. Those artifacts need not necessarily be robotic, although their “behavioral” potential is of course reinforced by their ability to react to certain events. Cf. [4].

off the ground, but we have already conducted studies investigating autonomous robotic artworks [31] and organized workshops[2] based on the development of a modular robotic toolkit to quickly prototype robotic artifacts.[3]

Analyzing movements that are not located within a familiar system of reference, be it a human body or other corporeal property, is not without problems when considering existing dance notation systems. Furthermore, movement notation is not formalized enough to be integrated into a software environment, even though some works are pursuing that goal.[4] Yet offering the possibility of easily configuring the behavior of robotic objects is a stimulating perspective, both for artistic creation, design, design of interactions, and to introduce new practices aimed at informed users (see [25], for a similar perspective).

Working on the expressive quality of movements and their interpretation in terms of meaningful behavior requires the elaboration of original tools for evaluation and annotation. In pursuit of that goal, we propose a work comprised of three main sections:

1. from the viewpoint of the understanding of action in cognitive psychology, we delineate an articulation between movement and behavior through crucial psychological attributions;
2. from the viewpoint of dance and musical notation, we elaborate on the notion of gesture and interpretation to advance the description and formalization of basic movements, independent of the human body;
3. a comparison of these two approaches is attempted in order to build the first blocks of a system of notation devoted to the description, conception, and implementation of behavioral patterns in robotic artifacts.

[2]For example: "The Misbehavior of Animated Objects" Workshop, 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI 2014). February 2014, Munich. URL, July 9, 2014: http://www.tei-conf.org/14/studios.php#s9.

[3]The *MisB* Toolkit developed by the EnsadLab/Reflective Interaction team, under the direction of Samuel Bianchini, by Didier Bouchon, Colin Bouvry, Cécile Bucher, Martin Gautron, Benoît Verjat, and Alexandre Saunier, in the context of the project The Behavior of Things, with the support of Labex Arts-H2H and the Bettencourt Schueller Foundation. For more information, URL, July 9, 2014: http://diip.ensadlab.fr/fr/projets/article/the-misb-kit.

[4]See for instance project LOL (Laban On Lisp) by Fred Voisin, from Myriam Gourfink's research in choreography. Cf.: http://www.fredvoisin.com/spip.php?article164 et Frédéric Voisin, *LOL: Un environnement expérimental de composition chorégraphique*, in *Ec/cart*, vol. 2, Eric Sadin ed., Dif'Pop, Paris, 2000.

1.1 The Understanding of Action: A Psychological Framework to Understand Relationships to a Non-anthropomorphic/Non-zoomorphic Robotic Artifact

Naive psychology is an ensemble of psychological faculties that collaborate to produce a rich and coherent picture of the social world around us. As human beings, we are endowed with refined capacities to perceive a vast range of attitudes in others creatures—humans mostly, but not only; to impart goals, desires and beliefs; to evaluate actions performed by other agents; to assess their motivation to cooperate; to determine their emotional state; or to engage in relevant interactions and communication behaviors. The core properties of naive psychology are the ability to extract relevant information from a flow of movement, which implies the possibility of segmenting this flow into meaningful units [36], and the ability to categorize actions in terms of whether the action is fortuitous or not, meaning whether it reflects an intention from an agent or not [1, 35, 44].

When observing a robotic artifact, we usually exploit these psychological resources to interpret the sequences of actions produced by that artifact, much as we would interpret the behavior of an animal or a human being. Anthropomorphism is a reflection of the "overuse" of our interpretative skills when confronted with an entity that does not necessarily possess the psychological attributes we impart to it [13]. We cannot help but attribute intentionality to robots' actions, and endow them with mental states [23, 50], and this process of anthropomorphization determines a type of interaction that is social in nature.

In the process of designing effective motions to express affects and aesthetic feelings, taking some basic principles of naive psychology into account may be of considerable help in informing the relationship between humans and a robotic artifact. Since the robot does not need to possess the psychological properties we want it to express, all that is needed are certain convincing cues—in the way the object moves and interacts with its surroundings—to trigger specific psychological attributions.

1.2 The Process of Psychological Attribution

In social psychology, the term *attribution* refers to the process of explaining behavior, as well as inferring traits from behavior [32]. The two meanings are related in the sense that ascribing a psychological trait is often a way to explain the reasons a person is doing something (e.g. *he goes to the door because he wants to go out; he wants to go out because he is bored*). The process of attribution has been seen as an attempt by the cognitive system to recover the causal and social structure of the world [44], or to extract invariants from an agent's stream of ongoing behavior [22]. Psychological attributes may be considered the output of a process that seeks to determine stable properties in the social world: intentions, motives, traits, and sentiments participate in the explanation of a current perceived action, while also forming a basis upon which to predict future behavior. Recent development in HRI have included this process of psychological attribution to elaborate credible and meaningful interactions with robots (e.g. [3, 15, 25]).

In the model we propose to qualify the psychological attributions given to a robotic artifact, the process of attribution evolves with the complexity of the robot's observable behavior: a human observer collects cues from the robot's movements and various transformations, and infers psychological properties about its perceptive skills (how much of the environment the robot is aware of), its ability to plan an action, to reason, to make decisions adapted to specific circumstances, etc. As the possibilities of movement and flexible behavior increase, so do the inferences and the resulting attributions.

What is interesting to consider in the process of conceiving such an artifact is how we want to limit the psychological attributions in a human observer. Do we want to give the impression of a conscious agent, willingly acting to accomplish specific goals? Or do we want to represent a more erratic, perhaps inscrutable behavior? These psychological traits and attitudes that a human observer spontaneously ascribes to a moving object depend on specific behavioral parameters. In the model we propose, these behavioral parameters are categorized according to three levels of interpretation: the animacy level, the agency level, and the social agency level (Fig. 1). In essence, the three levels correspond to the three following questions: Does the object look alive? Does the object appear to act intentionally? Does the object appear to interact socially with other agents?

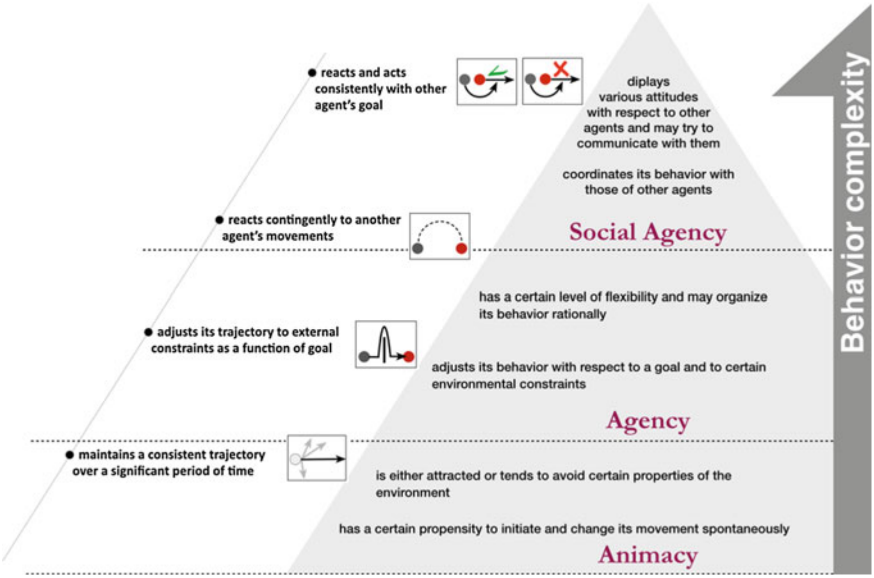

Fig. 1 Three levels of interpretation to describe behavioral patterns

At the **animacy level**, a moving object is perceived as basically autonomous: it seems to move on its own and may give the impression of reacting to its immediate environment. While the object may initiate an interaction with its surroundings, through movements of attraction or repulsion, its behavior is still too erratic to be qualified as fully intentional. At the **agency level**, the behavior of a moving object is construed as goal-oriented: the object seems to act for the realization of specific actions and to organize its behavior flexibly and rationally to reach those ends. At the **social agency level**, a moving object already identified as intentional is also granted some social skills: its behavior is not only related to the properties of the immediate environment, but also to the behavior of others agents with whom it may try to interact and communicate.

