Qualitative Models of Selection Strategies: Possible Approaches and Limitations

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Abstract

This paper discusses means to model object selection tasks qualitatively. In a selection task, one out of several objects is selected according to some selection strategies that prefer one object over others. Depending on context, experience or other circumstances, one such selection strategy dominates others. Put differently, selection is a causal consequence rooted in a particular selection strategy. Selection tasks are thus well within the scope of QR models and it should be possible to construct an intuitive model. However, problems remain in modelling. This paper describes open problems in such models with the aim of extending QR semantics to model selection tasks intuitively.

1 Introduction

We are motivated to study cognitive modelling of dyadic interaction. In particular we are interested to investigate whether qualitative modelling techniques are sufficient to obtain such model.

In a dyadic interaction, two humans are required to direct their attention to a joint focus, for example an object in the environment. The process of selecting the joint focus can be influenced by various means. Humans are highly sensitive to eye movements as cues indicating the attention and intentions of others. The ability to adopt the visual perspective of others [Lukošiūnaitė *et al.*, 2024] and interpret their line of sight is a central component of social cognition. Individuals are also able to focus their attention simultaneously on the same object, event or situation — also referred to as shared attention — which is a fundamental prerequisite for social cognition and intersubjective understanding [Emery, 2000]. In a dyadic interaction, one person typically initiates the gaze and a second follows it (observer), whereby a (non-verbal) exchange of information takes place [Stephenson *et al.*, 2021].

When the observer estimates the initiator's gaze — for example, to infer which object the initiator is looking at — perception is driven not only by bottom-up sensory input but also shaped by top-down processes, including prior expectations and assumptions [Kok *et al.*, 2013; McGovern and Otten, 2024]. Such assumptions or beliefs of others are continuously refined through exposure to new social information and constructed to enable more accurate predictions of behaviour [Mende-Siedlecki *et al.*, 2013] and thereby influence our strategies and decisions in interpersonal contexts.

Understanding this combination of perception, beliefs, and resulting decisions better and developing models that can capture core components of this interplay is relevant because it provides a framework for understanding how humans integrate perceptual information with prior expectations or beliefs when interpreting social cues. Modelling our understanding of how beliefs about another person shape the (implicit, subconscious) strategies underlying decision-making additionally generates experimentally testable predictions. By including causal effects as well as unobservable variables, such as beliefs, expectations, and assumptions, such models can reveal why individuals differ in social inference, cognitive biases, adaptability, and flexibility in interpretation of sensory input. This has important implications for psychology, as it may improve our understanding of mentalising difficulties and interpersonal misunderstandings. At the same time, such models are crucial for human–robot interaction, as robots need to infer human intentions, beliefs, and potential misconceptions as well as predict their current strategies and decisions rather than relying solely on sensory information. Therefore, a crucial question is: Can we build a qualitative, hence explicit and explainable model, of directing attention?

The contribution of this paper is to discuss attempts at modelling the underlying selection task and pin-pointing shortcomings in the current vocabulary of qualitative model components.

1.1 Model Application and Experimental Setup

To give a broader context of the research in which the qualitative model is to be used, we outline the psychological experiment that will be used to evaluate candidate models. We are planning an experimental study mainly consisting of an object selection task that captures the combination of sensory social cues and beliefs about another person. In our experiment, two people sit opposite each other and share a visual space containing objects with different values. One person (initiator) looks at one object, while the other person (observer) sees both the initiator's eye movements and the objects and is asked to identify the target object based on the ambiguous gaze of the initiator. If the observer selects the correct object, both participants receive points; otherwise, neither does, creating a cooperative setting. This procedure is repeated across multiple trials.

If observers assume the initiator is cooperative, they are likely to expect the selection of a high-value object, as this maximises the team's reward. This expectation is considered strategically alongside gaze behaviour during object selection. In contrast, an adversarial assumption may bias observers towards interpreting ambiguous gaze as an indication of low-value objects. Without either assumption, object value should not influence object selection. If one assumes that the initiator is generally cooperative but gets bored at times or did not fully understand the task, this could be an alternative potential explanation of behaviour and object selection could still be influenced by the cooperative assumption but with slightly higher randomness induced by the additional belief that the person shows unintuitive behaviour at times. Thus, different assumptions about the other's behaviour result in different strategies – even if they may not always be entirely conscious – which influence the object selection process. There can be multiple of such strategies which coexist, though their influence varies in strength, and which, taken together, affect the decision.

As beliefs about others can change over time (e.g., less cooperative and more adversarial following negative feedback), the impact of the different strategies for the object identification and thereby also the influence of object value on the identification process are expected to change accordingly. Additionally, there might be inter-individual differences in whether, when and how quickly people update their beliefs about the other person and therefore adapt the chosen strategy, and whether this updating is biased.

1.2 Advantages and Challenges of QR models

There are various approaches to modelling mental processes. However, a major limitation of many of these approaches is that they require all relevant variables to be directly observable. This poses a challenge because many psychological phenomena and mental processes are not explicitly accessible, despite being assumed to influence the process under investigation. Furthermore, models should be able to include causal relationships between variables, even though the numerical quantification of such associations can be difficult. These requirements are met by QR models.

A further advantage of QR models is that they are not limited to predicting a single outcome state but can return multiple possible future states. This is particularly relevant for decision-making processes, where several plausible outcomes may arise from the same situation when human behaviour is investigated. Instead of relying on repeated simulations to explore different possible trajectories, QR models can directly represent alternative states, enabling empirical data to be assessed in terms of whether human behaviour aligns with one of the predicted outcomes.

