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REVIEW

# A psycho-ethological approach to social signal processing

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**Abstract** The emerging field of social signal processing can benefit from a theoretical framework to guide future research activities. The present article aims at drawing attention to two areas of research that devoted considerable efforts to the understanding of social behaviour: ethology and social psychology. With a long tradition in the study of animal signals, ethology and evolutionary biology have developed theoretical concepts to account for the functional significance of signalling. For example, the consideration of divergent selective pressures responsible for the evolution of signalling and social cognition emphasized the importance of two classes of indicators: informative cues and communicative signals. Social psychology, on the other hand, investigates emotional expression and interpersonal relationships, with a focus on the mechanisms underlying the production and interpretation of social signals and cues. Based on the theoretical considerations developed in these two fields, we propose a model that integrates the processing of perceivable individual features (social signals and cues) with contextual information, and we suggest that output of computer-based processing systems should be derived in terms of functional significance rather than in terms of absolute conceptual meaning.

**Keywords** Social signals · Social cues · Social cognition · Reliability · Social signal processing

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## Introduction

This paper aims at describing how empirical analyses of behaviour can inform the field of social signal processing (SSP), conceived here as the automatic analysis and synthesis of human social signals by computer systems (Pentland 2007; Vinciarelli et al. 2009). The concepts that will be presented in this article derive from a number of disciplines that dedicated considerable effort to the study of communication in humans and animals. These disciplines are ethology, behavioural ecology, evolutionary psychology, and social psychology.[1] The work done in these disciplines represents more than a century of research in the domain of nonverbal communication and reached an elaborate degree of conceptualization that SSP cannot afford to ignore if it aspires to be solidly anchored in the behavioural sciences. Conversely, conceptual developments in the behavioural sciences may only be possible thanks to the new methodological approaches offered by SSP. We are therefore faced with a major opportunity to join theoretical insight from cognitive and behavioural sciences together with machine learning and pattern recognition algorithms for the development of computational analysis of human social behaviour. As one of the first formal attempt to establish such collaboration on the European continent, the social signal processing network (SSPNet) has to provide a strong conceptual basis for future research on SSP. This article contributes to the establishment of this conceptual basis.

Social signal processing includes the word "social" and the word "signal." As human ethologists, social psychologists, and behavioural scientists, we feel that it is our task

[1] Though not extensively, this paper will also consider notions of linguistics and pragmatics.

to elaborate on these two concepts. We will start by introducing the theoretical background used in ethology to study social interactions and relationships, then present a definition of social signals (and related concepts) based on the theoretical and empirical work conducted in ethology and behavioural ecology. The definition will include a presentation of different functional categories of signals. The evolutionary function of signalling and its relevance to SSP will be discussed. We will then elaborate on the proximate mechanisms involved in the perception and production of social signals as they are studied in social psychology. In this section, we will mostly build on the concepts developed to study emotional communication, interpersonal perception, and social cognition. The relationship between more specifically human aspects of communication, symbolism, and emotional expressions will also be discussed briefly. Finally, we will present a psycho-ethological model of what, in our view, SSP should be able to achieve.

## What is it to be social?

Sociality is concerned with all the aspects that make individuals interact with each other to satisfy needs that could not be achieved by individuals alone. As opposed to the mere aggregation of organisms around favourable environmental conditions, sociality implies interactions between individuals. These interactions can be of different kinds, depending on the individuals involved and their dispositions, needs, and goals. For example, interactions can be conflicting, like in competition over resources; they can be cooperative, when reaching a goal depend on joint action; or they can involve dependency, like the interactions between a newborn and its caretakers. The set of all social interactions between, at least, two individuals constitute a relationship, and the collection of all the relationships between members of a group constitutes the social structure (Hinde 1976). Taken as a whole, the set of relations between different groups constitutes society. Regulation at each level of the social structure is achieved by the display and processing of social signals and cues.

Sociality has evolved as an elaborate solution to face important biological issues like defence from predators, exploitation of resources, reproduction, and rearing of progeny (Dunbar 1988; Janson 2000; van Schaik 1983). Since these biological issues are common to most organisms, sociality is deeply ingrained in the cognitive architecture of many species, including primates (Dunbar 1998; Humphrey 1976; Whiten and Byrne 1988). Being integral parts of the primate order, humans are extremely social, and this tendency transpires in all aspects of human activities: management of resources, reproduction, leisure, art, media, religion, etc. Because the emergence of sociality as an evolutionary stable strategy precedes by far the apparition of the human species on the tree of evolution, a conceptual analysis of social signals cannot ignore the research findings and theoretical developments made in disciplines investigating the biology of behaviour in other animal species. We adopt the position that many aspects of our current social behaviour reflect adaptations to social problems that arose during the evolutionary history of primates.

Although sociality brings important survival and reproductive advantages, it also comes with costs, for example, increased competition for resources such as food or sexual partners. Social behaviour and cognition—the full repertoire of which can be called social strategies—have evolved precisely to help organisms achieve the right payoff balance between the costs and benefits of group living. Living in large and complex groups, it became very important for individuals to accurately respond to contingencies such as: Whom to mate with? Whom to rely on in social alliances? Whom to avoid during conflicts? The ability to acquire and process up to date social knowledge about group members whose values and dispositions can fluctuate over time is considered as the hallmark of cognition in apes and humans (Barrett et al. 2003). Similarly, individuals who could successfully advertise their personal qualities as valuable mates, successful leaders, or serious contenders in conflicts (or individuals who could influence others into believing that they possess such qualities) enjoyed serious survival and reproductive benefits. The monitoring of group members and the management of interpersonal encounters are achieved through communication (Owings and Morton 1997), which can therefore be considered as one of the most significant biological adaptations of primates.

There is an increasing tendency in ethology to consider communication as an adaptive solution to manage and assess the social environment (Krebs and Dawkins 1984; Owings and Morton 1997; Owren et al. 2010). On the one hand, individuals have to organize social information in a way that helps them take adaptive decisions. This means: to make the right social choice at the right time; to know what one needs from others and what others' needs are; and to seek adaptive traits and dispositions in others. Communication skills also require that individuals know when it is the right moment to display, consciously or not, a potent behaviour and to advertise, deceptively or not, his/her own intentions and dispositions. The management and assessment of the social environment are achieved through the production and perception of social signals and the cognitive processing of social cues.

## What is a social signal?

To our eyes, ethology offers a useful definition of signals because it is not bound to the attribution of specific meaning to signals, nor to the idea that signals are produced intentionally to convey information. In its broadest sense, *a signal is an act or structure that influences the behaviour of other organisms, which evolved because of that effect, and which is adaptive because the receiver's response has also evolved* (Maynard-Smith and Harper 1995, 2003). It is generally accepted that signals "carry" information that is adaptive to the receiver otherwise receivers would cease to respond. Indeed, it is believed that the risk of deception and social exploitation placed a strong selective pressure on receivers to develop mind reading abilities that discriminate signals associated with adaptive information from deceptive and manipulative signals. The evolution of mind-reading abilities, in turn, placed a selection pressure on signals to become more reliable. It implies that the evolution of signalling has led to a reliable communication system in which senders and receivers benefit from the transfer of information (Zahavi and Zahavi 1997).