More specifically, objects situated at the animacy level have a propensity to initiate and change the direction and speed of their movements spontaneously. These simple motion cues have a strong impact on the naive perception of animacy [2, 41]. Seeing a simple dot on a screen changing direction suddenly is often enough to give the illusion of a living being, although the strength of the impression depends largely on the importance of the direction change and possibly of the speed change [47]. The transition from an autonomous yet erratic entity to a goal-oriented entity will depend on the consistency of the behavior over time: if the object maintains consistent trajectories rather than changing direction at every turn, we are likely to infer in it the ability to maintain consistent objectives [16]. This impression will be reinforced by the possibility of connecting the robot's movement to a specific location towards which it appears to be moving [17, 48]. Compared to the animacy level, entities at the agency level have a flexibility in their behavior; they act purposefully and may organize their actions in a rational manner so as to reach a goal in the most efficient way. Seeing a moving object adjusting its behavior with respect to external constraints is a potent indication that it does indeed possess the ability to select appropriate means to achieve a goal [12]. At the social agency level, agents possess the capacity to act not only relative to their own goals but also relative to other agents' goals. Based on the apparent coordination of two moving objects, an observer can determine whether their respective goals converge (and thus attribute a positive social attitude) or diverge (and attribute a negative social attitude) [21].

Depending on the cues offered by the object's behavior, and the level at which it is construed, certain personality traits may be spontaneously attributed to the object. A robotic artifact may look curious, mischievous, indifferent… based on the way it organizes its movements, reacts to external events, or interacts with other agents. An object seen merely as autonomous (animacy level) may not be granted any proper personality traits, its behavior simply not being organized enough to be qualified with a psychological attribute. However, as soon as the object's behavior can be related to intentions (agency level), a vast range of psychological dimensions are available to qualify it, for instance how effective the agent is in the accomplishment of an action, how rational, how persistent, how thorough it is in the exploration of its environment, etc. At the social agency level, even more psychological components can be used to qualify the agent's behavior, based for instance on the proficiency with which it interacts socially, its propensity to engage in communication behaviors, or its tendency to pursue positively or negatively valued behaviors.

1.3 Emotion and Empathy

The previous model is essentially concerned with the attribution of perceptive skills and abilities to adjust to environmental and social constraints. It does not tackle the affective component of an organism's behavior. However, the affective dimension is very important in human–robot interaction (e.g., [40]), because among many other functions it is strongly related to empathy. Research on empathic agents are divided in two main branches: agents that simulate empathic behavior towards the users and agents that foster empathic feelings from the users [38, 39]. While anthropomorphic robots are capable of facilitating social interactions with humans since they are utilising social interaction dynamics analogous to those observed in human-to-human interactions (e.g., [37]), some recent studies show that it is also possible to achieve these effects by using minimalistic behaviors to convey a sense of sociability from a non-anthropomorphic robot (e.g. interest, rudeness, empathy, etc. [43]).

Hence, to complete the description of the types of attributions a person may entertain when observing a robotic artifact, we shall evoke the relationship of empathy, defined as the ability to understand and respond to others' affective states [24, 42], that may take place during the interaction between a human and a robotic artifact (e.g., [14, 23]). When observing an animal or a human, we are sensitive to its affective state: we sympathize with the actions it tries to accomplish, we feel for its frustrated efforts, we experience an echo of its pain or pleasure. This affective relationship is also dependent on cues that may be expressed through a robotic artifact's motion (see [26]) for an extensive survey on body movements for affective expressions).

Very schematically, an observer may identify three different states an organism can find itself in: a state of comfort, a state of discomfort, or a state of distress. As depicted in Fig. 2, the **state of comfort** is the basic state. Despite a certain level of natural variations occurring in different physical variables (temperature, blood pressure, glucose level, oxygenation of blood, etc.), regulatory mechanisms conspire to maintain these variables at a safe level so that the organism is not lacking in any crucial life components (this is the principle of homeostasis, initially described by Claude Bernard and Walter Cannon). But, as the environmental conditions change constantly, the organism is under pressure from external events that may cause a homeostatic imbalance, corresponding to the **discomfort state**. Through negative feedback, corrective mechanisms launch and bring the system back toward normal variations (vasodilation, decreased metabolic rate, sweating, etc.). Negative feedback can be internal and unobservable, but it can also consist of an observable motor behavior, for instance an organism may look for shade in a heated environment.

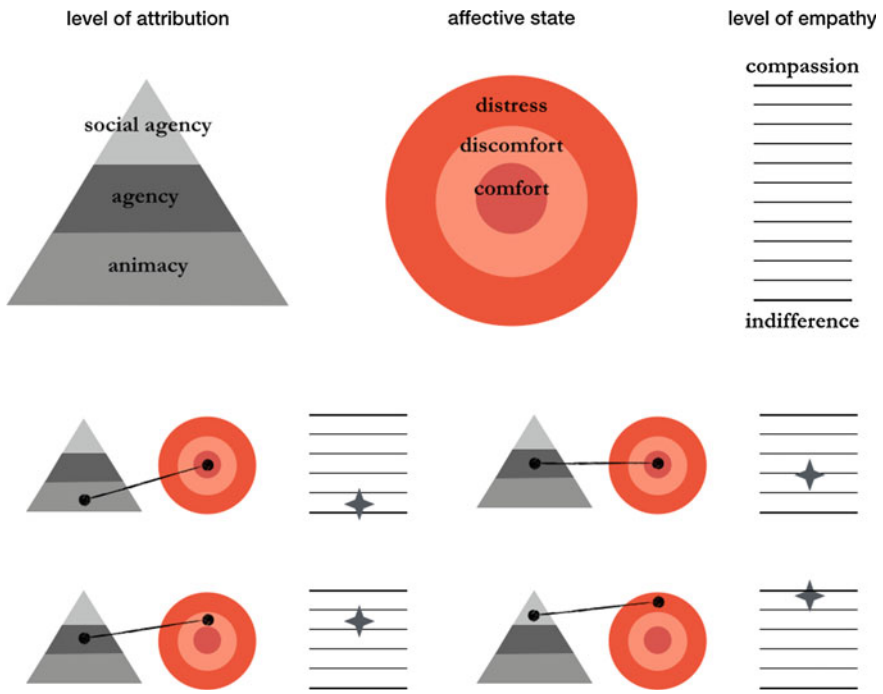

Fig. 2 Relationship between psychological attribution and affective states

Sometimes, external variations are so strong that the organism cannot adapt rapidly enough, causing temporary or permanent damage to some life functions and leading to a **state of distress**. If this does not lead to death, a repair process will take place, leading back to the discomfort zone where damage to the body is transformed into a mere uncomfortableness.

