Social Signal Processing: What are the relevant variables? And in what ways do they relate?

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Abstract

Previous frameworks that describe the processing of social signals and behaviour have isolated a few important variables to the exclusion of others. Here, we attempt to provide a broad overview of the relevant variables and explain what they signify. To fully comprehend their significance, a proper understanding of how the variables relate is necessary. Variables interact not only on an intrapersonal level but also on an interpersonal level. It is also recognised explicitly that a comprehensive framework needs to embrace the role of context and individual differences in personality and culture.

1. Introduction

A landmark review of psychology concluded that, after a century of research, it had reached the stage of trying systematically to identify the relevant variables [1]. It was not a nihilistic conclusion. The point was that a great deal of effort had been expended discovering that the relevant variables were not obvious.

Social Signal Processing should not need to spend a century reaching the same stage, because several disciplines – including psychology – have worked to identify relevant variables. However, because the literature is large and diverse, it is easy to drift unintentionally into assuming that the variables are obvious. The aim of this paper is to offer the emerging computational discipline of Social Signal Processing a structured overview which helps to offset that tendency, and highlights some potentially relevant variables.

It is obviously not possible to review all that is known about social signal processing in a short paper. But it seems possible to provide a broad layout of the relevant literatures, and that is what the paper aims to do.

2. Alternative frameworks & models

Social behaviour, interactions, and cues interest researchers from a variety of fields and disciplines. Research has often focused on determining how humans detect, interpret, and classify social cues, and consequently how this information affects behaviour during social interactions. This leads to the proposal of often discipline-specific models and frameworks that explain and represent the processes involved in human-human interactions. These discipline-specific models are generally led by a methodology which lends itself to exploring some of the relevant variables and relationships involved in human social behaviour, but not all. Hence they tend to highlight one or two aspects of social behaviour and social cognition, and gloss over other relevant aspects. A key challenge for Social Signal Processing is to incorporate their different strengths into a comprehensive framework.

Experimental psychologists have focused primarily on how humans display and perceive cues during interactions, particularly but not only cues to emotional, and with particular emphasis on the face. Seminal work by Paul Ekman proposed 6 basic emotions (i.e. happiness, sadness, anger, fear, disgust, and surprise), each of which has a corresponding and universal facial expressions [2, 3]. That has generated a large body of work on how humans can accurately detect emotional states by picking up on facial cues commonly associated with the basic emotions (e.g. a dropped jaw with relaxed lips and raised eyebrows associated with surprise [4, 5]. From there, research has diverged into topics from the ability of individuals with psychological disorders (e.g. autism [6], schizophrenia [7]) to identify emotional expressions, to sex differences [8], to developmental pathways [9]. Methods that promise objective measurement, from physiology to eye-tracking, have been eagerly embraced.

Psycholinguists, not surprisingly, have focused on making explicit the structure implicit in dialogue. Some ideas, such as the pragmatic analyses associated with Grice and his colleagues, have become very well known. Others, particularly the analyses that deal explicitly with exchanges between two parties, are less familiar. For example, it is widely accepted that conversations occur on two tracks [10]. The first and main track represents the dialogue dedicated to the exchange of information between the individuals. The second track represents the dialogue dedicated to the clarification and grounding of the main track's information to ensure that all individuals involved in the conversation understand and agree on what is being discussed. For example, in the following conversation about the Harry Potter movies, both tracks are being used.

-I can't wait to see the next Harry Potter movie.

-Me too. But it will be so sad to see Dumbledore die.

-True, but I'm sure Michael Gambon will be brilliant in the scene.

-Who's Michael Gambon?

-The actor who plays Dumbledore.

The first three lines are part of main track as part of the original exchange of information. The last two lines are classified as the second track because they serve to clarify information given in the track 1 exchange. This is one example of a range of models that aim to characterise the structure of dialogue.

Sociolinguists, in contrast, have focussed on the way speech encodes information about the social affiliations and relationships between speakers. Features such as dialect and lexical selection play important, and quite complex roles here.