An alternative view of signalling places the functional emphasis on social influence rather than on information transfer (Owren et al. 2010). The influence principle is well illustrated in a quote by Krebs and Dawkins (1984, p. 380): "Just as a wing performs its normal function by working on the air, so a signal performs its normal function by working on another animal via its sense organs." According to this view, what matters for a signal to evolve is to have a positive impact on the signaller's fitness, irrespective of whether the perceiver benefits by acquiring some information. In a recent essay on the meaning of animal signals, Rendall et al. (2009) emphasized the weaknesses of an approach based on the transfer of information between a sender and a receiver to explain animal communication. They contend that information is too vaguely defined as a concept to constitute the central aspect of signalling. In their view, signals mainly evolved to match receiver's perceptual systems implying that a signal's properties are not sources of information per se but are means of improving detectability and localizability, but also to avoid habituation. Although their critique is mainly focused on the way ethologists reflect on animal communication, it underlines the importance of considering alternative explanations for the evolution of human nonverbal behaviour (Owren and Bachorowski 2003).

As psychologists, we find it relatively uncomfortable that ethological definitions of social signals are not directly applicable to human communication, as they usually avoid the topics of symbolism and language.[2] Ethologists indeed recognize that language has its own rules that are separate from those governing animal signals (Rendall et al. 2009). However, the importance of multimodal communication makes it difficult to approach the study of social signals without considering language and its complex interactions with nonverbal behaviour. For example, the meaning of words can be modulated by visual behaviour (Bavelas and Chovil 2000), and some "nonverbal" acts, like emblems, can have a direct verbal translation that is understood by all members of a group, class, or culture (Efron 1941; Ekman and Friesen 1969). Similarly, gestural codes like sign language present properties that characterize the most elaborate systems of symbolic communication. Therefore, we feel that refinement of the ethological definition should be made in order to accommodate the specificities of human communication.

We formulate here a modified definition of social signals that integrates ethological and symbolic aspects: *human social signals are acts or structures that influence the behaviour or internal state of other individuals, that evolve because of that effect, and that are effective because the perceiver's response has also evolved; signals may or may not convey conceptual information or meaning*. The influence of signals on internal states reflects changes in cognitive, physiological, and emotional experience following the perception of a signal. This refers, for example, to the modification of cognitive representation after exposure to conceptual information; to the alteration of emotional state following the hearing of laughter (Bachorowski and Owren 2001) or infant cries (Frodi et al. 1978); or to the increase in testosterone following exposure to odours of opposite sex individuals (Miller and Maner 2010). The cognitive, emotional, and physiological changes that follow the perception of signals may be associated with a behavioural response that should, on average, benefit the signaller. In some cases, the perceiver also benefits from the signal, although the benefits are derived from adaptive inferences made on the basis of the signal rather than from the properties of the signal itself.

The important aspect of this definition is that the encoding of information is not necessary for an act or structure to be called a signal, as we believe that encoding[3] is restricted to only a subset of social signals (namely, symbolic, or conventional signals). The difference between the present definition and the one provided by Maynard-Smith and Harper (1995, 2003) for animal signals is that our definition clearly encompasses the idea that some aspects of human communication involve the coding of mental representations into concepts that can then be transferred using symbolic or conventional signals, which

[2] Although this topic is still hotly debated (Owren et al. 2010; Seyfarth and Cheney 2003), semantic aspects may also be present in the communication system of non-human primates (Arnold and Zuberbühler 2006; Seyfarth et al. 1980).

[3] We will discuss the issue of encoding in a later section of this paper.

meaning is understood by perceivers who possess the appropriate, culture-specific, decoding rule to retrieve the mental representation that was originally encoded by the signaller.

Ethologists have noted that the reliable transfer of information through the encoding of individual dispositions into a signal may be maladaptive because it could expose signallers to social exploitation (Grammer et al. 1997; Krebs and Dawkins 1984) and ultimately lead to the extinction of informative signals. For informative signals to be evolutionarily stable, both the signaller and perceiver have to benefit from the transfer of information (Hinde 1981; Maynard-Smith and Harper 2003), which is only the case in mutualistic or cooperative interactions. Although these contexts may be more the exception than the rule as far as nonhuman species are concerned (Owren et al. 2010), cooperative interactions are believed to be the ground for the evolution of symbolic communication in humans (Smith 2010; Tomasello 2008), which in turn plays a major role in maintaining large social groups together (Dunbar 1999). Thus, one particularity of human communication is that a fair proportion of informative signals are used in everyday interactions to smooth the functioning of cooperative groups.

Another aspect that makes human communication particular is that some social signals (mostly the conventional and symbolic signals) are produced intentionally. It is not to say that other animals do not communicate intentionally, there are indeed a number of anecdotes suggesting that nonhuman primates use signals intentionally to deceive others, but the evidence in that respect is much harder to gather. A large part of human communication is intentional and is built on the signaller's understanding that the meaning of arbitrary units of communication is shared with perceivers. Intentionality in communication refers to the ability of the signaller to control the production of a given signal and to understand its consequences on perceivers. The encoding of information into conventional signals implies a certain degree of intentionality, for encoding requires the manipulation of conceptual information and the anticipation of social consequences of the signalling act. Social signals such as pointing may be fundamentally human and are believed to be the first instances of cooperative communication (Tomasello 2008, p. 11). More precisely, Tomasello suggested that pointing functions to create shared intentionality, assumed to be a building block of symbolic communication. The integration of symbolic signals in human communication will be addressed in a later section.

Human biological adaptations for communication therefore entail a large variety of signal types, ranging from signals which production depends on complex interactions between psychobiological and contextual factors, and which relationships with "referents" such as internal states and future behaviour are only probabilistic; to conventional or symbolic signals that can be produced intentionally for informative purposes and which relationships with referents are the object of a consensus among members of a given cultural group (i.e., signals with meaning). We will argue that the first class of signals involve most of the nonverbal aspects of human communication and retained the functional principle of influence; whereas semantic aspects, that is, verbal utterances and symbolic acts like emblems (Efron 1941; Ekman and Friesen 1969) and some gestures (Duncan 1972; Kendon 1988; McNeill 2005) constitute the informative components of communication. It is the interaction between these components that make signals more efficient in allowing individuals to better manage their social environment.

The complex interaction between verbal and nonverbal behaviour therefore requires that both the social influence and informational aspects be considered. Although words and symbolic acts carry specific meaning, it is possible that influence or authenticity is achieved through the use of nonverbal cues, in particular, the emotional characteristics of signals like subtle facial movements or specific vocal characteristics. In other words, the symbolic units of communication (e.g., words, emblems, etc.) would fulfil the informative function of social signalling; whereas a large portion of nonverbal signals, not intrinsically loaded with specific information, would make the meaning conveyed through symbolic signals more authentic or more influential. The relevance of this argument to SSP is that automatic analysis may wish to focus on the investigation of function—through an analysis of contexts and consequences of social signals, rather than exclusively focus on the search of a meaning for every single perceptible unit of behaviour.

## Social signals versus social cues

*Social signals* are defined as entities that evolved as a result of their effects on perceivers. There is another class of entities also relevant to communication but of a different nature than signals in that they have not evolved as communicative units. These entities have been called *cues* (Hasson 1994; Lorenz 1939) and are defined as features of the world that can be used by other individuals as a guide to future action. The difference between social cues and social signals is subtle but is essential to understand the intricacies of communication. The crucial element here is that for social cues to evolve, there is no need for perceptual systems in the environment, as their function, if any, is found outside the realm of communication. For

signals to evolve, however, there has to be some perceptual systems coupled with responding ability.