Behavior, emotion, and empathy are closely intertwined. For an organism, engaging in a behavior is one way to maintain stable life conditions and stay in a state of comfort, either reactively, by acting directly on the environment, or proactively, by foraging or removing potential threats. Emotions may accompany these activities when stable conditions are no longer guaranteed: stress may be the primary form of emotion, being a signal that indicates to the organism that it needs to react quickly to some external variations before any internal adaptation takes place. In certain species, emotions also constitute a social signal to congeners, telling them to prepare themselves for a threat. This is where empathy comes in. It can be understood as a response to the signals an organism displays when outside its comfort zone and seeking to return to normal conditions. Thus, the natural connection provided by empathy can be channeled when trying to modulate the expressivity of a robotic artifact, providing cues about the different states, from comfort to distress, in which it can find itself.

1.4 Relationship Between Attribution and Expressivity

From indifference to compassion or fear, the relationship to a robotic artifact may take many forms. Based on the models we described, we can imagine a rather systematic relationship between the psychological properties attributed to a robotic artifact and its expressivity, which we define as the ability to convey some affects and create a relationship of sympathy or empathy (Fig. 2). Two sets of behavioral cues determine the robot's expressivity (although those two sets can overlap): the ensemble of cues that provide some information regarding the perceptive and cognitive skills of the robots, and the ensemble of cues that indicate in which state of comfort/discomfort the robot finds itself. Manipulating these cues may make it possible to vary the relationship between a human observer and the robot, and to create different types of interactions, from simple coexistence to active communicative interaction.

For instance, a robot construed as merely autonomous, without any cues about intentional behavior, may evoke nothing other than relative indifference. But adding some evidence that it is in pain would conjure a degree of empathy. That empathy could be strengthened by cues indicating the robot's ability to pursue intentional actions, provoking sympathy (a tendency to put oneself in others' shoes) for the action in which the robot is engaged. Adding a social component to the robot's behavior allows for some additional values to be considered, especially by determining how positively or negatively it relates to one's own intentions and goals.

The model we propose to describe some general properties of psychological attribution and the motion cues on which it is based makes it possible to elaborate some general objectives regarding the expressivity of a robotic artifact. Before any concrete implementation, one could determine what kind of behavioral properties to impart to the robot in order to elicit a psychological attribution at a particular level of interpretation. This "psychological prototyping" is merely a starting point in the process of determining the movement qualities a robot should possess to attain an appropriate level of expressivity. It should therefore be supplemented with tools designed to precisely qualify the nature of the movement we want to implement in a robotic artifact, both in its intrinsic quality and its temporal execution.

2 Towards an Analysis of Qualia of Gesture: Gesture and Meaning

2.1 Take Note of Movement

If, to paraphrase Goodman [19], a score is the object that guarantees the identity of a work allowing for different incarnations, interpretations, and performances, we should consider the need to invent a system of notation in robotics. Should we speak rather of description or transcription or an analytical grid for analysis? To

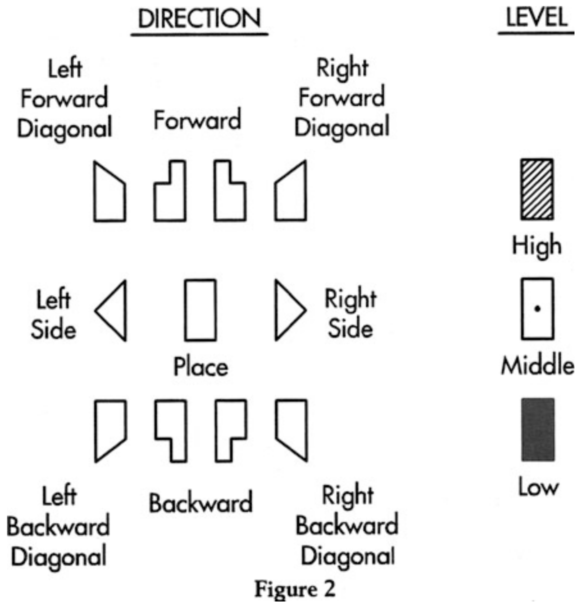

Fig. 3 Eight directions in each spatial plane and three levels of direction for body segments

record human movement, one of the most effective and widespread systems is Kinetography Laban or Labanotation (Fig. 3). In that system of notation, for example, there are only 8 directions in each spatial plane, and three levels of direction for body segments (high, middle, and low): a system of notation must necessarily reduce the contingency and complexity of a movement to a reproducible, representative system that is sufficiently precise to account for a phenomenon, but ambiguous enough to be able to describe a similar, but different, behavior.

To create a behavior notation or transcription system, it is essential to start from geometry. Movements and rotations on the three planes must be noted for all segments and in relationship to a "root" of all the segments. Since the human body is radially symmetric in kinetography, the basic orientation of the figure is the pelvis. But if we want to transcribe or note a behavior, it is necessary to do more than describe the relative motion of the parts of the body performing it, especially when discussing the behavior of non-anthropomorphic robotic figures. To understand why and how to note the other aspects of a behavior, we must start by differentiating movement from gesture. A movement is the shifting of an object or one of its segments in space and in time relative to a system of reference. An apple that falls from a tree, a train hurtling at top speed, or a pendulum perform movements, but not gestures.

2.2 *From Movement to Gesture: Performative Agogics*

The definition of the gesture develops around the question of meaning, the signifié attributed to a movement (by the author and/or the observer): a gesture is a movement that has a specific meaning within a specific culture. That meaning is not necessarily a matter of a coded semantics—modern and contemporary dance emerged, after all, in opposition to a codification of both bodies and movements. If movement is denoted by its form, gesture appears as an element of a discourse. But how is that discourse defined? And how can the expressiveness of a gesture be defined?

Taking the example of a simple gesture (extending a forearm previously folded back over the humerus held out forward), Hubert Godard explains that the gesture can of course be accomplished in a number of ways, but that it will almost always be understood through the application of two pure trends: on the one hand, it can be seen as an order or a command, on the other as a request or an appeal. The two movements, however, should, be noted exactly in the same way in Kinetography (extension of the forearm with the arm oriented on the sagittal plane facing forward, middle level). To summarize, for Hubert Godard, the reading of the meaning of a gesture is not limited to the analysis of the motions of the moving parts, but is more a relationship to postural tensions that act like a background for the frontal figure, which corresponds to what medicine defines as *Anticipatory Postural Adjustments* (APA).[5]

Hubert Godard proposes calling the ensemble of that activity "pre-movement" [18]. Pre-movement is based on a specific relationship to weight and gravity, and precedes and anticipates movement. The same gestural form—such as an arabesque—can be charged with different meanings depending on the quality of the pre-movement, which undergoes very large variations as the form endures. It is what determines the tautness of the body and defines the quality, the specific color of each gesture. Pre-movement acts upon gravitational organization, meaning the way the subject organizes its posture in order to remain erect and respond to the law of gravity in that position. A whole system of anti-gravity muscles, whose action largely escapes vigilant consciousness and will, is responsible for our posture; they are the ones that maintain our balance and allow us to remain standing without having to think about it. It so happens that these muscles are also the ones that register our changes of affective and emotional states. Thus, any change in our posture will have an effect on our emotional state, and conversely, any affective change will lead to a modification, even an imperceptible one, of our posture.

