

# Epistemic Foundations of Saliency-Based Coordination

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Received: 4 April 2019 / Revised: 19 October 2020 / Accepted: 11 November 2020

*Abstract:* This paper aims to assess current theoretical findings on the origin of coordination by saliency and suggests a way to clarify the existing framework. The main concern is to reveal how different coordination mechanisms rely on specific epistemic aspects of reasoning. The paper highlights the fact that basic epistemic assumptions of theories diverge in a way that makes them essentially distinctive. Consequently, recommendations and predictions of the traditional views of coordination by saliency are, in principle, based on the processes related to the agent's presumptions regarding the cognitive abilities of a co-player. This finding implies that we should consider these theories as complementary, and not competitive, explanations of the same phenomenon.

*Keywords:* Coordination; correct belief; epistemic symmetry; rationality; saliency.

## 1. Introduction

There are many coordination challenges in our everyday lives (greeting patterns, traffic rules, dancing moves, etc.), yet we do not feel that these kinds of everyday interactions involve some sort of obstacle because our

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behaviour usually seems straightforward and effortless. The key question is how this behaviour emerges for the first time if we cannot rely on precedent, agreement, or rules. What are the underlying processes enabling this type of interdependent behaviour of multiple agents? How many different but parallel ways can bring about coordination in this setting? The notion of *salience* was preliminarily specified in terms of “standing out” or “conspicuousness” (Schelling 1960; Lewis 1969a),<sup>1</sup> and it was used to explain the process of inducing coordinated actions of agents who are not able to appeal to any stronger background or decision principle.<sup>2</sup> Namely, an individual who wants to coordinate with others, but does not know which behavioural pattern is precisely suitable for the situation, may look for the assistance of a salient feature of an interaction (contextual clue, labelling of choice) and then coordinate (Schelling 1960).

Currently, the issue has been revived as the topic of the emergence of coordination is reflected by the new empirical evidence (Mehta et al. 1994; Bardsley et al. 2010; Colman et al. 2014). In general, my aim is to assess two leading proposals and answer the following question: Is it the case that people coordinate by salience because they frame contextual cues and conceive the situation from a new perspective—as described by the *variable frame theory* (Bacharach and Bernasconi 1997; Bacharach and Stahl 2000; Bacharach 2006), or because individuals have a ‘hunch’ about another’s behaviour and try to respond to this as best as possible—as suggested by the *cognitive hierarchy theory* (Camerer and Chong 2004)? I want to argue that both theories are built upon some elementary assumptions about the beliefs of others, and the logical structure of these epistemic foundations makes these two approaches compatible. Therefore, I suggest there are two parallel kinds of salience-based coordination processes (based on the above-mentioned theories), and their usage is determined by the epistemic context

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<sup>1</sup> Alternatively, Sugden (2011) defines salience more clearly as “an individual’s pre-reflective perception that certain elements of the situation stand out from the rest”.

<sup>2</sup> There are three widely accepted ways of how coordination can emerge (Lewis 1969, 24–42). The first two are implicit and not purposeful: coordination based on salience, the one I am discussing in the paper, and coordination due to precedent (Schelling 1960, chap. 4; Young 1996). The third is an explicit communication such as agreement.

of an interaction. More specifically, I will show that *epistemically symmetrical* conditions of interaction favour reasoning modelled by variable frame theory, whereas *epistemically asymmetrical* conditions support reasoning with cognitive hierarchy.

The paper is structured as follows: In Section 2 I reveal the problem of coordination, and why it presents a challenge for any theory of coordination. Section 3 discusses two recent and dominant views of saliency which are then described and analyzed in terms of their epistemic underpinnings in Section 4. Finally, Section 5 summarizes my argument by introducing notions of epistemic symmetry and asymmetry and reflects some general implications.