The difference between cues and signals can be illustrated with the following example: consider a tree, which branches bend due to the action of the wind. An observer can easily deduce that the wind goes in a certain direction by looking at the branches. Since we can make the reasonable assumption that flexibility is a property of branches that has not evolved to communicate information about wind direction, or to provoke a response in observers, the overall stimulus that lead to our knowledge of wind direction is seen as a cue. If, on the other hand, the same observer finds himself at an aerodrome and sees a windsock floating in the wind, he will also be able to infer the direction of the wind, and eventually its speed. Although the knowledge gained through observation of the tree and the windsock is the same, the difference with the tree is that the windsock has been conceived and designed to provoke a cognitive response in individuals looking for information about wind direction and speed (i.e., to communicate the direction and speed of wind). The windsock is therefore considered as a signal. In the case of the tree, some information is only extracted by an observer, whereas in the windsock example, some information is made available through the properties of the instrument. A social cue is therefore a perceivable stimulus produced by an organism, which perceivers can use to take adaptive decisions. Unlike a social signal, a social cue may not necessarily benefit the producer of that cue in a social context.

Social signals can be classified according to their nature (sound waves, chemicals, morphological structure, etc.), the modality they target (vision, audition, etc.), their dynamic properties (permanent vs. transient), and their function (what benefit they bring to the signaller). An example of classification is presented in Table 1. At this stage, it is important to mention that emotions, attitudes, personality, or social stances are not social signals as such but are psychological phenomena that are not directly accessible to the outside observer and that constitute the information that perceivers are eager to infer from the perception of social cues and signals. By definition, social cues and signals are perceivable entities that can be used by individuals to draw inferences about internal characteristics of the signaller or about specific aspects of the environment.

Although not specifically designed by evolution to function in a social context, some cues are nonetheless associated with social information sought by perceivers to make socially adaptive decisions. Cues that provide social information can be ordered in two categories: physiological responses and motor responses (Morris 1956). Physiological responses include observable features of thermoregulation, respiration, pupil dilation, pilo-erection; whereas motor responses include intention movements, protective actions, displacement activities, and possibly emotional expressions. It is believed that, through an evolutionary process called ritualization (Huxley 1966), signals evolved from the cues that were used by perceivers to construct representations about their social environment. Given the increased specialization of sense organs and brain structures to process and make connections among environmental stimuli that are adaptive to the organism (Rosenzweig et al. 2002), and because of the importance of the social environment in primates evolutionary history (Dunbar 1998; Humphrey 1976; Whiten and Byrne 1988), it is reasonable to assume that perceivers became relatively specialized in the inference of information from nonverbal cues via associative learning. These cognitive abilities constituted the psychological landscape on which social signals evolved.

Signals differ from cues in four ways (Wiley 1983; Johnstone 1997). First, in order to increase the likelihood of detection by perceivers, signals are more conspicuous and more noticeable than cues. Second, signals are more redundant than cues. Redundancy is achieved by increasing the repetition rate of the signal over time or by adding elements to it, like in multimodal signals. Third, signals are more stereotyped than cues, as they are relatively consistent over time and show little variation in timing and intensity. Finally, signals may include alerting components to warn perceivers that a signal will occur. Consequently, social signals should be detected more easily than cues but their information content should be treated more carefully. Indeed, if we consider that signals have mostly evolved to benefit signallers, there is more room for deception and manipulation, hence more uncertainty about the adaptive

**Table 1** Different types of signals and examples of functional domains of adaptation

| Nature | Modality | Dynamic properties | Examples of function | Examples of signals |
|---|---|---|---|---|
| Chemical | Olfaction | Transient | Mate choice | Pheromone |
| Sound wave | Audition | Transient | Intra-sexual competition | Vocalization |
| Morphological structure | Vision, touch | Permanent | Mate choice | Skin texture |
| Muscular contraction | Vision, touch | Transient | Cooperation | Facial display |
| Artefacts | Multiple | Permanent/transient | Cooperation | Traffic light |

character of the inferred information. On the other hand, cues have evolved for other purposes than communication and should present more consistent relationships with physical or social properties of the environment. Therefore, because their evolution is more independent from social contingencies (including influence and manipulation), social cues should be more reliable sources of information than social signals. The features that distinguish informative cues from social signals are of prime importance to SSP because the ability to detect and to link behavioural patterns to useful information will depend on the nature of what is perceived.

## The reliability of social signals

The question of reliability refers to the relationship that a signal maintains with some underlying quality of the signaller that is of interest to a perceiver. Ethologists and evolutionary biologists have argued that a signal should be, on average, reliable because it is related to a receiver's response that would, in the case of unreliable signalling, cease to exist (Maynard-Smith and Harper 2003; Zahavi and Zahavi 1997). There are three ways in which signals could be reliable: (a) the cost of the signal is too high for signallers that do not possess the quality to be advertised, in which case the signal is called a handicap (Zahavi 1975); (b) signaller and perceiver place the outcome of information transfer in the same order of preference, in this case the entity is called a minimal-cost signal; and (c) the signal cannot be faked due to physical constraints, in which case it is called an index (Maynard-Smith and Harper 1995). We will now present these three possibilities in more detail.

In a very influential text, Zahavi and Zahavi (1997) argued that signals are honest indicators of an individual's attributes. They contended that the cost of the signal guarantees its honesty because it is directly related to the disposition it is meant to advertise. This implies that in order to be reliable, a signal must be costly, that is, it must seriously impair the fitness of individuals who do not posses the quality in such a way that they are prevented from producing the signal. As a consequence, the signal is only produced by individuals who possess the quality. Zahavi and Zahavi (1997) claimed that a decrease in a signal's cost would diminish its signalling value because it would allow all individuals in a population to display the signal and, as a result, prevent perceivers from discriminating between individuals who possess the trait from those who do not. This proposition is called the handicap principle, and a costly reliable signal is called a handicap. Maynard-Smith and Harper (1995) have termed this type of signals *cost-added signals*.

A signal's costs can be divided in two broad categories: efficiency costs and strategic costs (Guilford and Dawkins 1991). Efficiency costs are the costs necessary to ensure the transmission of the signal to the perceiver; whereas strategic costs are costs incurred to ensure the reliability of the signal (e.g., handicaps or cost-added signals). Strategic costs are further divided into production costs, that is, the physiological and metabolic expenditures needed to produce and maintain the morphological structure or the behavioural pattern; and in perceiver-related costs, which are the costs incurred by perceivers' response to the signal, for example, increased risks of competition and predation, or retaliation (punishment) if a signalling convention is breached (Vehrencamp 2000). A detailed analysis of these costs is necessary to understand the functional significance of human social signals. Unfortunately, psychological science has invested very little research efforts in this direction.

Like most signals, multimodal signals include both efficacy and strategic costs. We adopt the position that multi-component signals evolved to face two constraints imposed by receiver's psychology: perceptibility and responsiveness (Rowe 1999). The first constraint can be met by adding elements to a signal to improve its detectability, discriminability, and memorability (Guilford and Dawkins 1991; Rowe 1999), but also to prevent habituation (Searcy 1992). The second constraint can be met by adding elements that ensure reliability, for instance, components that rely on physiological processes reflecting dispositions that are adaptive to perceivers. We suggest that—because of their association with automatic cognitive appraisal, physiological preparation, and action tendencies—emotional expressions could act as reliable components of communicative behaviour. In support of this claim, recent research showed that "Duchenne smiles" (Ekman and Friesen 1982)—smiles that involve the activation of orbicularis oculi, a facial muscle under the influence of physiological arousal—is associated with altruistic dispositions (Brown et al. 2003) and perceived generosity in faces (Mehu et al. 2007a, b). More recently, we have shown that enacted emotional expressions that involved the activation of facial muscles that are difficult to control voluntarily—hence that may be under the control of the physiological component of emotion—are more easily identified and are perceived as being more authentic and more intense (Mehu et al. 2012). Further investigation should focus on the costs associated with the production of emotional expression and on perceived authenticity of emotionally loaded verbal utterances.

