Agent Decision-Making Heterogeneity - Agent (Meta)Frameworks for Agent-Based Modelling

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Abstract. Agent-based models have continuously increased the complexity of agent decision making. This poses questions for the ontological foundation of ABM as well as having implications for research design and data collections. This paper situates the meta-modelling framework CAFCA within other contextual and multidimensional agent-architectures, in particular focusing on its contributions to ontology and research design. We also present the challenges for data collection as a consequence of this increased complexity.

Keywords: heterogeneous agent models · realistic agent behaviour · agent theory frameworks

1 Introduction

Agent-based models (ABM) are there to understand how social or macro phenomena can result from individual interactions with other agents and an environment as well as how these macro phenomena feed back to the individual agents. Starting off with implementing simple reactive behaviours in cellular automata (reacting to what a neighbouring cell does), ABM has increasingly moved towards modelling more cognitively complex agents [2]. Binary choices become sets of choices, criteria for choice selection have to be found, different levels of social engagement need to be modelled. It means that the agent behaviours in an ABM become more realistic (i.e. to be more like real people behave) also means that models become less tractable. Competing paradigms between KISS (Keep it simple stupid!)[1] and KIDS (Keep it descriptive stupid!)[7] have been battling it out as has a discussion about validating ABM, in particular about validating the rules going into the model e.g. [27]. The call for realism in agent modelling has been part of the history of the field of social simulation, at least for the non-technical oriented part of the modelling community, and is presented in a clear way in EROS (Enhancing the realism of simulation) [13] - although

the paper has a bias towards implementing psychological theories, reserving social theories to be seen as the resulting macro effects of the micro interactions, cutting the micro-macro-micro linkages in half. It also focuses on creating an integrated framework,

One of the developments within KIDS is the recognition of decision heterogeneity between agents as well as for the same agent at different times within the simulation. Inter-agent heterogeneity is already part of simple game theoretic models with populations of mixed strategies, e.g. Hawks and Doves [16]. In cognitive models, these differences in behaviour and decision making are often encoded as differences in an agent's internal states (e.g., believes, norms, utility), as is the implied target of EROS [13]. For example, Fearlus is a goal driven multi-dimensional utility architecture to model common pool resource management [5, 19]. The agents decide what to do based on one of three possible strategies (statisficing, imitation, or innovation) depending on their performance and individual characteristics/preferences. The ASSOCC model [6] integrates needs, goals, and social norms to model the behaviours of agents during the Covid-19 pandemic. The different factors are integrated via modelling each of them as needs and a weighing mechanisms expressing need preferences. The Consumat is a context driven architecture with agents using different decision mechanisms in different situations [14, 15]. The context dependent decision making is developed using dimensions of *cognitive cost* and *(un)certainty* in a 2 by 2 matrix, connected to psychological theories. The MoHuB framework aggregates a huge variety of cognitive architectures into a generalised meta-framework to enable finding, communicating and eventually integrating theories from the social and behavioural sciences in models, thereby thus reflecting context sensitivity by explicitly distinguishing between what an agent/human knows and what becomes accessible/activate in a given context [21]. Finally, the Model Social Agent is an analytical framework grounded in cognitive and social science theories and concepts [4]. It consists of a 5 by 6 matrix of the types of knowledge and the cognitive processing capabilities respectively that are needed to allow for different types of social behaviour, the authors apply this matrix to two theories familiar to and used in ABM, namely Festinger's Social Comparison Theory [10] and Turner's Social Interaction Theory [23], to illustrate how these theories map onto different knowledge and processing combinations in the framework and thus put demands on how to model agents for these.

The Contextual Action Framework for Computational Agents (CAFCA) [9] is a conceptual framework for context sensitive decision making. Like MoHuB, CAFCA is a meta-framework but different from MoHu, CAFCA does not try to generalise over the internal processes of an agent's decision making but rather classifies the contexts in which decisions can occur, or contexts which can make a difference to decisions. It is starting out with two dimensions that are most prevalent in agent-based modelling, the social setting of a decision and whether the situation is habitual, strategic, or normative. [CAFCA is first and foremost a framework for a modeller to think about which decision mechanisms might need

to be incorporated into a model. Only secondly should it be used to inform the internal dynamics of agent decision making.]