Anthropologists like linguists rely heavily, but not solely on verbal exchange when developing models. They have proposed that there are universals in language that influence the foundation of social interactions. One of the best known examples is Brown and Levinson's model of politeness [11]. An assumption of this model is that all individuals (regardless of culture or language spoken) enter social interactions with the mutual understanding that both parties want to protect their 'face' and avoid harming the other person's 'face'. Face is defined as each individual's public self-image which they do not want compromised by humiliation or embarrassment. Brown and Levinson further distinguished between positive and negative face which represent desires. Positive face represents the desire for approval by others, whereas negative face is the desire for freedom of action. According to the model, all adult individuals know that they have these desires and know that everyone else also has the same desires. Consequently, individuals employ politeness strategies, which are proposed to be universal, to minimize their own face threat and any face threat towards a person they are interacting with.

One of the factors that distinguishes different approaches is that they are associated with different applications. From that point of view, Social Signal Processing is a discipline whose applications are very different from, for instance, language teaching, or psychological therapy. Hence it is appropriate that it should attempt to develop its own framework.

3. Towards a comprehensive framework

To achieve a framework that suits Social Signal processing, a new model should strive to incorporate lessons from all the approaches outlined above. That cannot be done simply by adding together ideas from the various disciplines: the result would be an amorphous mass. To avoid that, a framework is needed that is capable of giving the relevant pieces a meaningful place. A first step towards that is to enumerate all the relevant elements – the potentially relevant signals, and the things they may signify; and then to consider the ways in which the elements may relate.

3.1. Broad categories of variables

3.1.1 Verbal characteristics.

As suggested by linguists, information transmitted via spoken language needs to be part of a comprehensive framework to understand social interactions. Not only is the content of the exchange important, individuals can also gather information based on the sentence structure, vocabulary, and purpose of the statements (e.g. self-disclosure, question, and request)[12, 13]. As previously discussed, dialogue can have more than one purpose, for example, to exchange information and to clarify misunderstandings.

Additionally, voice tone is also perceived by humans and interpreted for information not provided in the verbal content [14]. Voice tone plays an essential role in projecting and determining sarcasm or sincerity, nervousness or confidence, and approval or disgust, to name a few. Lack of voice tone that has made computer-mediated communication more likely to lead to misunderstandings. When emailing and instant messaging first became popular, individuals did not know how to properly project or interpret tone (e.g. sarcasm) from the written exchange [15]. To help with that, emoticons and net lingo (e.g. writing 'lol' to signify 'laugh out loud' to project humorous tone) have arisen to inject tone into written exchanges.

3.1.2 Facial characteristics.

Facial emotion expression research has demonstrated that adults are fairly accurate at detecting and classifying facial expressions[16, 17]. Much of the information available during social interactions regarding emotional states comes from facial expressions and not from verbal content.

It is important not to take a narrow view of facial signals, dominated by the mouth and the eyebrows. In particular, the eyes have been identified as a salient feature for conveying not only emotional states, but also determining intent [18]. Some functions are inherently interpersonal, such as establishing joint attention via eye gaze [19]. Joint attention refers to when a minimum of two individuals are discussing or are focused on the same event, object, or person. For example, if John makes a flattering comment about a third party who is standing near him to his friend Bill. Bill can identify who John is talking about by tracking John's eye gaze, and can tend provide his own opinion about the individual. John does not have to specifically state who he is talking about, his eye gaze provides that information. Channels of that kind are complex, but would pose real difficulties for an artificial system that could not use them.

3.1.3 Body characteristics.

In addition to the face, the body provides other relevant signals. Body posture (e.g. standing straight up, being slouched over, arms crossed) are useful social

signals that have inspired the idea of body language [20]. Physical gestures also contribute to the information conveyed by the body. Many gestures can easily be identified and interpreted during social interactions (e.g. hand waving to say hello), which can indicate politeness, friendliness, aggression, and so on. Furthermore, the physical distance between both individuals can signal intent. For example, if a woman stands in very close proximity to a man, it could indicate attraction. If the woman keeps a noticeable distance between her and the man, it could suggest that she is not interested in his advances [21].