The analysis of "pre-movement" is that of the non-conscious language of posture. Erect posture, beyond the mechanical problem of locomotion, already contains

[5]The literature on APA is vast, but among the first to have had the intuition and then to have conducted experimental research were: N.A. Bernstein, *The coordination and regulation of movements*, Oxford, Pergamon, 1967; S.M. Bouisset, M. Zattara, "A sequence of postural movements precedes voluntary movement", *Neuroscience Letter*, 1981, n. 22 pp. 263–270.

psychological and expressive elements, even prior to any intentionality of movement or expression. It is pre-movement, invisible and imperceptible for the subject itself, that activates at the same time the mechanical and affective levels of its organization. Depending on our mood and the imagination of the moment, the tensing of the calf, which prepares without our knowledge the movement of the arm, will be stronger or weaker, and will therefore change the perceived significance. The culture and history of a person, and their way of experiencing and interpreting a situation, will induce a "postural musicality" that will accompany or catch out the intentional gestures executed [18].

So, to understand and read a gesture, alongside what happens in the geometry of the kinesphere (the sphere of motions in the directions of space), it is necessary to analyze the organization of the whole gravitational relationship and the tensions that anticipate and underlie the entire equilibrium. Those are what produce voluntary movement within the kinesphere. To summarize, a gesture is, according to Hubert Godard, a movement plus a pre-movement.[6]

United in gesture, movement and pre-movement produce a unique dynamic that Laban called the "dynamosphere" or the "connection between the outer movement path and the mover's inner attitude" [27], meaning all of the APAs, plus the energy used (the measurable product of the work) and the play of co-contractions (or non co-contractions) of agonistic and antagonistic muscular groups. To note those dynamics, Laban invented a notational system less well-known than his kinetography, called the *Effort Shape* [28]. The system only integrates four parameters, and does not allow for the notation of the shape of a movement, but does make it possible to note all of the fundamental dynamics (Fig. 4).

In general, perception of dynamics is visual, but can also be auditory. Hubert Godard often presents this example: someone lives in a house they know well. The house has a wooden staircase that makes noise when someone goes up or down the stairs. If the person knows the other inhabitants of the house well, just by listening to the sounds made by the stairs when someone uses them, he or she can know who is going upstairs and that person's tonic and psychological state. Godard's example is interesting because it evokes a listening context, and therefore refers to the sound effect of body movements. The listening context described is that of acousmatics—which designates the fact of hearing sounds without seeing their source. Launched

[6]The experiment carried out in the framework of the TechLab workshop of the Dance Monaco Forum (by a team that included, among others, H. Godard, A. Menicacci, E. Quinz, the research team in IRCAM directed by F. Bevilacqua, and the research scientist in behavioral neuroscience I. Viaud-Delmon, CNRS) led to an interesting discovery. By using optical fiber flexion sensors to measure the lateralized movements of two dancers, in particular making repeated arm movements to the right and left, it was possible to determine that the movements involved a whole series of adjustments that were not bilaterally symmetrical as we might have imagined. That indicates that the geometric kinesphere is only a theoretical premise and that when it is experienced through the contingency of a gesture it is dented and asymmetrical. The perceived space is not homogeneous and it contains variable directions and intensities. Cf. A. Menicacci, E. Quinz, "Etendre la perception? Biofeedback et transfert intermodaux en danse", in "Scientifiquement danse", *Nouvelles de danse 53*, Brussels, 2005, pp. 76–96.

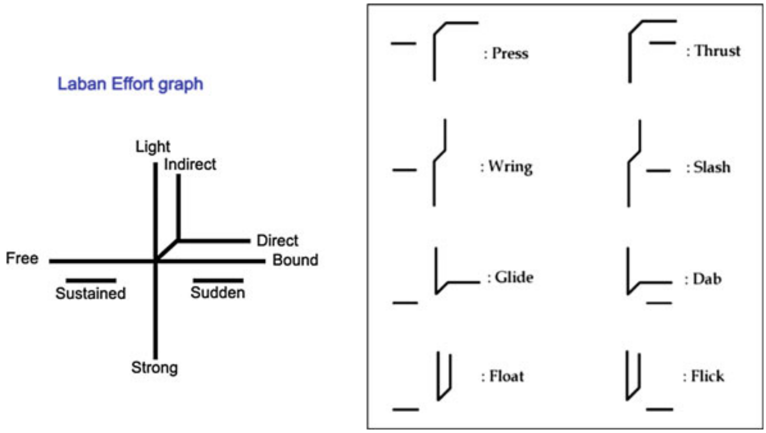

Fig. 4 The Laban Effort graph, and the eight fundamental dynamics

by Pythagoras to make his disciples concentrate on his voice, the technique was taken up by composers of musique concrète in the 1950s and 1960s. In that context, several attempts were made to analyze and note down the qualities of what Pierre Schaeffer called "acoustic objects" [11, 45, 46], objects that escaped—through their irregular morphology—traditional systems of notation. Sachaeffer, in the propositions in his *Solphège de l'objet sonore* (Music Theory of Acoustic Objects), explored several approaches to notation for the timbre parameter—offering notions such as the *harmonic timbre* (which defines the constellation of harmonics that surround a sound), the *grain* (texture of the sound matter), or the *allure* (oscillation of the ensemble of the sound's characteristics). The sound parameter that could prove most promising for our research is agogics.

In music, agogics designates the slight modifications of rhythm that affect the interpretation of a piece of music in a transitory way, as opposed to a strict and mechanical performance. If timbre concerns the instrument, agogics concerns the player. It manifests itself in the form of slowing, acceleration, caesurae, or pauses that "color" and personalize the performance of a movement, like identifying traits or hesitations. Agogics can be useful in our research because it makes it possible to re-incorporate qualia—which are characteristic of gesture—into movement.

There have been several attempts to notate agogics: episemes (from the Greek ἐπίσημον, "distinguishing feature"), which specify a nuance of rhythm—especially in Gregorian chant, up through diagrams supplied by the analysis of physical energy of the performer's gesture [29, 30]. Even if agogics only functions on one level, that of the distribution of accents (basically, energy in movement) and is reflected in the choice of emphasis in one plane of space, it can make it possible to work on the idea of an "individualizing" effect that manifests itself in the form of a script that adds bumps to the linear and fluid (therefore mechanical) performance of a movement that can give it "gestural" connotations: slowing down, accelerating, backing up, etc. Agogics is interesting because, like gesture, it lies at the crossroads between the physical (anatomy) and the psychological.[7] Similarly, Hubert Godard's analysis of the kinesphere is interesting in that it connects the physical to the psychological, considering that a subject's history can also be read through physical elements.