CACFA moves the complexity of agent decision making into the recognition of the context instead of it being a multi-dimensional architecture of (a subset of) needs, values, emotions, relationships, and utilities such as the examples described above. The purpose of CAFCA is for the modeller to think carefully which decision contexts are needed in a particular simulation model. For example, early game theoretic agent-based models (social/strategic) were extended by social norms, adding the CAFCA dimension of social/normative to the model, e.g. [3] In [8] the collective dimension of team reasoning is added to a standard game theory question of common pool problems.

CAFCA does not prescribe how these different dimensions are implemented but opens new ways of thinking about decision making in agent-based models. It thus widens the social ontology considered in ABM (Section 2). It also informs new ways for data collection for ABM, as can be seen in an example of its application to fisheries (Section 3).

2 CAFCA and Social Ontology

Social ontology is the part of philosophy analyzing the nature and properties of the social world. "What exists" is a contentious part of the social sciences, ranging from positions in which only individuals exist (individualism) over methodological positions that explanations in the social sciences need to start from the individual (methodological individualism) to positions which ascribe existence and causal powers to extra-individual entities, such as institutions, norms and social groups.[5]

ABM has often been associated with methodological individualism as a research paradigm [18]. Whilst of course the individual agent and an "agent-centric worldview" is a central tenet of ABM, it is not limited to an ontology of individuals [28]. CAFCA contributes to the ontology of agent-based modelling by explicitly drawing attention to two types of sociality, the dimension of the social, focusing on social interaction and the dimension of the collective, focusing on social belonging/inclusion. CAFCA's social dimension starts with the individual agent level, where no other agents (are seen to) exist or influence the decision-making of the agent. Context in which the presence of other agents in the environment, and their actions and decisions influence the agent's decision-making forms the social level. The final category is the collective level, building on the work in social ontology on collective intentionality and group mind. Here, agency is at the collective (team, group) level rather than the individual agent level [11]. Thus, other agents in the same collective are seen as part of the collective decision-making rather than as individual decision-making agents with which one interacts. Below we will see how this makes a difference.

[5] The debate is also known as the agent-structure debate, for more detail see [12].

3 CAFCA Research Design and the Need for Analysis of Data

As described in [22], for accurate modelling of the Covid epidemic, fine-grained data is needed to represent specific local conditions and the social reactions of individuals. Most Covid models are aiming for adequate estimates of disease spreading at a macro level but fail to cover the relevant behavioural and social complexity of societies under pandemic crisis. This limited their usability for meso and micro level analyses and predictions. Another example of the need for more detailed and fine-grained data concerns research on common-pool research problems. In most of the research, individuals are modelled as rational choice type of decision makers, where the social level is thus limited to CAFCA's social level while claiming to investigate collective consequences and behaviour. Moreover, in experimental settings to investigate more detailed interaction processes, the number of participants is small, usually not known to each other, and communication is not included, effectively excluding any collective level phenomena. In the following two sections we will look closer at these two examples.

3.1 Example of CAFCA Data (Un)Availability: The *Coronavirus and the social impacts on Great Britain* Dataset

The Office for National Statistics (ONS) in the UK started a large weekly survey at the end of April 2020 collecting data concerning the Covid epidemic.[6] People were asked about their behaviours relating to reducing the spread of Covid-19, including wearing face coverings, social distancing, working from home, regular hand washing, and self isolation. People were also asked for some questions why they behaved as they did, e.g. financial or mental health considerations. In particular the "why" data could be used to locate the reasoning of the participants on the CAFCA matrix.