3.1.4 Physiological characteristics.

Physiological reactions can provide useful information social and emotional information [22]. Some physiological reactions are undetectable without the aid of machines. For example, during a conversation, detecting someone's frontal EEG patterns is not possible unless they have electrodes on their head. However, other physiological reactions are not only noticeable, but important social signals. For example, blushing, blinking rate, and sweating are signals that are detectable and indicate many different states including being nervous, aroused, or embarrassed.

3.1.5 Other physical characteristics.

There are other physical characteristics that can influence social behaviour and provide useful cues. The most salient of these are sex characteristics. Gender can usually be correctly identified based on observable physical characteristics. For example, short hair, a beard, an Adam's apple, and a flat chest are clear indications that the person is a man. These cues will influence the interpretation and the production of social behaviour. For example, a man is more likely to make emotional self-disclosures to a woman rather than other man [23]

Height and especially weight [24] are also social signals that can convey, but not always accurately so, useful information about the other person. A man who is physically fit is more likely to be asked questions about how to get involved with the local sports team than a man who is overweight.

Apparent age (what age a person physically appears) and chronological age both come into play. Apparent age is a social signal that the other person may detect and consequently affect their behaviour. One's chronological age will influence the person's own behaviour and interpretation of the other person's signals. A 60 year old man and a 20 year old man may have different criteria for determining what is a signal that indicates politeness.

3.1.6 Relational characteristics.

Social interactions are influenced by the familiarity and the nature of the relationship between two people. Fewer cues and more subtle social signals can be detected by two people who have a close relationship [25]. For example, siblings can transmit more information with a look or one word than strangers can with an entire conversation. Less effort is also expected from people who are close compared to those who are unfamiliar with one another. For example, fewer strategies need to be employed when making a request of a friend than of a stranger.

3.1.7 High order characteristics

In addition to the variables already described, another set of characteristics must be considered. High order characteristics, however, do not represent distinct variables, but instead refer to the quality of the other variable sets. One such quality is the intensity of the signals and behaviour. The forcefulness of a gesture or the intensity of a facial expression can provide additional information beyond the signal or behaviour itself. Another quality to consider is repetitiveness or habits. If an individual always speaks quickly or blushes easily and frequently, these signals consequently become less useful as social signals.

3.2. What variables may signify

Identifying the variables is one of two parallel tasks. The second is to establish what the variables may signify.

The most obvious is that the signals or behaviour are providing an explicit message that one person is trying to convey to the other. That is the natural way to think about linguistic communication, and it transfers to many kinds of non-linguistic communication too. However, that is only one possible kind of significance.

A second kind of communicative significance involves implicit meanings which the person may not consciously be trying to project. A clear example is that signs and behaviours can indicate the person's cognitive and affective states. For example, facial expressions are usually presumed to signify affective states. A smiling face is supposed to represent a happy affective state. Note, though, that there are other interpretations – a smile may be more analogous to a speech act.

A related set of possibilities, with strong links to philosophy and AI, is that variables may serve to convey a person's beliefs, desires, intentions, and attitudes. These may be conveyed in part or in whole by language, but many systems can contribute.

Many signals and behaviour can also be used to establish or alter social relationships. For example, the signals could be used to project dominance, authority, respect, or affinity. These signals and behaviours make a major contribution to successfully engaging in social interactions with others.

More abstract analyses have been developed, and have a great deal to offer the field. There have been sophisticated attempts to operationalise the nature of a goal of a communication, invoking both proximal and distal explanations. Theories in ethology imply that there

tend to be strong evolutionary pressures towards manipulation in social signals [26]. In contrast in theories concerning the evolution of human language there have been attempts to explain how cooperative goals can lead to cooperative social signals [27, 28]. More proximal intentions are perhaps easier to incorporate within a framework by acknowledging that signallers have goals even if it is as straightforward as a desire to sustain an interaction.