## 2. Coordination Problem

In the opening paragraph, I have briefly mentioned cases in which people try to coordinate their behaviour to achieve a mutually beneficial outcome. For example, a pedestrian and a car driver face the crucial decision of whether to *wait* or *go* once they reach an intersection at the same time (assuming there are no traffic lights). Undoubtedly, their goal is to arrive at a state of the world in which the only one chooses to *go*, while the other *waits*. Similarly, when we meet someone in a theatre, we tend to greet this person. But how? Should we hug a person, kiss her, shake her hand? In game theory, it is common to use a notion of coordination game to denote a strategic interaction that poses an issue of selection between many viable alternatives. The game represents a situation in which two or more agents make a decision from the set of available options with the intention of directing their actions towards a certain outcome. Moreover, agents' preferences in the interaction are such that they favour the same outcome (since it is beneficial for both of them), and that outcome cannot be achieved by acting alone or by neglecting to consider others' actions. Because of this, each player forms beliefs about other agents' actions to estimate the potential consequences.<sup>3</sup> It is also important to keep in mind that the preference

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<sup>3</sup> In other words, coordination as a type of strategic interaction expresses the idea that beliefs about others have an important significance within this decision-making process. This aspect makes it different from decisions such as whether I should take



You can see that the players decide simultaneously what to do, and then they establish an outcome of the game, a product of their strategy-combination (chosen from row and column by respective players). Given this, we can easily and clearly evaluate their choices, and say how preferable the result is considering their utilities.<sup>5</sup>

However, what complicates this situation is a feature of the game that allows three possible outcomes to be equally acceptable (ranked by both player with utility 1).<sup>6</sup> This is *the coordination problem*. It is a problem because it questions our competence to decide what exactly the solution of the game is, and therefore it imposes the difficulty of selection (Harsanyi and Selten 1988). In real-life situations, people usually use *agreement* to solve the indeterminacy, or they rely on some *precedent* that helps to stabilize their expectations of a possible solution. On the other hand, under circumstances when agents cannot communicate and no pattern of behaviour from previous encounters is known, there is still one remaining way to solve this curse of symmetry. External factors can make one of the choices somehow salient. Intuitively speaking, salience breaks the symmetry by the fact that some strategies will stand out and appear strikingly different in comparison to others.

### 3. Theories of Salience

The focus of interest for the rest of the paper, therefore, is a particular model of interactions that are well represented in everyday life, and the role

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<sup>5</sup> The assumptions behind this are the standard ones: preferences are expressed in Von Neumann-Morgenstern utilities, and players are rational in the sense that they maximize expected utility due to common knowledge assumptions.

<sup>6</sup> In game-theoretical terms, the game has three payoff-symmetric pure Nash equilibria. In addition to these, there is also Nash equilibrium in mixed strategies. For more details on categories of coordination games, see Camerer (2003). Also, it is worth mentioning that the many-solutions problem is crucial for the game because the coincidence of interests is not a sufficient condition for coordination, as shown by Ullmann-Margalit (1977, 79–80).

of salience in these interactions.<sup>7</sup> However, the phenomenon of salience (as preliminarily mentioned in Section 1) is, for now, placed in a more refined theoretical foundation that provides more robust explanatory grounds for reflection on different modes of reasoning. I will briefly introduce two prominent theories of salience-based coordination—*variable frame theory*, and *cognitive hierarchy theory*—and then reveal their epistemic background to show why I think these theories complement each other.

Michael Bacharach invented a formal extension of the game-theoretical model of coordination in *variable frame theory* (Bacharach and Bernasconi 1997; Bacharach and Stahl 2000; Bacharach 2006).<sup>8</sup> It attempts to explain a salient choice in terms of conceptual frames or labelling, given that, it takes a step beyond orthodox game theory by enriching apparatus with the notion of frame.<sup>9</sup> Frame is a set of concepts or labels by which the agent perceives the interactive situation, and Bacharach accounts for a salient choice in terms of the agent's framed decision-making. If individuals conceptualize interaction through the same lens, then salience may occur and guide their decisions towards coordination. Suppose you are playing a matching game with another person and you must choose from a set of five distinct objects: whisky, wine, water, beer, or sherry (assume they have stickers attached to them, so you do not have to taste them). Variable frame theory assumes that players describe the interaction through various predicates. For instance, *alcoholic* and *non-alcoholic* suggest themselves as

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<sup>7</sup> Technically speaking, all attention is devoted to a one-shot normal form coordination game in which the preferences of agents perfectly coincide and no communication or (direct) past experience is allowed. Unless stated otherwise, in all remaining sections I consider such a game as the default option.