In Figure 1 we can see that adherence to behaviours to reduce the spread of Covid-19 change over time. For the purpose of this paper we want to highlight the two behaviours with the most dramatic changes over time: staying at home (green) and wearing a face covering (orange). For both behaviours, the question only entered the survey after May 2020. The curve for staying at home shows 80% of the population adhering during May, but quickly halving during 6 weeks of slowly opening up from complete lockdown. This change is particularly interesting in comparison to the low variation in the working from home rate (navy), despite government communication strongly urging people to go back to their workplace. In the second national lockdown adherence never went back to 80% but peaked at a maximum of 60% in early January. It is thus clear that priorities, needs, and rule adherence had shifted over time leading to different

[6] The ONS Coronavirus and the social impacts on Great Britain Dataset can be found at https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandwellbeing/datasets/coronavirusandthesocialimpactsongreatbritaindata

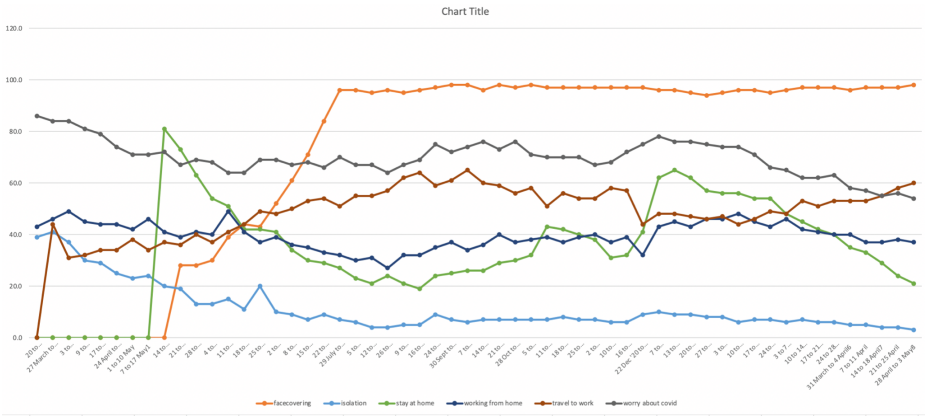

Fig. 1. Behaviour and attitude changes over time in response to Covid-19 between March 2020 and May 2021. The black line shows the proportion of the population worried about Covid-19 which is consistently between 60 and 80%, slightly higher at the very beginning of the pandemic and slightly lower since March 2021. Behaviours covered are wearing face covering, isolation, staying at home, working from home and travelling to work.

decisions regarding socialising. The decision to work from home remained stable, but decisions to meet people for socialising changed.

The second highly variable behaviour is the wearing of face coverings. From the 29th of July face coverings became mandatory in the UK for visiting indoor public places and people were following the rules with adherence levels consistently between 90 and 100%. However, the time between the 21st of May and the 29th of July is interesting as we can see a rapid increase in wearing of face coverings. Given that there were no official rules and that face coverings have high visibility, this can be interpreted as a social norm establishing. For the wearing of face coverings, the survey asks participants when and where people wear masks, plus an interesting additional question: "While shopping in the last seven days how many other people did you see wearing protective face coverings to help slow the spread of coronavirus?", a question pointing towards interpreting the wearing of face masks as a social norm.

Both examples of observed or reported behaviour change can fit CAFCA matrix, but the questions included in the survey offer too little support for a full analysis. The question set was not consistent over the whole time frame of interest, and formulated in a quite indirect yet very specific way. Observations outside of the shopping context are not included for instance, and the relationship between what participants have seen and their own choices remains opaque.