Some authors claimed that signals do not always need to be costly to be reliable (Maynard-Smith and Harper 2003). In fact, when the sender and receiver place the outcome of the interaction in the same order of preference, like in

cooperative interactions, there is no need for signallers to deceive, hence signals are expected to be reliable. In these circumstances, receivers do not need to develop resistance to deception, which results in signals being more discreet and their detection by perceivers highly sensitive (Krebs and Dawkins 1984). These signals are called minimal-cost signals (Maynard-Smith and Harper 2003). In humans, symbolic signals like words could be considered as good examples of minimal-cost signals, as their production cost may be relatively low[4] and their use depends on knowledge shared by the signaller and perceiver. More research is needed to evaluate the applicability of the concept of minimal-cost signal to human communication.

Another specific case of low-cost reliable signalling is the one provided by indices. An index is said to be a reliable signal because it demonstrates a quality that cannot be faked due to physical constrains (Maynard-Smith and Harper 1995). Indices are usually signals that facilitate the evaluation of a cue by a perceiver. For example, a posture that facilitates the assessment of body size can be considered as an index. Body size is a cue to physical strength (Sell et al. 2010) and can be enhanced by an erect posture, like the one usually observed in the expression of pride (Tracy and Robins 2004). In this case, perceived body size is increased but within the limits offered by the actual size of legs and chest. Since body size can hardly be extended beyond the postural change (exception made of the use of cultural artefacts), the behavioural pattern that makes it salient is an index that reliably advertises body size and its associated dispositions.

Although the circumstances favourable to the evolution of reliable and informative signals may be relatively rare in animal communication (Owren et al. 2010), the prevalence of symbolic signals and intentional communication in human interactions is not negligible and is believed to have paralleled the evolution of cooperation and group cohesion (Dunbar 1999; Gärdenfors 2002; Smith 2010; Tomasello 2008). The relation between symbolic and nonsymbolic signals will be addressed in a later section, and we would like to conclude this part by underlying the importance of the ethological perspective for the field of Social signal processing. The detection and interpretation of honest signals should be informed by (a) the analysis of efficacy costs and strategic costs, (b) consideration of the relationship between signaller and perceiver, and (c) the physical constrains that underline the signal and its possible association with informative cues. Taking into account these three functional aspects of signals (handicaps, minimal-cost signals, and indices) should greatly increase our understanding of a signal's function but also enhance predictions about the future course of an individual's behavioural stream. The distinction between signals and cues should be of prime importance to SSP because of their differential associations with underlying characteristics of the signaller. Perceptual models should include the possibility that, although cues will be less conspicuous hence more difficult to detect than signals, their information content should be more reliable because of a more stable relationship with underlying characteristics of the signaller that potentially interest perceiver. Similarly, the selection of signal features should take into account the properties of signals that have a strong impact on perceivers not only in terms of inferred meaning but also in terms of psychobiological responses that appear to be adaptive to the signaller.

[4] Although the development of the capacity to speak can be relatively costly, once that capacity is acquired, there is little variability in cost for the production of different types of words/signals.

## The production and perception of social signals and cues

The production and perception of human social behaviour have been widely studied in social psychology, more specifically in relation to three major aspects of social relationships: emotional processes, interpersonal attitudes, and symbolism. The link between emotion and nonverbal behaviour has been a major topic of psychological research in the last five decades (Ekman and Oster 1979; Izard 1971; Scherer and Ellgring 2007a; Tomkins and Carter 1964; Wallbott 1998). This research suggests that emotional behaviours represent evolved adaptive responses to fundamental life events (Ekman 1992; Frijda and Scherer 2009). Among these behavioural responses are specific expressive configurations, like facial and vocal expression, acting as signs (in our terminology, cues) that indicate the presence of an emotional state (Ekman et al. 1980; Scherer 1986). The exact mechanisms involved in the production of these cues have been investigated further by componential theorists of emotion (Frijda 1988; Scherer 2001; Smith 1989). More specifically, the Componential Process Model (Scherer 2001) posits that the activation of behavioural units of expression depends on the result of cognitive appraisal. In this view, complex patterns of emotional expression reflect the cumulative effect of sequential evaluation checks made on the environmental situation in which the expresser finds him/herself. The efferent effects of the cognitive evaluations simultaneously influence all expressive modalities, the voice, face and body, and therefore result in multimodal coherence of expression. Detailed predictions about to the effect of cognitive appraisal on emotional expression can be found in Scherer (2001, 2009).

From the discussion of ethological concepts presented earlier, one may be left with the question of whether

emotional expressions are social cues or social signals. Although not explicitly phrased in the terms that were defined here as cues and signals, emotional expressions have been considered to be the vehicle of information about emotion with a clear function in social interactions (Buck 1994; Ekman 1992; Keltner and Kring 1998). This view is supported by the observation that emotional expressions have significant impacts on perceivers in a variety of domains: social inferences (Hess et al. 2000; Knutson 1996), competitive interactions (Camras 1980), and cooperative actions (Brown et al. 2003; Mehu et al. 2007a, b). In addition, emotional expressions are particularly salient in social contexts (Kraut and Johnston 1979; Parkinson 2005). Still, emotional expressions have also been shown to provide individual benefits through emotional regulation (Gross and Levenson 1997; Keltner and Bonanno 1997; Papa and Bonanno 2008) but also through enhanced sensory acquisition (Susskind et al. 2008). Spontaneous emotional expressions could therefore be considered as social cues and social signals.

The Organon Model proposed by Karl Bühler (1934) represents an interesting paradigm to understand the ambiguous nature of emotional expressions. Inspired by this model, Scherer (1992) suggested that emotional expressions entail three aspects: symptom, appeal, and symbol. The symptomatic function of emotional expression refers to their intrinsic association with underlying physiological processes, that is, externalized by-products of the latter. The symptomatic function of emotional expression is equivalent to the concept of social cue discussed above. The appeal function of emotional expression reflects the social influence that they exercise on others, which corresponds, in the ethological framework, to their social signalling function. Finally, the symbolic function illustrates the formalization of emotional expressions as socially accepted representations of emotional experience. The ethological concept that most closely corresponds to the symbolic function of emotional expression is that of conventional signal (Guilford and Dawkins 1995). Theoretical developments on emotional expression by psychologists were not based on the definitions of signals that we presented here, making connections between the ethological and psychological views of emotional expression more difficult to make. Nonetheless, we argue that Bühler's (1934) Organon Model can be used to draw parallels between ethological and psychological concepts. The challenge for modern researcher is to articulate these different conceptual strands in a cohesive framework to expand our knowledge of human communication.

Research in social psychology was also inspired by Brunswik's Lens Model of the visual perception process (Brunswik 1956; Hammond 1966) for the study of interpersonal perception (Gifford 1994; Scherer 1978) and emotional communication (Juslin and Laukka 2003; Kappas 1997; Scherer 1986). The Brunswikian approach of social perception posits that stable traits or transient states are externalized in the form of distal cues, the perception of which is represented as proximal percepts by receivers. The attribution of a trait or state then results from an inference process reflecting a psychological interpretation of the proximal percepts (Scherer 1978). In a recent attempt to achieve a more comprehensive view of emotional communication, Scherer (2011) proposed the dynamic Tripartite Emotional Expression and Perception Model (TEEP, Fig. 1) inspired by Bühler's (1934) Organon Model and by a modified version of Brunswik's (1956) Lens Model.

The TEEP model proposes that a number of externalized signs are produced by an individual as symptoms of emotional processes with or without communicative intentions on the part of the expresser (the symptom function in Bühler's model). These signs are externalized under the influence of psycho-biological factors related to survival functions of the organism (push effects). Observers perceive these signs as proximal percepts, which in turn form the basis for subsequent inferences and attributions. Bühler's appeal function is reflected in the fact that proximal percepts lead to a number of attributions, internal changes, or behavioural responses by perceivers. Finally, the socio-cultural setting strongly influences the communication process via the operationalization of conventionalized feeling and display rules (pull effects), whereby expressive signs are also understood as a shared symbolic nonverbal code (Bühler's representation function).