2.3 From Gesture to Behavior

Once the dynamic aspect has been integrated into the geometry and temporality of movements, only one parameter remains to read movement in humans: the relationship to the context. A gesture is always performed in a historically and geographically determined context, one that is also read, interpreted, and categorized by the moving subject. It is the analysis of what happens in the kinesphere, plus what happens in the dynamosphere, plus elements contextualizing the gesture that make possible the overall reading of the meaning of the gesture, or what Hubert Godard calls the "gestosphere",[8] or all of the emotional and symbolic data that connect the person making the gesture to their environment.

Behavior can be a series of predetermined (such as a fixed choreography) or generative actions, a set of rules that determine a sequence of decisions and actions in time which can be not completely frozen in their structure (such as an improvisational system in dance or music). Thus defined, even the motions of a sensorless robot can be described as a behavior, because even the most rigid and purely functional movements have their own precise spatial qualities established by a choreographed program and by a relationship to gravity. The simplest robot therefore has a certain type of behavioral relationship to its environment that is its own. That behavior, however, is of an autistic type: the robot does not really listen to its environment and does not necessarily adapt to it, or very little. It does not change its qualities according to a relationship of proxemics, and therefore has no semantic relationship to space. One could say that it has a connection without relationship, since, in clinical psychophysiology, for there to be a relationship

[7]See the research projects led by Antonio Camurri (Università di Genova, Italy). Starting from the mapping of «emotional indexes» embodied in the body movement, Camurri has developped since 1999 the software EyesWeb and EyesWeb XMI Gesture and Social Processing Software Library. See Camurri [7, 8], et A. Camurri, B. Mazzarino, G. Volpe (2004) Analysis of Expressive Gesture: The EyesWeb Expressive Gesture Processing Library, in A. Camurri, G. Volpe (eds.), Gesture-based Communication in Human-Computer Interaction, LNAI 2915, pp. 460–467, Springer Verlag.

[8]The "gestosphere" or "sphere of the gesture" is proposed by Hubert Godard as the ensemble of connections (physical, perceptive, affective, and symbolic) that relate people to their environment. In contrast to Laban, Godard insists on the way the "dynamosphere" is psychologically and symbolically experienced by a person. We could therefore advance that the Godardian gestosphere is based on the dynamosphere, but goes beyond it from the viewpoint of meaning, since it immediately takes into account the psychological experience of the person. Cf. L. Louppe, *Poétique de la danse contemporaine*, Brussels, Contredanse, 1997, pp. 68–70.

(and not only a connection), consideration and hearing of the other in a shared space is necessary. A robot without "sensory organs" (i.e., sensors) is trapped in a geometric and functional fundamentalism in which listening to the other is subservient to its functions, its program. And it is not capable of adapting temporality or geometry to its task. One could speak of a perverse relationship to the other, the perversion being the non-recognition of the other as an other.

For a humanization of behavior, to move from the dynamosphere to the gestosphere, the robot must be endowed with two things in addition to the ability to move: "sensory organs" and an axiology, meaning a system of perceptual categorization that allows to assign meaning, to establish priorities, to know how to focus on certain important aspects of the environment and to know how to ignore others, according to circumstances and setting. The organs must sense the world, but it is the attribution of meaning to the perceived elements that allows for the definition of thresholds for the triggering and the accomplishment of actions. That attribution of meaning is certainly what determines emotion vis-à-vis the world. Emotion seeps through body, through pre-movement and the dynamics that color and provide "timbre" to the movement, building the layers of its harmonics, transforming it into a gesture, which finally gives it its meaning. The meaning given to the environment gives shape to our senses which in turn give direction to our movement (sens) by transforming it into behavior.

In summary, a three-tiered structure is once again taking shape:

1. the kinesphere, based on the geometry and motion that define the movement
2. the dynamosphere, based on the energy accents that define the gesture
3. the gestosphere, which is to say the relationship of a gesture to the context that defines the behavior

Consequently, can we use that general model to describe gesture in order to move closer to an implementable system? And can that model be compatible with the one elaborated in psychology of action?

3 Towards a System of Notation and Implementation of Behavior

We are attempting to identify the main features of what could constitute a system of notation and implementation of behaviors for non-anthropomorphic, non-zoomorphic robotized objects. Our goal is to go beyond a simple description of movement in the form of linear scores evoking motions in space by integrating the qualitative, relational, and behavioral aspects previously mentioned. We have retained two approaches to evoking the relationships among motion in space, semantics of movement and contextualization of behavior. The first is a product of the psychology of the perception of action, and allows us to better understand the way the psychological properties spontaneously attributed to an object endowed with movement are organized. The second seeks to define what, beyond the geometry of movement, constitutes a gesture in its relationship to the postural, dynamic, and contextual organization of the body. As for the notion of an agogics of movement, it puts forward the texture of movement in its idiosyncratic dimension.

3.1 Notating Movement to Attempt to Implement Behaviors

Notation, be it choreographic or even musical, makes it possible to formalize and transcribe in a conventional form (established by a code) the components of a work and, more specifically here, a series of notes or actions to be accomplished in order to produce or to instantiate the work in question. Consequently, that notation is shareable with a community that has knowledge of the conventions and can thus perform the work in accordance with that notation. The notation makes it possible to store, distribute, and perform the work just as it makes possible the creation of works without carrying them out, remaining in an "ideal" phase. Those works are then allographic in nature [19, 20], principally characterized by a two-stage operation: the time of notation, then that of instantiation, which then leads to the realization of the work. That dual temporality calls to mind another, so common today: that of programming and its running by a computer. What are the fundamental differences between these systems of executable notation? How and why could we bring these two worlds that share the same dual-time system closer together? And to what extent is it possible?

If computer programming is an increasingly common practice, it is a product of an abstraction that does not always make it possible to comfortably reconstruct or work out, even mentally, what running it will produce. Many programming environments therefore function in layers, from lowest, very abstract and detailed, to much more concrete, even figurative, levels that make it possible to have a global vision. The latter include auteur-oriented software such as graphic programming environments that work through patches (such as Max MSP, Pure Data, Isadora, etc.) or with command boxes such as Scratch (from the MIT Media Lab) followed by Snap (from Berkeley) or the Lego Mindstorm software, or even Blocky. All this software are also based on a system of graphics objects that can be snapped together like bricks or pieces of a puzzle.

More specifically within the scope of our research—though dedicated to Aldebaran robots (NAO, Pepper, and Roméo, all three of which are eminently anthropomorphic)—the software environment presented by Aldebaran (around the NAOqi OS) is very interesting, particularly Chorégraphe, a graphics programming authoring software itself using a system of "blocks" that can be connected amongst themselves to create a "flow diagram" and behaviors (or that can use a library of already available behaviors), with the possibility of publishing (via Curve) movements via a TimeLine in accordance with logic stemming from animation, or by publishing those movements through programming.

Bringing together choreographic notation and graphic programming environments would make it possible to manipulate a system of signs relating to the concrete physical reality of bodies while making the system executable by a computerized machine requiring an abstract logical system, a program. Such a notation/programming environment for movements, even behaviors, would make it possible to compose scores for objects at the meeting point of the two worlds in question (choreography and computers), for robots, especially in human form (humanoid or android).

