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A variational model for context-driven effects in perception and cognition

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HIGHLIGHTS

- Variational analysis of brightness matching.
- Gives an overview on variational analysis.
- Context-driven judgements as an optimal balance between contrast and dispersion.
- Generalization of the variational framework to perceptual and cognitive phenomena.
- Possibility to derive new constraints for context-driven effects.

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ABSTRACT

Starting with a computational analysis of brightness matching, we develop a novel variational framework able to model perceptual context-driven effects that may be extended to non-physical judgments as well. The most important feature of the variational framework is the description of these phenomena as a suitable balance between contrast and dispersion. The optimal balance is defined through the simultaneous minimization of functionals characterized by two terms in opposition to each other. When the minimum is reached, the equilibrium between contrast and dispersion is attained. To show the flexibility of the proposed framework, we discuss several examples of such functionals in the field of color perception and cognition which show adherence between theoretical predictions and empirical results. With regard to social cognition theories, the simultaneous occurrence of contrast and dispersion conflicts with sequential models, thus supporting the idea of a concurrent presence of both effects in each judgment. The variational framework can serve as a view from above on perceptual and cognitive phenomena that may help in deriving new constraints for disambiguating alternative theories.

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1. Introduction and state of the art

Context-driven effects are one of the most frequent observations in psychology. We can define a context-driven effect as an over- or under-estimation of a stimulus embedded in a given context compared to the same evaluation task performed in isolated conditions. Within the field of visual perception, a typical example is the contrast effect observed in the brightness matching experiment performed by Wallach (1948). Using Rudd and Zemach's reinterpretation of Wallach's experiment (Rudd & Zemach, 2004), we developed a general variational model where context-driven

effects can be described. Formulating a problem in terms of variational principles is a common strategy in practically every scientific discipline. The main purpose is to obtain a broader view of the problem, thereby enabling us to derive a higher level explanation of the phenomenon and to detect its underlying functional constraints. Furthermore, by using this approach it is possible to highlight new constraints that may help to disambiguate alternative interpretations.

When the brightness matching experiment is seen as a calculus of variations problem, judgments of a stimulus embedded in a context can be interpreted as the result of the balancing of two opposing processes. The first (that we will call with the standard term *contrast*) tries to emphasize differences in the final percept, whereas the second (that we will call *dispersion*) tries to emphasize similarities. We attempt to present evidence that a

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variety of contextual effects observed in non-physical judgments (such as those of social cognition) can be analyzed using the same variational framework.

1.1. Context effects for physical judgments

In the domain of perception, as early as in the seventeenth century the philosopher [Locke \(1690\)](#) had described the contrast effect by noticing that a hand's contact with tepid water can produce either the sensation of cold or hot if the hand had been previously placed in hot or cold water, respectively. The contrast effect has been considered since the earliest days of psychophysics ([Chevreul, 1855](#); [Wundt, 1896](#)) and extensively investigated for judgments in the context of physical dimensions, such as the loudness of a tone ([Melamed, 1971](#)), the brightness of light ([Wallach, 1948](#)), weight ([Heintz, 1950](#); [Sherif, Taub, & Hovland, 1958](#)), length of lines ([Krantz & Campbell, 1961](#)), and so on. In parallel, since [von Bezold \(1876\)](#) described a phenomenon "in which a colored surface appears lighter when overlaid by thin white lines or small white dots and appears darker if the lines or dots are black," assimilation effects (after the name given to them by [Evans, 1948](#)) were also studied ([Blakeslee & McCourt, 2004](#); [De Weert & Spillman, 1995](#); [Festinger, Coren, & Rivers, 1970](#); [Helson, 1963](#); [Kingdom & Moulden, 1991](#)), especially in visual phenomena such as the white effect ([White, 1979](#)), Bressan's dungeon illusion ([Bressan, 2001](#)) or the *cube* illusion of [Agostini and Galmonte \(2002\)](#). Within the domain of brightness perception, assimilation is considered the opposite of contrast. However, given the variety of models, theoretical approaches, and empirical results, such a notion is rather controversial and it has been employed as a convenient catch-all in which to place anti-contrast effects ([Gilchrist, 2006](#)). In particular, when referring to brightness judgments, the term 'assimilation' has a special and different meaning from the concept described in this paper. So, as we wrote before, we will employ the term dispersion instead to indicate a positive correlation between the judgment and the context. The use of this generic term will also be helpful because we are going to refer the corresponding context effects in the social cognition and cognitive psychology fields where the word assimilation may have different meanings.