<sup>8</sup> Bacharach followed in the footsteps of Gauthier (1975), and significantly extended his original intuition by providing a comprehensive theoretical framework. It was Gauthier who first innovatively suggested that salience induces a payoff-modification that transforms the original pure coordination game into a game with asymmetric equilibria (Hi-Lo game); and he augmented the account by the principle of coordination, which states the normative claim for an agent to choose a payoff-dominant equilibrium.

<sup>9</sup> In traditional game theory, it does not matter how an agent perceives a game since theorists have an objective way to describe interaction by indicating strategies and payoffs. See Luce and Raiffa (1957).

obvious categories. The non-alcoholic drink (water) appears to be a good candidate for the salient choice (cf. Bardsley et al. 2010).

Why? To detail how this process of framing works, I show the formalization of the example in conformity with Bacharach (2006). The standard model of game is extended with frame  $F$  containing different families of predicates (here, generic family  $F_0$  and  $F_1$ ) and these families are, moreover, specified by parameters of how likely their occurrence is in the player’s mind (availability,  $v(F) = p$ ;  $0 \leq p \leq 1$ ), and what strategies—in the sense of traditional objective game—are among the predicates in the family (extension of a predicate,  $E$ ). As a result of this configuration, it is possible to capture the idea of how saliency transforms the payoff structure of the game.

$$\begin{aligned} \Gamma_{\text{beverages}} &= (N, S, U, F) \\ \mathbf{N} &= (i, j), \mathbf{S} = (\text{whisky, wine, water, beer, sherry}) \\ \mathbf{U}: U & (s_i, s_j) \dots \text{if } s_i = s_j \text{ then } u_i = u_j = 1 \\ & \dots \text{if } s_i \neq s_j \text{ then } u_i = u_j = 0 \\ \mathbf{F}_i &= \{F_0, F_1\}, \mathbf{E}: F \rightarrow S \\ \mathbf{F}_0 &= \{\text{thing}\}; E(\text{thing}) = \{\text{whisky, wine, water, beer, sherry}\}, \\ & v(F_0) = 1 \\ \mathbf{F}_1 &= \{\text{alcoholic, non-alcoholic}\}; v(F_1) = 1 \\ E(\text{alcoholic}) &= \{\text{whisky, wine, beer, sherry}\}, \\ E(\text{non-alcoholic}) &= \{\text{water}\} \end{aligned}$$

	<i>Choose the non-alcoholic</i>	<i>Pick an alcoholic</i>	<i>Pick a thing</i>
<i>Choose the non-alcoholic</i>	<b>1, 1</b>	0, 0	0.2, 0.2
<i>Pick an alcoholic</i>	0, 0	<b>0.25, 0.25</b>	0.2, 0.2
<i>Pick a thing</i>	0.2, 0.2	0.2, 0.2	<b>0.2, 0.2</b>

Figure 2. Framed matching game

In comparison to all other possibilities, the *non-alcoholic* drink offers the best chance for a match in coordination, as the extension of the predicate contains only one element. This conclusion is not very surprising, but the

formal notation reveals further details.<sup>10</sup> First, an important consequence of framed games is that they break the curse of symmetry by introducing asymmetrical equilibria (in bold in Figure 2).<sup>11</sup> Therefore, the coordination problem is essentially altered into a new game structure (Hi-Lo game) solely under the influence of framing. Second, this reshaping of the original pure coordination game brings us closer to an explanation. However, it does not—in this form—establish a definite solution to the game. The reason for this is simple: a player may be equally justified in ‘picking an alcoholic drink’ if he or she reasonably expects the other to make the same decision.