We clearly see the value of such executable scores, which could be produced by authors equally to store or transmit or to have a humanoid robot produce a series of actions by using a symbolic graphic system, though also by analogy to the human body, like the main choreographic notations (Laban and Benesh).

However, that perspective presents two problems, one general and the other specific to our approach. The first relates to the fact that the computer and robotic paradigm is primarily interactive before it is linear. To have a robot perform a linear score of movements is of very limited interest when one considers it from the perspective of robotics or more broadly from interaction design. How can openings, variables, or a conditional principle be integrated into the notation system? That issue is absolutely central, including specifically for our approach, because that is also a question when it comes to passing from movement to behavior, something that is primarily relational and contextual.

The second problem is more directly related to our approach: what about when one is interested in non-anthropomorphic—even non-zoomorphic—objects? Even objects with no limbs—abstract or utilitarian objects, for instance? How then to take from these notation systems the dimensions that make possible the notation of movement not according to bodily positions, but according to qualities transposable to other forms and interpretable as concerning psychological, behavioral characteristics?

Another fundamental difference between the performance of a score by a human being and the running of a program by a computer obviously resides in the quality: variable and dependant on the humanity of the performer and (usually) invariable for a machine. As we have seen, in performance there is a dimension that goes beyond respect for the score, the notation, and which is perceptible precisely in the manner, the style, the energy, the agogics, etc. with which the performers take possession of the score, producing an instantiation as respectful of the work as it is singular. That performance, if we follow its trail, makes it possible to describe the author, to feel certain traits of their personality, their character, their way of functioning, their behavior. Where the performer, a human, makes gestures, the robot makes movements. How can we appeal to the intrinsic quality of those movements and to their relational and contextual qualities, such that those mechanical movements can have similarities with gestures, or even fall within the province of behavior, including for non-anthropomorphic, limbless robots?

To do that, we pose the hypothesis of this twofold approach: one part (psychology of action) starting from human perception of movements and the resulting attribution of behaviors (from animacy to social agency), and the other (gestural analysis) starting from movement and going back toward its context (from the kinesphere to the gestosphere). The question then is how to bring those two approaches together in a model allowing, in the end, for an implementable formalization, while factoring in two imperatives: that our system be conditional (open to contextual conditions) and applicable to non-anthropomorphic and non-zoomorphic objects.

3.2 Shape the Movement with a Set of Constraints

As we have seen in this article, the shift from movement to behavior—that is from a purely geometrical description of movements to a description integrating psychological attributes as well as a spatial and temporal context—necessitates several steps: an account of body posture and its relation to terrestrial gravity (pre-movement); a description of the dynamic movement organization, calling forth the notions of effort and energy, specifically in the context of the dynamosphere and agogics; and the representation by an observer of certain properties of the scene—physical constraints and psychological properties. To summarize this approach, we could define three dimensions that may organize the notation system we are looking for:

– **Movement**: This is the description of movements within a kinematic model, that is without referring to causes of motion, in terms of relative positions within a system of reference and differential properties (speed, acceleration). In the domain of dance notation, this dimension corresponds to the **kinesphere**, as described by Laban;
– **Gesture**: With respect to a notation based on geometric properties, a qualitative notation introduces certain attributes that do not depend on the linear progress of a score, but leaves room for certain fluctuations, the specific texture of a performance (agogics). This corresponds to the dynamosphere, based on energetic emphases;
– **Behavior**: The behavioral dimension in notation integrates different possible junctions of a movement sequence, its different evolutions depending on contextual variations. This dimension corresponds to the gestophere, the sum of projective and symbolic relationships to the environment, before and during the movement.

Those dimensions do not strictly correspond to the psychological organization we elaborated in Chap. 2: animacy, agency, and social agency. In fact, the three dimensions, movement, gesture, and behavior, are present at each of those levels. However, they do not bear the same weight. For instance, the movement dimension is more critical at the animacy level, inasmuch as the objects described at that level do not yet possess intentional properties that would allow the connection of their displacements to non-physical attributes. The behavior dimension, in its symbolic aspects, is more critical at the social agency level, insofar as the social interaction abilities may enable communication behaviors to take place.

To progress in the direction of a system of notation able to integrate these different aspects, the movement dimensions should be considered in relation to the psychological mechanisms engaged by an observer when perceiving the movement of an object. Some quantifiable motion features (direction, speed, or a change of volume of an object) should be linked to the scene features that an observer mentally represents and that may constrain the interpretation of the motion (for instance whether the observer is aware of certain forces that organize the motion, or of certain computational characteristics of the robot that determine the way it behaves). To move forward in that direction, we could conceive of a system of constraints that would determine the actualization of a movement in a robotic artifact and the interpretation given by an observer.

As we have seen, authoring environments rely on relatively abstract graphic interfaces and allow to program with patches, building blocs or following a time-line. Those different visual paradigms have already proved themselves useful, but we are looking for an even more intuitive solution that could go a step further in the representation of a behavior. We are just contemplating hypotheses that need to be developed and confirmed, but right away we want to consider some possible orientations. We assume that behavior, as expressed through evocative movements, is the result of different forces and constraints that we could formalize as a sort of landscape expressing the arrangement of these parameters. If this approach follows the line of Laban's «spheres» and graphic programming environments, the goal here is to integrate behavioral properties that could elicit specific psychological attributions, through a graphic interface with a high-level of abstraction. To configure a behavior as a landscape of forces and constraints, the idea is to create a dynamic and contextual cartography that takes into account the internal states of the objects as well as the context in which it evolves. Take for instance an object that moves on its own but tends to be scared by people around him. Assuming that this object is going to slow down in the vicinity of people, this inhibition could be transcribed in a landscape of force and constraints as a slope to climb, with a slope angle varying as a function of the degree of fear we want to impart to the object's behavior. The degree of inhibition is therefore configured as a constraint on movement, that is a resistance opposed to the initial object's velocity. Depending on the context and the type of object we want to animate, depending also on the degree to which this robotic object can be influenced by its environment, these constraints could also be external. This system of configuration by constraints amounts to a constellation of forces, both internal and external, from which a movement can result. This system could obviously be dynamic and adaptable, with different parameters to configure.

To progress on that idea of internalized landscape as a way to promote an abstract graphic representation of behavioral properties, we propose a hierarchy of constraints. Constraints at a superior level in a hierarchy would organize the way those at inferior levels act on the movement parameters (for instance, the intention to walk in a particular direction, a behavioral constraint, determines the postural