Emotion is not the only factor underlying nonverbal communication. Interpersonal attitudes and personality characteristics have also been widely studied in relation to

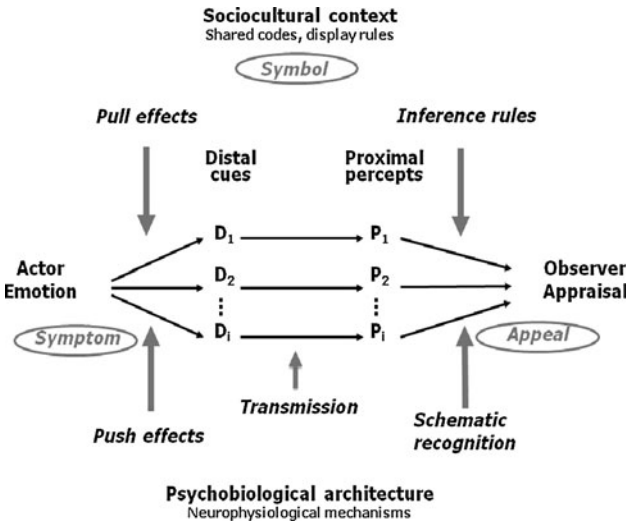


**Fig. 1** The Tripartite emotion expression and perception model (TEEP, reproduced from Scherer 2011)

nonverbal behaviour (Argyle and Dean 1965; Burgoon and Poire 1999; Sadler et al. 2009; Scherer 1978; Tusing and Dillard 2000). In this context, several authors have argued that nonverbal behaviour expresses two major dimensions that regulate interpersonal relationships: affiliation and dominance (Kiesler 1983; Mehrabian and Ksionzky 1972; Wiggins et al. 1988). As in most studies in nonverbal communication, the link between dominance, affiliation, and behaviour has been assessed by perceptual judgements. As a result, little is known about the mechanism responsible for the production of affiliative/dominance cues or signals in humans, though a few studies indicate that these cues or signals could be testosterone-dependent (Cashdan 1995; Dabbs 1997; Dabbs et al. 2001). More research is needed to establish the connection between dominant/affiliative tendencies and nonverbal behaviour. In addition, the argument that emotions also have a social function (Manstead and Fisher 2001; Parkinson 1996) and may act as regulators of social relationships (Hess et al. 2000; Knutson 1996) suggests that the factors responsible for the production of emotional expressions overlap to some extent with those underlying affiliative and dominance cues or signals.

From the perceiver's point of view, emotional states of the sender can be accurately inferred from observation of facial expression (Ekman and Oster 1979), body movements (Wallbott and Scherer 1986), and voice (Banse and Scherer 1996), though contextual effects on inferences based on nonverbal behaviour can be relatively strong (Aviezer et al. 2008; Cupchik and Poulos 1984; Righart and Gelder 2008). Inference of emotional states from behaviour could involve: (1) hard-wired detection mechanisms that automatically associate the perceived stimuli with a discrete emotion category (Ekman 1972; Young et al. 1997); (2) a reflex-like process of motor mimicry whereby a perceiver unconsciously mimics, or simulates, the behaviour of the signaller and uses the associated proprioceptive information to infer the emotion expressed (Lipps 1907; Niedenthal 2007); (3) a controlled cognitive decoding process that infers information processing activity and behavioural tendencies to re-construct the emotion experienced by the signaller (Scherer and Grandjean 2008); (4) the use by perceivers of socio-cultural and linguistic rules shared with the signaller to interpret his emotional intentions; (5) an evaluation of the probability that the perceived expression results from regulation strategies adopted by the signaller to mask, attenuate, or exaggerate the underlying emotional experience; and (6) the evaluation of the expression with reference to situational and interpersonal contexts (Carroll and Russell 1996), as well as personal needs or goals. These perceptual mechanisms range from instinctive low-level responses to elaborate cognitive evaluations and reflect the complexity of the processes involved in inferences made about emotional expressions.

The finding that brief exposures to nonverbal behavioural cues can lead to consensus among perceivers in attribution of dispositional traits (Albright et al. 1988; Borkenau et al. 2004; Funder and Colvin 1988) and a variety of interpersonal outcomes (for a review, see Ambady and Rosenthal 1992) suggests the presence of shared cognitive processes for social perception. Trope (1986) proposed two steps for the social attribution processes: identification and inference. Identification is the formation of a first representation of the perceived stimulus in terms of meaningful relevant categories. This representation then serves as input for the dispositional inference process that involves the inference of personal disposition guided by causal schemata. Research suggests that the type of inferences that are made revolves around two major dimensions of social relationships: dominance and affiliation (Oosterhof and Todorov 2008; Wiggins et al. 1988). Evaluation of these dimensions appears to be particularly adaptive for perceivers' decisions about whether a person should be approached or avoided, or if a person is a serious contender in conflicts. Note that decisions of this sort could also result from inferences about emotional expressions, since the latter are related to action tendencies and possibly indicate future actions. Because the ultimate function of social perception is to build accurate representations of the social environment (Humphrey 1976), future theoretical development should therefore integrate models of social inference with models for the perception of emotional expression.

## Encoding, decoding, and intentionality in communication

A fundamental question regarding the production of nonverbal behaviour is whether the cues or signals produced are the result of the *encoding* of particular traits in a perceivable entity, be it an externalized physiological response, a sound wave, or a muscular contraction. The question of encoding is crucial because it determines whether signals have intrinsic meaning or whether they are merely corollaries of physiological or behavioural processes that have formalized in order to optimize their impact on perceivers. Encoding is referred to as the translation, using a code, of information in one domain (e.g., a physiological condition of the organism) into another domain (e.g., a muscular contraction). The resulting entity therefore carries information that can then be recovered by perceivers through a process of decoding (applying the same coding rules backward). The application of the terms encoding–decoding to the production and

perception of nonsymbolic aspects of nonverbal behaviour can be misleading. First, there is no evidence for a process that would translate internal states or stable dispositions of the organism into observable entities. Although there are similarities in the perception and social inferences made by individuals, the consensus about personality traits or emotional states of a person showing a particular behaviour is not evidence that this behaviour is an encoded representation of these traits or states. With regard to nonsymbolic signals, the terminology encoding–decoding can, at best, be used as a metaphor to describe the externalization process that lead to the production of signals as well as the inference of information made by perceiver.

To some extent, the concept of encoding implies that the different domains of activity of an organism (physiological, cognitive, behavioural) are compartmented and that interactions between subsystems would require transcoding of information. To the contrary, we think that there is continuity between organismic subsystems (behaviour is merely an observable physiological condition of the organism) and that the nature of the relations between these subsystems determines the degree of reliability of the information inferred from the observable aspects of the process. According to the terminology used in the previous section, social cues and reliable signals should maintain more stable associations with underlying cognitive and physiological processes; whereas deceptive signals would have more inconsistent associations with internal states. It is therefore more plausible to conceive that the information derived from nonsymbolic signals is not made available through a code but through the natural relationship they maintain with psychobiological processes.