The options at this level are harder to articulate simply than the options for signals. However, it is clear that Social Signal processing has a great deal to gain from systematic work on the problem.

3.3. Relationships among variables

3.3.1 Isolated vs Combined Intrapersonal Effects.

A common paradigm in older research is to focus on a few selected variables and provide an explanation on how they convey information, how they are interpreted, and ultimately how they influence social behaviour. The resulting models focus on the isolated contributions of a variable. However, those isolated contributions are only simplified pieces of the overarching model. To compare the framework to the English language, each variable is like a letter. On its own, the contribution of each letter (or variable) to the English language is minimal. The power of the system derives from the way letters can be combined to form words and sentences. Similarly, each variable (or category of variable) is important, but not to the exclusion of the others. To properly model how humans perceive and produce social behaviour, each of the variables must be accounted for, individually and interactively.

During communicative episodes, individuals do not isolate only one variable or category. Instead, information is gathered from all available social signals and is processed, analysed, and interpreted. For example, when having a conversation, nobody focuses only on the other person's facial expression because that information could be misleading. If the other person is smiling, it could indicate that they are happy. But if that smile is combined with blushing, stuttering, and gazing at their feet, the person is most likely not happy at all, but is trying to mask embarrassment. To properly understand the significance of the variables, a person cannot simply rely on another person's facial expression, but must also attend to all the relevant signals including the verbal information, the body posture, physiological reactions and so forth. All of these signals are individual and collective cues that humans attend to and process.

A comprehensive computation model would need to address the complexity of the relationship between the variables. Additionally, the variables do not all interact on the same level. Some variables function as a signal and others primarily function as behaviours. Signals and behaviours interact to influence the conceptual level which is the perception and interpretation of the signals and behaviours.

These integrative qualities of the variables have important practical ramifications. In a worst case scenario a signal may be embedded in a minimal increase in intensity of lots of variables. This means each of these variables would need to be assessed if a signal is to be detected. The reality for research projects with limited resources is a selection of a set of variables has to be made, usually guided by practical or historical and discipline related contingencies. As a consequence there may be certain signals that may not be detectable without a broad and inclusive set of variables.

3.3.2 Bidirectional Interpersonal Effects.

To complicate matters further, the bidirectional influence between the individuals engaged in the social interaction must be addressed by the model. While one person is detecting and interpreting the social signals conveyed by the other person, their own social signals are also being detected and interpreted. Social signals emitted are constantly being modified based on these interpretations. The social signals and behaviour of Person A is influenced by the interpretations of the social signals of Person B, and vice versa [29, 30]. This influence continues back and forth simultaneously throughout the communicative episode. Consequently, a comprehensive model must take into account all the potential social signals of Person A, their interactive relationships, the social signals of Person B, their interactive relationships, and the interactive relationships between Person A's and Person B's social signals. With the addition of further people to an interaction, greater sets of social signals and interactive relationships have to be accounted for by a model.

The interdependence of the Person A and Person B's signals and behaviours not only influence the conceptual mapping, but also the statistical analysis of the framework. The analysis of these interacting variables can be challenging with traditional experimental statistical techniques, and therefore is not appropriate for the analysis of dyadic communication. Instead, other types of statistics (e.g. multilevel modeling) must be applied [29, 30].

Furthermore, a proper model needs to incorporate the ability to attend, perceive, and interpret multimodal signals. Communication is not solely auditory, nor is it solely visual, there are tactile and even olfactory elements. The signals available during communication cross over and interact between modalities. Consequently, the model must account for multimodal perception and attention. Fortunately, multimodal perception and attention is a growing area of research.

3.3.3 Logical relationships

It is tempting to assume that the logical nature of the relationships among variables is a simple conditional – if sign S, then condition C. However, much more complex

types of relationship are common, if not the norm. Relationships often abductive (i.e. the best explanation for sign S is that condition C is present) or cancellable (i.e. new evidence shows that my inference about sign S was wrong). These may hold even if S is a complex of signs rather than one in isolation.