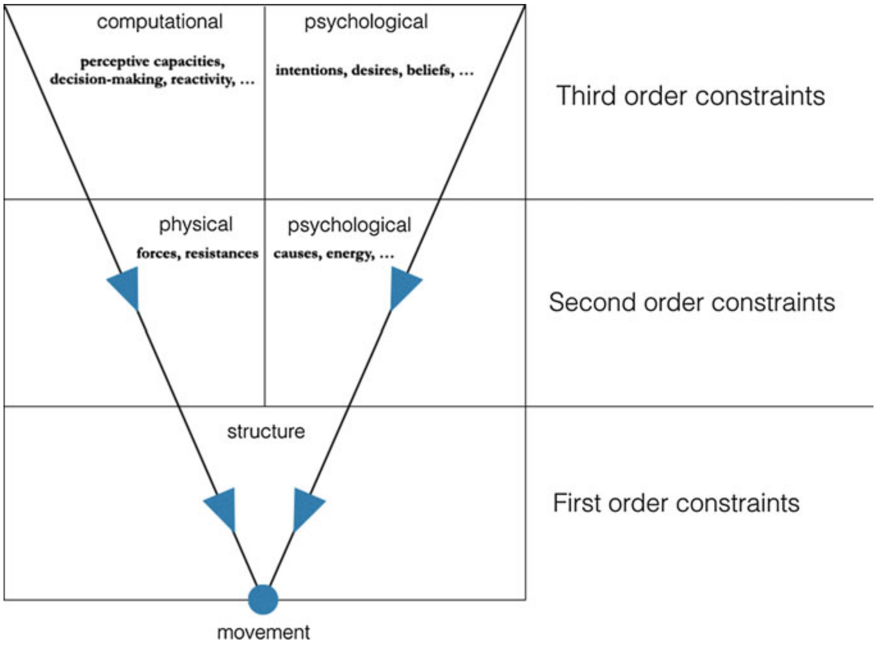

Fig. 5 Three orders of constraint to elaborate a robotic artifact's movement

adjustment and the dynamic realization of the movement, as a function of the ground). In that way, we can represent the process of conceiving and implementing expressive movements in a robotic artifact as the determination of variables at three levels of constraints (Fig. 5):

- **first-order constraints**: These constraints correspond to which movements are possible given the physical structure of the robot, the part it is composed of, and their degree of freedom.
- **second-order constraints**: These constraints correspond to the physical forces and resistances that may intervene during the realization of a robot's behavior and shape its execution. This type of constraint is at an intermediate level between the physical implementation of a robot and the behavioral properties we want it to display. They should make it possible to describe the movement's pace as a function of temporary energetic asymmetries that are resolved as the behavior unfolds. These constraints can be conceived as virtual forces and resistances inside an internalized landscape, meaning they need not be part of the actual physical world the robot is embedded into. Rather, they are meant to suggest to a human observer a particular dynamic organization, by interacting with her own intuitive physics and capacities of motion interpretation, in relation to contextual cues in the scene. For instance, an additional resistance applied to the robot's motion would produce an impression of sluggishness and overall difficulty to evolve smoothly. Other example: a constraint specifying an

external force resulting in a sudden acceleration and deviation from an initial trajectory, with a constant direction, may suggest, depending on the possibility to relate the deviation to an external landmark in the scene, that the robot is running away from something or that it is eagerly attempting to reach something.

– **third-order constraints**: These constraints correspond to the behavioral capacities that we want to be attributed to a robot by an external observer. These capacities need not be part of the actual computational endowment of the robot, but are to be suggested through consistent motion patterns and the interaction of the robot with its environment. The third-order constraints may correspond to at least three categories of cognitive abilities: perceptive abilites (to what extent the robot is aware of its surrounding), reactivity (to what extent the robot is prompt to change its behavior in reaction to external events), and decision-making (to what extent the robot's behavior is goal-oriented and flexible). Those abilities, expressed by constraints on the robots' movements, would be likely to receive a translation in terms of naïve psychology, that is according to intentions, desires and beliefs, as well as other psychological traits. For instance, constraints that specify the degree to which the robot's behavior is impacted by external events would determine an impression of awareness, curiosity, or indifference. Constraints related to the consistency of its behavior over time would influence the possibility for an observer to identify goals and determine how persistent the robot appears.

4 Conclusion: A Dual Interpretation to Analyze and Implement Behaviors

To analyze, conceive, and implement behaviors in objects that do not look like living beings, we have elaborated on two perspectives on the interpretation of movement. The first perspective corresponds to the psychological inferences spontaneously drawn when observing a movement in space. The second perspective is based on dance notation and the notion of emphasis in a musical phrase. We looked for a way to go beyond existing notation systems based on the human body [26], a system that could extract expressive movements that apply independently of the physical structure of the object, and contribute to a system of notation for non-anthropomorphic robotized objects. We delineated a solution that takes into account the human ability to interpret motion characteristics in terms of psychological traits, and we proposed a progression from movement to gesture as a way to move towards the description of genuine behavioral qualities and expressive attitudes and emotions. From these two perspectives, we proposed two typologies, both organized around three levels: animacy, agency, and social agency on the one hand; kinesphere, dynamosphere, and the gestosphere in the other. If these two typologies do not correspond directly, they can be joined based on a series of constraints at different levels of abstraction. These constraints, conceived as an arrangement of forces and constraints in a sort of internalized landscape, could contribute to the representation of behavior inside a graphic programming environment that takes movement notation beyond a mere linear score.

Because we propose a model that is based on constraints rather than on direct specifications, on conditions rather than on descriptions, it may be important to integrate a system of notation that would guide the implementation of movement in a robotic artifact. This system of notation could be composed of a library of movements, called forth as a function of a set of constraints defined upstream. This library should be composed of two elements: a system of movement notation with descriptions of the relative motions both in space and time, and a "qualitative" score that would, on the model of what is done in music notation, give specific performance instructions. This qualitative score could borrow from Labanotation, especially the Effort Shape notation, and/or from the agogic principles of notation in music.

References

1. J.A. Baird, D.A. Baldwin, Making sense of human behavior: action parsing and intentional inference, in *Intentions and Intentionality: Foundations of Social Cognition*, eds. by B. Malle, L.J. Moses, D. Baldwin (MIT Press, 2001), pp. 193–206
2. S. Baron-Cohen, How to build a baby that can read minds: cognitive mechanisms in mindreading. Cah. de Psychol. Cogn. Current Psychol. Cogn. **13**, 1–40 (1994)
3. C. Bartneck, T. Kanda, O. Mubin, A. Al Mahmud, Does the design of a robot influence its animacy and perceived intelligence? Int. J. Social Robot. **1**(2), 195–204 (2009)
4. S. Bianchini, R. Bourganel, E. Quinz, F. Levillain, E. Zibetti, (Mis)behavioral objects: empowerment of users vs empowerment of objects, in *Empowering Users through Design. Interdisciplinary Studies and Combined Approaches for Technological Products and Services*, ed. by D. Bihanic (Springer, Berlin, 2015)
5. C. Breazeal, A. Brooks, M. Hancher, J. Strickon, C. Kidd, J. McBean, D. Stiehl, Public anemone: an organic robot creature, in *ACM SIGGRAPH 2002 Conference Abstracts and Applications. SIGGRAPH '02* (San Antonio, Texas, 21–26 July 2002), pp. 76–76
6. C. Breazeal, A. Brooks, J. Gray, M. Hancher, J. McBean, D. Stiehl, J. Strickon, Interactive robot theatre. Commun. ACM **46**(7), 76–85 (2003)
7. A. Camurri, S. Hashimoto, M. Ricchetti, R. Trocca, K. Suzuki, G. Volpe, EyesWeb—toward gesture and affect recognition in interactive dance and music systems. Comput. Music J. **24**(1), 57–69 (2000)
8. A. Camurri, EyesWeb, in *La scena digitale, nuovi media per la danza*, eds. by A. Menicacci, E. Quinz (Venezia Marsilio, 2000)
9. A. Camurri, G. Volpe (eds.), G*esture-Based Communication in Human-Computer Interaction*. LNAI 2915. (Springer, Berlin, 2004)
10. G. Castellano, A. Camurri, M. Mortillaro, K. Scherer, G. Volpe, Espressive gesture and music: analysis of emotional behaviour in music performance. Music Percep. **25**(6), 103–119 (2008)
11. M. Chion, *Guide des objets sonores* (Pierre Schaeffer et la recherche musicale. Paris Buchet/Chastel, INA, 1983)