The idea of encoding is more appropriate to explain the generation of symbolic signals which relationship to a referent is mostly arbitrary, hence requires the translation of a perception into a concept that is understood as such by all members of a given culture. The use of arbitrary signals is indeed a particular feature of human exchanges. The culture-specific coding and decoding rules have to be learnt and constitute the basics of symbolic communication. As mentioned in the previous section, the encoding of information is not the only peculiar aspect of human communication, as intentionality in producing the signals also plays a major role. The intentional production of symbolic signals (e.g., language) most probably evolved in the context of cooperative interactions because the coordination and the smooth functioning of social groups required a more efficient transfer of adaptive information (Smith 2010), in particular, information about the activities and whereabouts of other group members (Dunbar 1996). The idea that language is cooperative by nature is also found in Grice's Cooperative Principle that is presented by him as a major conversational rule (Grice 1989). Intentional production of symbolic signals usually occurs in a context in which interlocutors share knowledge and have common intentions (see also the concept of shared intentionality, Gilbert 1989; Tomasello and Carpenter 2007), a context that maximizes the benefit of information transfer.

Intentionality in communication is not only concerned with the production of encoded messages. Some intentional behaviour such as pointing and eye gaze do not carry specific meaning but act as powerful signals that direct a perceiver's attention to relevant aspects of the environment. As Tomasello (2008) recently pointed out the efficiency of these signals in interpersonal communication is ensured by the common knowledge that signallers and perceivers share about the situation in which this particular act of signalling takes place. Because these signals indicate the signaller's intentions to communicate about a particular aspect of the environment or the interaction (the relevant information being in the context rather than being encoded in the signal itself), these signals could form a particular class of meta-communicative signals, which primary function would be to direct the perceiver's attention to particular pieces of information.

Although the use of symbolic signals emerged along cooperative contexts, the benefits of their use in deceptive communication (i.e., lying) are potentially large. Because symbolic signals are relatively cheap to produce, any individual who has learnt the coding–decoding rules could potentially use them to their own advantage. The emergence of symbolic communication has therefore placed considerable pressure on mind-readers to evaluate the authenticity of social signals, in particular, since social groups have become larger, hence populated with people with diverging interests. For example, lying has been documented to be particularly frequent in everyday interactions (Ekman 1985; Vrij 2008, pp. 11–35), and serious lies (those lies that involve more risk and have more damaging consequences) are often used to cover illegal or immoral acts performed by the signaller (DePaulo et al. 2004). The misuse of symbolic signals to foster selfish advantages may present a threat to social structures based on cooperation and collective action. Perceivers of symbolic signals are therefore required to use cues beyond the information that is literally encoded in the signal, in order to evaluate the intentions of the signallers.

Inferential pragmatics suggest that perceivers infer the communicative intentions of signallers based on a Cooperative Principle (Grice 1989) or following the principle of relevance according to which utterances that yield the highest positive cognitive effect with the lowest processing effort will be given greater relevance (Wilson and Sperber 2006). Because signallers can exploit perceivers' natural tendency to maximize relevance, relying solely on the symbolic content of signals may not be a beneficial strategy

to make social inferences. Rather, perceivers will take into account a variety of contextual cues to make their judgments. The most prevalent contextual cues to symbolic signals are the nonverbal components that are invariably associated with them in face-to-face interactions. These components are either social signals or social cues displayed simultaneously to the symbolic message. The interaction between symbolic and nonsymbolic signals is still poorly understood, although it is believed that attending to nonverbal cues is a good strategy to detect deceitful intentions in a signaller (Ekman 1985; Vrij 2008; Zuckerman et al. 1981a, b). Of course, other contextual cues (the physical aspects of a situation, the presence of other individuals, the past interactions between signaller and perceiver) are also taken into account in the perceiver's inferences.

Some have argued that emotional expressions play a role in the perception of trustworthiness (Boone and Buck 2004) and that they could act as honest signals of dispositions and social intentions (Brown and Moore 2002; Frank 1988; Mehu et al. 2007a, b). Little is known, however, about how the mechanisms underlying the production and perception of the relationship between symbolic and emotional signals, as researcher have not analysed the interconnection between these communicative components in great details. It is believed that the congruence between emotional and symbolic signals could be taken as supporting the authenticity of the semantic content encoded in the symbolic component of the signal. For example, when speaking of an emotional event, speakers should also display nonverbal cues congruent with that emotional experience (e.g., Duchenne smiles when talking of joyful event). A discrepancy between the emotional cues displayed and the assumed emotional experience associated with the event is taken as a possible indicator that the content of symbolic signals should not be trusted (Ekman 1985; Zuckerman et al. 1981a, b). This account may pose problem because it relies on the assumption that emotional components have specific meaning, that is, correspond to particular classes of emotion, a question still debated in the psychological literature (Scherer and Ellgring 2007a). Moreover, it assumes that some situations invariably lead to particular emotional experiences, while it is reasonable to expect individual differences in the way people react to a given situation (Davidson 1992; Kring et al. 1994). According to that model, the evaluation of a signaller's intentions based on the relationship between symbolic and emotional signals should therefore take into account a person's prototypical responsiveness (Ekman 1985).

Psychological research showed that emotional cues play an important role in interpersonal perception, as these cues strongly influence judgments of dispositions and intentions. We also discussed the importance of intentional production of coded messages in human communication, nuancing the fact that not all signals or cues that lead to social inferences actually involve encoded meaning. We have also discussed the relationship between symbolic and emotional signals and the possible role of the latter in reliable communication. This relationship should be better understood within the context of multimodal communication, the topic of the next section.

## Multimodal signals

The importance of multimodality is the object of a large consensus among researchers studying communication in ethology (Partan and Marler 2005; Rowe 1999), emotion psychology (Ekman and Friesen 1967; Massaro and Egan 1996; Scherer and Ellgring 2007b), cognitive neuroscience (Ghazanfar and Schroeder 2006; Pourtois et al. 2005), human–computer interaction (Jaimes and Sebe 2007), and affective computing (Bianchi-Berthouze and Lisetti 2002; Picard 1997). No one seems to question the idea that organisms communicate via a number of modalities: auditory, visual, olfactory, and tactile; and that modalities can include a number of channels, for example visual signals are displayed in the face, body, and hands. Multimodal communication most probably evolved as a result of perceivers' capacity to integrate information acquired through different channels and modalities and to use the combined input to optimize their responses to environmental conditions, including social situations. Multimodal signals are assumed to optimize communication through an increase in information transfer—the different modalities and channels convey different types of information, and robustness—the same information is conveyed through different channels (or modalities) to increase resistance to noise (Ay et al. 2007; Partan and Marler 2005). Rather than exclusively convey particular types of information, the different components of multimodal signals could also function to attract attention to the signaller, to prevent habituation to a signal, to prime or modulate the readiness to another signal, to increase memorability of other components, in other words, to increase the efficiency of a signal at provoking a response in the perceiver (see Rowe 1999 for a review). We will argue here that some components of multimodal signals displayed in human interactions function to ensure the reliability of related signal components.

Earlier we presented the idea that perceiver psychology is a major selective pressure for the evolution of social signals. Guilford and Dawkins (1991) underlined important perceptual modules involved in the processing of signals: detectability (the capacity to detect the signal in the chaos of environmental stimuli), discriminability (the capacity to

tell a signal apart from other signals), and memorability (the capacity to remember the signal in other situations). Habituation to external stimuli may also place a significant pressure on signalling, as to be responded to signals will need to avoid habituation of the perceiver (Searcy 1992). Further down the road of processing, mind-reading ability (the capacity to infer intentions to a signaller) and the evaluation of reliability of the coded information provided in symbolic signals are two inference mechanisms that may have evolved in response to deception. Preliminary evidence about the latter mechanism come from studies on perception emotional expressions in which individuals were shown to agree about authenticity of nonverbal portrayals of emotion (Mehu et al. 2012; Thibault et al. 2009). Other perceptual mechanisms involved in signal processing are relevance (Sperber and Wilson 1995), but possibly also appraisal checks derived from appraisal theories of emotion (Scherer 2001). Finally, the nature of the mental representations formed upon the perception of social cues and signals may well have driven the evolution of social signals towards greater abstract or conceptual information content.