The debate over the variables (and the underlying mechanisms) that determine different context effects is still open for discussion. Indeed, there is no consensus on how surface lightness is processed by the brain ([Gilchrist, 2015](#)) and thus under which conditions different context effects are observed. Within this debate, [Agostini and Galmonte \(2002\)](#) proposed that perceptual belongingness may determine the kind of context effect. According to it, gestalt laws (proximity, similarity, good continuation, common fate, closure, and *pragnanz*) ([Koffka, 1935](#); [Wertheimer, 1923](#)) can explain the tendency of the visual system to aggregate discrete stimuli within larger wholes and thus determine if a stimulus phenomenologically belongs to a larger object or not. The basic idea is that if two elements belong to different perceptual groups, their colors are contrasted with the color of the group to which they belong ([Agostini & Galmonte, 2000](#); [Agostini & Proffitt, 1993](#)). On the contrary, when an element is intentionally organized into one or another of two groups, its color is assimilated to the color of the group to which it belongs (so, in our terminology, a dispersion effect will be observed). For the sake of simplicity, in this paper we will assume [Agostini and Galmonte's \(2002\)](#) perspective because it is compatible with the proposed formal framework and it addresses an important open question in the literature. However, our analysis does not depend on this assumption and it can be compatible with other theoretical proposals.

1.2. Context effects for non-physical judgments

The results obtained for basic perceptual judgments have suggested investigating the influence of the context for non-physical judgments as well. Within social cognition, the word contrast is employed to define the case of a judgment negatively correlated with the contextual information, whereas the term assimilation refers to a positive correlation between the judgment and the contextual information. Those effects have been observed for non-physical judgments related to moral evaluations ([Parducci, 1968](#); [Pepitone & DiNubile, 1976](#)), pleasantness of music ([Parker, Bascom, Rabinovitz, & Zellner, 2008](#)), friendliness of a person ([Stapel, Koomen, & van der Pligt, 1997](#)), attractiveness ([Kenrick & Gutierrez, 1980](#)), prices of objects ([Matthews & Stewart, 2009b](#)), and a wide variety of social judgments and evaluations ([Biernat, 2005](#); [Moskowitz, 2005](#)). For example, when investigating the contrast effect in moral judgment, [Parducci \(1968\)](#) asked respondents to rate the seriousness of a number of acts, such as *poisoning a neighbor's dog*, alongside trivial acts, such as *keeping a dime you find in a telephone booth*, and very serious bad acts, such as *murdering your mother without justification or provocation*. He found that in the first case, the sentence *poisoning a neighbor's dog* was judged as more serious when compared to the second case. Different terms have been employed to indicate a judgment biased towards the context. Within cognitive psychology, [Tversky and Kahneman \(1974\)](#) used the word anchoring to indicate the bias of a numeric judgment towards a previously considered standard. In line with the observations made previously about physical judgments, given such terminological ambiguities, we employ the word dispersion to mean such kind of bias.

Several studies have identified many factors that can induce dispersion or contrast in judgment related to person perception ([Higgins & Lurie, 1983](#)) and self-evaluation ([Festinger, 1954](#)). For example, broad contextual categories (such as traits) are likely to produce dispersion whereas in the case of a context represented by narrow categories (such as exemplars), contrast effect will be observed ([Stapel, Koomen, & van der Pligt, 1996](#)). Other factors include processing goals (memorization vs. impression formation where the first induces assimilation and the second contrast, [Moskowitz & Roman, 1992](#)), distinctness of the context (in the case of high distinctness that is more likely to observe contrast, see [Wedell, Parducci, & Geiselman, 1987](#)), temporal distance between events (distant contextual events are more likely to induce contrast, see [Strack, Schwarz, & Gschneidinger, 1985](#)), and many others ([Biernat, 2005](#)).

Given the factors that can induce cognition-related context-driven effects, several theoretical models have been developed to furnish parsimonious and effective predictions about how and when dispersion or contrast occurs in a given situation. Among them, we can cite the set–reset model ([Martin & Achee, 1992](#)), the inclusion–exclusion model ([Schwarz & Bless, 1992](#)), the flexible correction model ([Petty & Wegener, 1993](#)), the interpretation–comparison model ([Stapel & Koomen, 1998](#)) and the selective accessibility model ([Mussweiler, 2003](#)). Those models differ in terms of the assumed degree of effort involved in the effects (automatic or controlled), if the two effects are simultaneous or sequential, the specific variables involved in the processes, and the assumed default process (either contrast or dispersion). However, the majority of them agree with the notion that the factors that make the context less distinct from the stimulus (in other terms, factors suggesting an inclusion of the stimulus in the context) induce a dispersion effect, whereas factors that make the context distinct from the stimulus (so, suggesting an exclusion from the context) induce a contrast effect. Such interpretation is coherent with [Agostini and Galmonte's \(2002\)](#) perspective about the factors determining context effect in physical judgments.

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