12. G. Csibra, G. Gergely, The teleological origins of mentalistic action explanations: A developmental hypothesis. Dev. Sci. **1**(2), 255–259 (1998)
13. N. Epley, A. Waytz, J.T. Cacioppo, On seeing human: a three-factor theory of anthropomorphism. Psychol. Rev. **114**(4), 864–886 (2007)
14. J. Forlizzi, C. DiSalvo, Service robots in the domestic environment: a study of the roomba vacuum in the home, in *Proceedings of the 1st ACM SIGCHI/SIGART Conference on Human-Robot Interaction, HRI'06* (ACM, New York, 2–4 Mar 2006), pp. 258–256
15. H. Fukuda, K. Ueda, Interaction with a moving object affects one's perception of its animacy. Int. J. Social Robot. **2**(2), 187–193 (2010)
16. T. Gao, G.E. Newman, B.J. Scholl, The psychophysics of chasing: a case study in the perception of animacy. Cogn. Psychol. **59**(2), 154–179 (2009)
17. S.A Gelman, G.M. Gottfried, Children's causal explanations of animate and inanimate motion. Child Dev. **67**, 1970–1987 (1996)
18. H. Godard, Le geste et sa perception, in *La danse au XX^{ème} siècle*, eds. by I. Ginot, M. Michel (Larousse, Paris, 2008), p. 236
19. N. Goodman, *Language of the Arts* (Indianapolis, New York, 1968)
20. N. Goodman, in *Of Mind and Other Matters*. (Harvard U.P, Cambridge, 1984)
21. J.K. Hamlin, K. Wynn, P. Bloom, Social evaluation by preverbal infants. Nature **450**, 557–560 (2007)
22. F. Heider, *The psychology of interpersonal relations* (Wiley, New York, 1958)
23. B. Hendriks, B. Meerbeek, S. Boess, S. Pauws, M. Sonneveld, Robot vacuum cleaner personality and behavior. Int. J. Social Robot. **3**(2), 187–195 (2011)
24. M.L. Hoffman, *Empathy and Moral Development: Implications for Caring and Justice* (Cambridge University Press, Cambridge, 2001)
25. G. Hoffman, W. Ju, Designing robots with movement in mind. J. Human Robot Interac. **3**(1), 89–122 (2014)
26. M. Karg, A.A. Samadani, R. Gorbet, K. Kuhnlenz, J. Hoey, D. Kulic, Body movements for affective expression: a survey of automatic recognition and generation. Affect. Comput. IEEE Trans. **4**(4), 341–359 (2013)
27. R. Laban, Choreutics, pp. 27–36. Dance Books Limited, London (2001) (1966 orig. ed.)
28. R. Laban, F.C. Lawrence, *Effort Shape* (Mc Donald and Evans, London, 1947)
29. P. Lalitte, Conditions de possibilités d'une rhétorique formelle perçue. Intellectica **1–2**, 103–114 (2008)
30. M. Leman, *Embodied Music Cognition and Mediation Technology* (The MIT Press, Cambridge Massachusetts, 2007)
31. F. Levillain, S. Lefort, E. Zibetti, Moving on its own: how do audiences interact with an autonomous moving artwork? in *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, *Proceeding of CHI 2015* (ACM, 2015), pp. 695–702. http://dl.acm.org/citation.cfm?id=2702973
32. B.F. Malle, Attribution theories: how people make sense of behavior, in *Theories in Social Psychology*, ed. by D. Chadee (2011), pp. 72–95
33. A. Menicacci, E. Quinz, *La scena digitale, nuovi media per la danza* (Marsilio, Venezia, 2000)
34. A. Menicacci, E. Quinz, *Etendre la perception? Biofeedback et transfert intermodaux en danse*. in Scientifiquement danse, Nouvelles de danse 53, Bruxelles (2005), pp. 76–96
35. A. Michotte, *La Perception de la Causalité* (Publications Universitaires de Louvain, 1954)
36. D. Newtson, Attribution and the unit of perception of ongoing behavior. J. Pers. Soc. Psychol. **28**, 28–38 (1973)
37. M. Noma, N. Saiwaki, S. Itakura, H. Ishiguro, Composition and evaluation of the humanlike motions of an android, in *2006 6th IEEE-RAS International Conference on Humanoid Robots* (IEEE, 2006), pp. 163–168
38. A. Paiva, J. Dias, D. Sobral, R. Aylett, P. Sobreperez, S. Woods, C. Zoll, L.E. Hall, Caring for agents and agents that care: building empathic relations with synthetic agents, in *Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems*, vol. 1 IEEE Computer Society, 2004), pp. 194–201

39. A. Pereira, I. Leite, S. Mascarenhas, C. Martinho, A. Paiva, Using empathy to improve human-robot relationships, in *Human-Robot Personal Relationships* (Springer, Berlin, 2011), pp. 130–138
40. R.W. Picard, Affective computing: challenges. Int. J. Hum Comput Stud. **59**(1), 55–64 (2003)
41. D. Premack, The infant's theory of self-propelled objects. Cognition **36**(1), 1–16 (1990)
42. S.D. Preston, F. De Waal, Empathy: its ultimate and proximate bases. Behav. Brain Sci. **25** (01), 1–20 (2002)
43. J. Saez-Pons, H. Lehmann, D.S. Syrdal, K. Dautenhahn, Development of the sociability of non-anthropomorphic robot home companions, in *2014 Joint IEEE International Conferences on Development and Learning and Epigenetic Robotics (ICDL-Epirob)* (IEEE, 2014), pp. 111–116
44. B.J. Scholl, P.D. Tremoulet, Perceptual causality and animacy. Trends Cogn. Sci. **4**, 299–309 (2000)
45. P. Shaeffer, *À la recherche d'une musique concrète* (Seuil, Paris, 1952)
46. P. Shaeffer, *Traité des objets musicaux* (Seuil, Paris, 1966)
47. P. Tremoulet, J. Feldman, Perception of animacy from the motion of a single object. Perception **29**(8), 943–952 (2000)
48. P. Tremoulet, J. Feldman, The influence of spatial context and the role of intentionality in the interpretation of animacy from motion. Percept. Psychophys. **68**(6), 1047 (2006)
49. F. Voisin, LOL: Un environnement expérimental de composition chorégraphique, Paris, Ec/cart, vol. 2, Eric Sadin ed., Dif'Pop (2000)
50. J.E. Young, J. Sung, A. Voida, E. Sharlin, T. Igarashi, H.I. Christensen, R.E. Grinter, Evaluating Human-Robot Interaction. Int. J. Social Robot. **3**(1), 53–67 (2010)
51. J.M. Zacks, Using movement and intentions to understand simple events. Cogn. Sci. **28**(6), 979–1008 (2004)