The multimodal nature of signals may therefore reflect the diversity of perceptual mechanisms involved in the processing of social stimuli present in the environment. In this view, multimodal signals would integrate several components that evolved to derive benefits from perceptual mechanisms: some components would be loaded with socially constructed meaning (like symbols), while other components (cost-added signals or handicaps, minimal cost signals, and indices) would mostly relate to individual attributes of the organism that are of interest to perceivers (identity related signals like age, sex, and personality, but also motivational signals like emotional expressions or conditional tendencies to react in a particular situation). Finally, other components, which could be exemplified by behaviour like pointing or gazing, would work to contextualize the communicative event by prompting perceivers to focus on particular aspects of the situation. Since these components act to contextualize communication, they can plausibly be called meta-communicative components.[5] This view implies that only the symbolic components of a multimodal signal would convey encoded messages, reliable components would maintain a natural relationship with socially adaptive characteristics of the signaller, whereas meta-communicative components would not carry information in and of themselves. Symbolic components and meta-communicative components can be produced intentionally, hence could be used in deceptive communication (though not exclusively) whereas reliable components would depend on complex interactions between psychobiological and social factors on which conscious planning and intentionality has only little control. Note that the different components of multimodal signals could, in some cases, act as social signals on their own.

The association between the different components of a multimodal signal could play an important role in the perception of authenticity, whereby the presence of components that reliably indicates the signaller's motivations and intentions could be used by perceivers to evaluate the reliability of symbolic information conveyed by other components. This idea is implicit in research that considers whether the congruence (or incongruence) between nonverbal emotional cues and verbal signals indicates that a person is telling the truth or is lying (Ekman 1985; Zuckerman et al. 1981a, b). A crucial question is whether perceived authenticity is achieved from the different signal components occurring in synchrony, or whether certain components are displayed earlier in a sequence in order to frame the effect of later components. In the field of emotional communication, the synchronization between different expressive systems is viewed as an indicator of reliability (Mortillaro et al. 2011) because this synchronization would represent the efferent effects of cognitive evaluations underlying emotional states (Scherer 2009), hence could only occur when the conditions for a given emotion are met. Reliable multimodal signals could also be characterized by a sequential built up of several components, with early (or late) emotional, or motivational, components having a contextual effect on the symbolic components. Future research should concentrate on the patterns of association between different components of multimodal signals and on the effects these different patterns have on the perception of authenticity of a signaller's intentions.

## SSP: what should the "processing" be about?

Broadly defined, social signal processing involves the automatic processing and synthesis, by means of computer programs, of social signals and social cues that are found in human communication. Our motivation to engage in collaboration on automatic processing of social behaviour is partly driven by the current drawbacks and needs of psychological research. We identify four areas in which automatic analysis could greatly benefit behavioural research. First, automatic analysis could provide more systematic and reliable measures of the physical properties of signals and cues, including their temporal dynamics. Second, automatic systems could manage the processing of a larger number of cues extracted from an individual

[5] Although similar, our concept of meta-communicative component is not precisely the same as the concept of meta-communicative signal introduced by Bekoff (1972).

(social cues) and from the situational context. This point is essential to address multimodal communication and to assess the impact of the context on signalling. Third, automatic systems appear to be necessary to extract patterns of association between indicators displayed by an individual, but also patterns of synchronization or influence between several individuals. Finally, data harvested by automatic systems could be used to predict outcome of social interactions and relationships.

At the most basic level, we think that the processing of social signals should include at least three steps (Fig. 2). The first step involves the detection, tracking, and classification of distal indicators (perceptible manifestations of individuals) using theory-free labels. At this stage, input to the system comprises audio and video recordings captured in optimal conditions (adequate lighting, reduced background noise, absence of machine generated artefacts). The output of this step is classified using physically relevant units of analysis like fundamental frequency (F0), voice formants, facial action units, or other theoretically neutral behavioural units. Whenever possible, the extraction of features should reflect temporal changes in intensity of the measured parameter and should operate on a comparable time window across channels and modalities in order to allow multimodal analysis of social signals. The acquisition of these measurements depends on the tools that are currently being developed towards automatic analysis of facial behaviour (Bartlett et al. 1999; Cohn et al. 1999; for a review see Pantic and Rothkrantz 2000) and the extraction of vocal parameters (Boersma 2001). Automatic analysis of postures and gestures still represents a challenge for SSP but progresses have been made on the detection of head movements (Kapoor and Picard 2001; Kawato and Ohya 2000; Tan and Rong 2003) as well as hand gestures (Erol et al. 2007; Morency et al. 2005) and body movements (Oikonomopoulos et al. 2009).

The second step involves the detection of contextual information that is necessary to interpret the function of social signals. This can be a variety of aspects of the physical environment such as the presence of valuable resources or physical constraints to signalling. Automatic processing systems should also take into account the social context like the number of individuals present as well as their age, sex, motivations, and interpersonal relationships. Input at that stage comprises information obtained online that reflect socio-environmental conditions (respective