3.2 CAFCA and Common-Pool Resource Problems

In a project concerning the study of collective action in common-pool resources (CPR), we have used CAFCA in several ways, and noticed several challenges, e.g.[26]. Allowing for agent heterogeneity in terms of how decisions are made depending on the context calls for data on in what context decisions are made, how agents express their take on the context, and how the different social and

"deep" the deliberation is taking place. Research in CPRs is strongly pushed forward using behavioural experiments [20, 17] pushing for a more generic understanding of cooperative and sustainable behaviour. Hence oriented to group behavioural patterns rather than individual decision making and thus focusing on quantative data - how much of the common resource is each individual extracting over time, with the overall state of the resource as the input to the next decision cycle. Qualitative data would be needed to investigate the details of the decision-making modes at play and the transitions between them for a CAFCA-esque model to go beyond most CPR simulation models. Indeed, most modellers turn to different theories from the social and behavioural sciences. However, most of these theories concern relatively simple decisions with few alternatives, short evaluation horizons, and tend to be within their own domain silo. In a long running set of studies, we are investigating resource user decision-making in fishing communities in several countries, integrated in ongoing studies with other researchers. The aim of the project for to formalise the influence of perception of change in the resource on the participants' actions via internal characteristics and processes, see [24] for a detailed description of the studies. In these studies, the data gathering consists of:

1. the resource extractions/harvesting done by participants in a common-resource problem game experiment (rounds of deciding how much fish to catch) in a small group of 4 local fishers;
2. observational data of the communication between the experiment participants;
3. questionnaire data with the experiment participants; and
4. interviews with the observers (semi-structured, audio recorded and transcribed).

The initial study followed a basic approach, extending lab experiments to experiments in the field, with resource users as participants (i.e., not students or other non-stakeholders). When analyzed using a CAFCA perspective, we found the data and behaviour labelling had gaps. These gaps were addressed in two stages - pending the space our part of the study had in the larger scheme of things. The gaps include group dynamics, participants perceptions and attributions, but also whether the participants felt like a group, whether this changed throughout the experiment, etc.

Concerning the observational data, we developed an observation scheme where the observers were tasked to check every round whether there was any communication. If there was and the observer noted if communication concerned reflections on what just happened and/or what they should do next; whether they came to an agreement and if yes what they agreed about, and anything they noticed. At the end of the game the observers also filled out some general observations, about their knowledge and confidence, whether they talked about the end of the game, whether the fact they played a certain treatment (uncertainty) played a role, if and how leadership was visible and about the group dynamics in general. These factors were a result of trying to apply CAFCA to a previous

study in the same series in which we found that the data was too fragmented and high level to make assumptions on the CAFCA processes involved.

The observation protocols and interviews did provide some detailed data. A preliminary analysis of the data shows that the relatively small number of interactions (the experiments consist of 20 rounds of decision-making on how much fish to catch) does not offer many opportunities for new social effects that emerge during the experiment. Rather, the pre-existing knowledge of the other participants (part of the same fishing community) plays a role as well as general socio-cultural norms (e.g., one should respect the elderly, thus their voice in the decision-making process has extra weight) [25].

The need for detailed information puts high demands on the observers. As the experiments were carried out in countries of which the researchers did not speak the local language(s). Thus, the observers need to be able to express themselves clearly in English. As we are unaware of all culture-related details while the data comes to us via our interviews of the observers, the observers need to have enough distance to their own cultural background to recognize the interesting processes and utterances from the experiments. To note any transitions between individual, social, and collective they need to observe what is obvious and therefore invisible to the insiders .

4 Discussion & Conclusion

Agent-based modelling needs to constantly walk the tightrope between realism and tractability. We want our models to be simple but no simpler than the problem or research question demands. We hope CAFCA can help to find the right level of abstraction for a model by helping to think through which decision dimensions are relevant in the particular setting. For example the Consumat uses individual and social habitual and strategic dimensions of decision making to replicate consumer behaviours. A model of mask wearing might need a population of collective normative agents, some social and collective habitual ones and some social strategic ones to replicate the dynamics of adherence to Covid restrictions.

In addition to allowing the modeller to think about the dimensions needed to model a given target, CAFCA can then also help with the appropriate data collections by focusing surveys, interviews, and focus groups on why people do things and how they might change their behaviour depending on contexts. This may include the need for training of those that help modellers collect the data needed.

[Reflection on CAFCA's role in allowing the thinking of even more complexity in ABM]

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