3.3.4 Computing relationships.

Running through the discussion of relationships is a standard computational issue. It is standard to contrast two approaches to constructing an internal representation of a relationship, conceptually-driven and statistically driven. Conceptually-driven models are based on theoretically proposed structures and relationships. These models have traditionally been fragile. Statistically-driven models involve models derived via machine learning by developing statistical relationships between the structures. These tend to be more robust, but at the expense of conceptual significance, and hence of generalisability. It is not obvious how Social Signal Processing should regard the two options. Some of the disciplines on which it draws are deeply sceptical of statistically-driven analyses, for non-trivial reasons. However, there are obvious practical reasons to use them in many applications.

3.4. Context of communication

3.4.1 Medium.

A framework that includes and models the relationships between all the possible variables needs to be flexible. Some modalities and corresponding variables may not be available during every communicative episode. The medium is a strong determinant of which modalities are present. In a face-to-face conversation, all modalities are usually available. Technological advancements have provided alternatives means to communicate. The technologically-mediated means of communication arise due to modality specific advances and therefore exchange of content occurs in one modality at the expense of the others. For example, during telephone conversations, verbal exchange and voice tone are present. Other variables such as relational characteristics are implied and usually understood. However, some modalities (e.g. visual cues) are no longer providing social signals. The model must be able to explain how the absence of those modalities degrades a signal and affects the accuracy of the processing and interpretation of the communicative episode.

3.4.2 Setting.

This includes cues such as the lighting, the space, and the scenery. Being in a darkly lit room results in a degradation of the social signals that are detectable, and this reduction in signal quality can consequently influence behaviour and the interpretation of the communicative episode.

3.4.3 Situation.

This relates to the purpose of the communicative episode instead of its setting. For example, social signals and behaviour will be different during a job interview compared to being in a cinema.

3.4.4 Person by Context Interactions.

Individual and cultural differences affect communicative episodes in two important ways. Firstly, an individual's ability to accurately detect and interpret social signals is influenced by their personality and their culture. For example, research has shown that individual differences in personality can influence children's accuracy in the categorisation of emotions [31, 32]. Furthermore, individual and cultural differences will influence the social signals and behaviour emitted by a person. For example, an extremely shy person will produce signals of discomfort during social interactions, whereas his non-shy peer is less likely to do so [33].

The effects of individual and cultural differences are also highly dependent on the setting and situation. As proposed by Bem & Allen [34], some individuals are more strongly influenced by context, whereas others remain fairly consistent across situations. Recent research in computer-mediated communication (CMC) has highlighted the person by context interaction. CMC research has demonstrated that some individuals remain consistent in their behaviour across conditions with reduced social signals, whereas other can actually benefit from the reduction. In particular, shy individuals [35] or individuals with low self-esteem [36] benefit from a reduction in visual social signals.

3.5. Whose interpretation?

A final consideration when developing a computational analysis model is whose interpretation of the signals and behaviour the model is representing. First there is the question of should the model reflect how an observer would interpret the signals and behaviours, or should it reflect the meaning that the person giving the signals and doing the behaviour intended. Once that issue is resolved, there is the additional concern that the model would need to be able to adapt to the individual and cultural differences that influence the interpretation. For example, for a British person, a raised index and middle finger with the palm facing in is a vulgar hand gesture. The same gesture for a North American simply represents the number 2.

4. Conclusion

A comprehensive framework is no doubt complicated by including many variables, relationships, levels, individual and cultural differences and contextual effects and interactions, and modalities. The next important step is to develop a computational analysis model that can represent the human process of detecting, interpreting and producing social signals and behaviour.

The most sensible way to do this is by applying the model to a specific social phenomenon like politeness. By doing so, a model that is both conceptually and statistically driven can be adopted to explain the communicative process of politeness and then be generalized to other communicative processes.

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