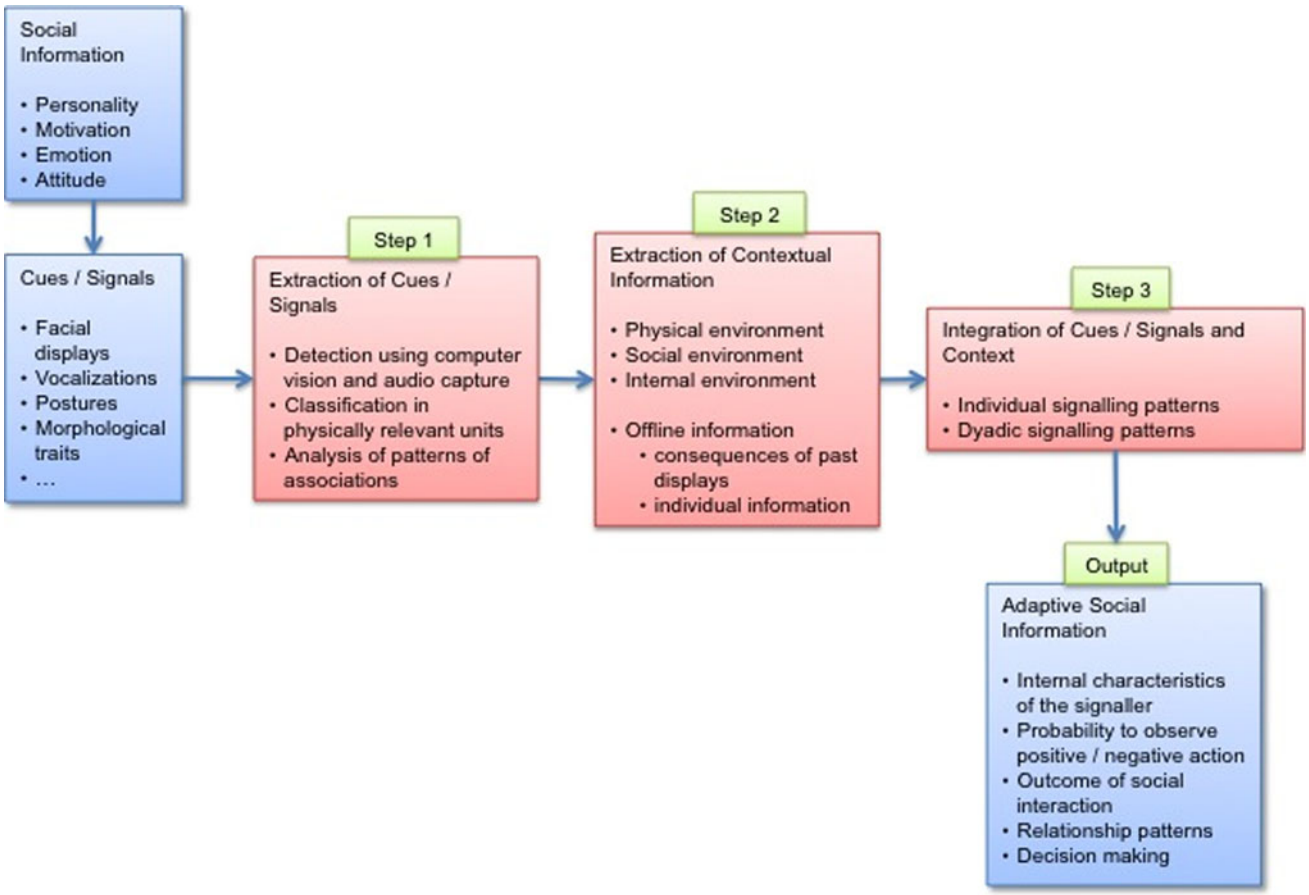


**Fig. 2** Essential steps for social signal processing

location of individuals, vocal features, etc.) and possibly, in some laboratory situations, physiological measurement like heart rate and respiration. The output of online capture of socio-environmental conditions would be expressed in terms of interpersonal distances, age and sex of individuals (inferred from vocal parameters) and estimates of emotional arousal. Tools for the extraction of contextual information from the physical environment are being developed (Beadle et al. 1997), and ideas for their integration into a more complex computing environment have emerged (Ben-Mokhtar and Capra 2009; Henricksen and Indulska 2006; Zhou et al. 2010). Automatic analysis of social context has, however, not yet been developed, possibly due to a lack of consensus on how to annotate social situations. Data about the context should also include information collected offline about the factors that cannot be captured live by sensors such as information about the outcome of past interactions between signallers and perceivers, preferences and attitudes expressed through self-report, assessment of personality, or position in a formal hierarchy. The latter type of information may be more difficult to collect and special care should be taken to specify its nature and origin (self-report, behavioural measures, time these measures were taken, etc.). The information taken at step 2 is used as is and passed directly to the next stage of the process.

The third step is concerned with the integration of outputs of steps 1 and 2. At this stage, information about features is integrated to contextual information and patterns of association between these two types of information are computed. These associations should represent: (a) temporal contingencies between cues/signals and contextual information at the individual level and (b) temporal contingencies between contextual information and signals/cues displayed by all the individuals involved in the interaction. These patterns of association could help understand the influence of context on social signals and cues, but also the inter-dependency between different individuals' behavioural streams (Gardner and Griffin 1989) or people's adaptation to their interactive partner (Cappella 1996). These patterns of association can then be used to model the outcome of an interaction (Carrere and Gottman 1999; Patterson 1982). The output of the third step includes inferences about psychobiological characteristics of the signaller, the probability that individuals will engage in a particular behaviour, and an estimation of the outcome of the social interaction in terms of individual and collective benefits.

To summarize, inputs to the system at different stages include (a) raw information that can be captured by sensors including distal indicators (step 1) and "online" contextual information (step 2); (b) conceptual information that represents factors that cannot be directly captured by sensors: outcome of past interactions, subjective preferences, etc. (step 2); and (c) captured information such as physiological measurements, psychological assessment of personality. (step 2). The final output of the system will include an augmented knowledge about the signaller's internal state taking into account the relationship between the different units of input. This markedly differs from earlier classification methods that based their outputs (often a limited number of emotion categories) on visual features only, largely ignoring the importance of context on the attribution of internal states to the signaller. An important element of output is an assessment of the probability of the signaller to engage in a particular course of action, assessment that can inform about adaptive social decision-making. The real challenge is not only to develop tools that automatically acquire the necessary information at each step of the process, but also to integrate these tools in a coherent platform that will provide the desired output (output that will ultimately depend on the application users want to make of the system).

The inclusion of subjective interpersonal judgements as a variable into the system may be desirable. However, it is necessary to evaluate the circumstances in which these judgements were made in order to have an idea about possible contextual influences on these ratings. If SSP researchers want to implement "meaning" as an output of their system, it is important that the level of interpretations made by automatic systems represents the largest consensus possible between human perceivers within the targeted cultural group and that it acknowledges the different levels of interpretation resulting from individual differences between human perceivers. In other words, the output of an automatic system expressed in "meaning" terms should be weighted on a continuum that goes from idiosyncratic interpretation of a given behaviour to a consensual meaning based on interpretations by the entire population. Nevertheless, inferences about function or about a signaller's intentions should be preferred to inferences about meaning, as the former outputs offer greater predictive power with regard to the future outcome of interactions.

The quality of the output at the three stages depends on the amount of data that can be captured and on the recording conditions, the latter being optimal in highly controlled laboratory settings that isolate the individual from sources of interference. However, the need to extract features that are as close as possible to natural behaviour asks for laboratory settings that are not too constraining for individual behaviour. The use of individual samples of natural behaviour recorded "on the fly" in the field or from the media should be evaluated with respect to the importance of strategic behaviour and the availability of a minimum of control information allowing appropriate statistical inferences (see Scherer 2011). Therefore, the

difficult task is to find a compromise between ecological validity and quality of recordings. An example of a portable tool that can be used to measure vocal features, body motion, and relative location in the social space is described in Olguín Olguín et al. (2009). Because the use of mobile devices presents an excellent initiative to record behaviour as it occurs in natural interactions, these tools appear to be crucial in the development of social signal processing.

## Conclusion

The synthesis between ethology and social psychology promises to boost our understanding of social signalling by integrating a functional, evolutionary, approach to behaviour with the mechanisms involved in the production and perception of social behaviour. We argue that SSP will greatly benefit from such an integration of concepts because the combination of both disciplines promises to enlarge the scope of research questions traditionally addressed in communication research. For example, the important distinction between social signals and social cues should inform the attitude to take regarding the reliability of interpretation that is usually made about the features detected by automatic processing systems. The psycho-ethological approach to SSP should also bring new insight into the type of social information available from social signals and cues, by combining research findings from biologically oriented research and from emotion and personality psychology. Finally, behavioural sciences will benefit from the development of tools that can enlarge the range of measures and procedures for the analysis of social behaviour.

By introducing ethological principles to the study of social signals, we underlined the importance of focusing on the functional aspects of signals and cues rather than on the pursuit of their absolute meaning. The investigation of context and consequences of signals is crucial if we want to understand their role in social relationships and if we want to prevent undesired outcomes of social interactions. The utility of this approach has to be found in the practical applications of SSP research to a variety of domains in human relations, for example, conflict resolution, clinical settings, intra- and inter-group interactions, etc. Virtually all domains that require understanding of human behaviour could benefit from SSP research.

At the heart of SSP lays a tight collaboration between computer oriented and human oriented scientists, who should both benefit from the findings made in each field. We believe that the standard measurement systems (that mostly rely on manual annotations) and the modelling techniques that are traditionally utilized in psychology may not be sufficient to understand the complexity of human communication. The development of new measurement tools and modelling algorithms will therefore complement and enhance the scope of psychological research. Conversely, the rich literature in academic disciplines like linguistics, psychology, and ethology has generated ideas that will help formulate appropriate research questions to guide the development of new tools and modelling techniques. This back and forth movement of ideas and technology between human sciences and computer sciences fuels the engine that will push the field of SSP forward.

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