However, applying QR models in this context, and more specifically to the described experimental setup, gives rise to two key challenges that require further investigation: (1) the selection of an object under the influence of multiple, potentially competing factors and (2) the choice of a strategy for object selection based on beliefs about another person whereby the selected strategy in turn shapes both the relevance and the weighting of different factors in the decision-making process. Beyond the content-related benefits of such a model, the consideration of these challenges also contributes to extending the applicability of QR models, as these aspects have not yet been addressed in existing models.

2 Selection Tasks as Qualitative Simulation

We attempt to capture the experiment described above as a Qualitative Causal Model. Similar to causal models used in Bayesian inference, the variables contribute to and predict the outcome of the experiment. At its core, the experiment is a selection task: given a set of observed or estimated variables, which object is most likely to be selected by the modelled participant?

We adopt the modelling components used by Garp3 [Bredeweg *et al.*, 2009]. In this framework, variables are represented as quantities defined over coarse domains called quantity spaces. These quantities can be simulated over time, such that a qualitative value, composed of the quantity's magnitude and derivative, may change. However, each change must be justified by a causal dependency, such as an influence or proportionality, between quantities.

The qualitative causal model should be able to identify a single object that is deemed *most likely* to be selected according to the causal dependencies used to model the participant. Two approaches are apparent: (1) modelling the selection as a single quantity whose values correspond to the possible objects, or (2) using several quantities to model the confidence associated with each individual object. Both approaches have important limitations.

The first approach can be implemented by creating a quantity space whose ordered values correspond to the objects that can be selected. Conceptually, however, this representation does not fit the proposed experiment well. The selection of an object is arguably discrete, whereas the model would require the selected object to transition through an ordered continuum of intermediate values. A further, fundamental limitation of such approach lies in the fact that involved strategies may be based on different orderings. For example, according to interpretation of eye gaze, object A might more likely chosen than B, and B more likely than C. In a different strategy, however, object B might be preferred over C over A. With such incompatible orderings, it is not possible to have influences that lead to increasing or decreasing of a value such that both strategy influences can be represented at the same time.

The second approach represents the likelihood of selecting each individual object relative to the likelihoods of selecting the other objects. For each object, we introduce a quantity defined over a quantity space containing intervals from zero to positive infinity. Given a qualitative model and fixed input quantities, one of the presented objects should eventually emerge as the most likely candidate. We attempt to model the competition between the objects by making their corresponding quantities pairwise negatively causally dependent.

For three objects, this yields the following dependencies, represented as negative proportionalities: $ob_1 \ \ P^- \ \ ob_2, ob_1 \ \ P^- \ \ ob_3$ and $ob_2 \ \ P^- \ \ ob_3$, together with the corresponding dependencies in the converse directions. The intended interpretation is competitive: an increase in the tendency to select one object should decrease the tendency to select every other object.

This representation works for two objects, but it does not generalise to three or more objects. Let $d_i \in -1, 0, +1$ indicate whether the qualitative derivative of ob_i is decreasing, steady, or increasing, respectively. Under the adopted interpretation of negative proportionality, each dependency requires the derivatives of its incident quantities to have opposite signs.

Thus, if $d_1 = -1$, the dependencies between ob_1 and the other two objects require $d_2 = d_3 = +1$. The dependency between ob_2 and ob_3, however, requires $d_3 = -1$ when $d_2 = +1$. Consequently, the same derivative would have to be both increasing and decreasing. This argument is independent of the initially chosen direction.

Formally, representing the derivative signs as values in $-1, 0, +1$, the three pairwise constraints imply $d_2 = -d_1$,$d_3 = -d_1$ and $d_3 = -d_2 = d_1$.

Hence, $d_1 = -d_1$, which is possible only if $d_1 = 0$. It then follows that $d_2 = d_3 = 0$. The resulting state graph therefore contains only the state in which all three quantities remain steady.

3 Selection Constraint

To achieve our goal of building a qualitative model of a selection task, we propose to introduce a new selection constraint into QR models. Selection constraints are n-ary constraints that affect n variables representing whether an object is selected on a qualitative scale of at least discrete values, allowing preference orderings to be represented.

The constraint influences a quantity as follows:

- If two or more quantities hold the same value, the constraint applies an increasing influence on some values (at least one) and a decreasing influence on the other values (at least one). Which quantities receive an increasing influence, respectively decreasing influence is determined by further influences applied to the quantities and non-deterministically chosen if no further influences exist.
- No influence is generated if all quantities are different.

As a result of applying the selection constraint, quantities will converge to a total ordering that reflects further influences present. Where no influences are present, quantity values can develop freely over time, representing a non-stable state in the decision process.

4 Discussion and Conclusions

Modelling cognitive processes that are of a causal and qualitative nature should be achievable with using qualitative models such as GARP [Bredeweg *et al.*, 2009]. However, we were unable to construct a model of a selection tasks in which one entity out of three or more entities has to be selected. The approach to model likelihood of each object being selected as unique variables appears intuitive and would also allow to derive explanations why one object receives a higher likelihood than others. As we were unable to implement the selection process that converges to one object being favoured over others, we propose to extend QR models by a dedicated n-ary selection constraint that directly affects the likelihood quantities of n variables.

In future work, we aim to implement the selection constraint described in a qualitative simulation and test the constructed cognitive model empirically. Furthermore, we are interested to investigate how the selection constraint can be part of a model synthesis method that could induce qualitative models from observations.

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