The missing piece of the puzzle is the kind of reasoning that supports this decision. Could a player appeal to some principle of coordination when choosing a Hi-equilibrium (in my example ‘choosing the non-alcoholic drink’)? Variable frame theory answers this question by explaining this mechanism and providing its elaborate justification. Rational agents do not consider their choices only on the basis of standards of individual rationality—they think as a team, considering what is beneficial for *them*, collectively.

This means that a new principle of rationality enters the scene, with the formal consequence of directing individuals’ choices towards a Pareto-optimal equilibrium.<sup>12</sup> Bacharach is convinced that there are strong reasons that lead individuals to team-beneficial choices since we tend to identify with a certain group. In particular, group identification occurs as a result of

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<sup>10</sup> Keep in mind that both theories I present provide a formal explanation of salience, therefore they make no further assumptions as to what specific factors trigger this effect. Moreover, I believe that every substantive theory would be incomplete in its content since it is difficult to list all significant building blocks. And of course, the vast diversity of cultural contexts makes this effort even harder.

<sup>11</sup> What happens in special cases when there are many singleton predicates or availability of families of predicates variables is not an important issue here because it does not weaken my conclusion. For a complete account, see Bacharach and Bernasconi (1997) and Bacharach (2006).

<sup>12</sup> Strategy combination  $(s_i, s_j)$  is Pareto-optimal if there is no other combination  $(s_i^*, s_j^*) \in S$  that satisfies:

- a)  $\forall i \in N, U(s_i^*, s_j^*) \geq U(s_i, s_j)$
- b)  $\exists i \in N, U(s_i^*, s_j^*) > U(s_i, s_j)$

perceived common interest, or strong interdependence (Bacharach 2006, 142–44), and is followed by the mode of team reasoning (or we-reasoning).<sup>13</sup> Variable frame theory, broadly speaking, establishes a new form of non-standard reasoning that revises the traditional conception of rationality such that agents are now considered to be capable of recognizing an efficient outcome that gives *them* the best prospect of coordinating.<sup>14</sup> Therefore, salient choice is produced by a particular frame that transforms a game-structure from pure coordination to Hi-Lo game, and then agents make a decision as team members in favour of a mutually beneficial outcome. These two essential components of the theory—framing and team reasoning—reliably explain why ‘water’ is the salient choice in the prototypical matching game.

But, to make things more complex, there is another alternative explanation for coordination by salience that stems from *cognitive hierarchy theory* (Camerer and Chong 2004).<sup>15</sup> This model is, in principle, based on the assumption of a boundedly rational agent, who takes a limited number of reasoning steps before he or she decides, and, in the case of coordination, whose strategic thinking is rooted in some kind of rudimentary non-strategic non-rational salience. Hence, an overall account of salience-based coordination presented by this theory rests on two pillars: one that establishes weak symmetry-breaking behaviour, and the second, which postulates a finite belief hierarchy, and an individual who chooses the best strategic response

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<sup>13</sup> Some have identified several problems with team reasoning. It seems to be too narrowly specified in terms of social categorization (Hindriks 2012), and somewhat unstable in experimental testing either due to slight payoff asymmetry (Crawford, Gneezy, and Rottenstreich 2008) or due to the influence of other strategic options (Cooper et al. 1990).

<sup>14</sup> This revisionary standpoint is, however, highly controversial as it puts into question a standard assumption of game theory—methodological individualism. Yet, on the other hand, many experimental studies show evidence in favour of this reasoning mode (Bacharach and Bernasconi 1997; Colman, Pulford, and Rose 2008; Bardsley et al. 2010).

<sup>15</sup> The theory was initially developed to provide another way of thinking about solution concepts in game theory. And it had an impact on dominance-solvable games (e.g., Beauty Contest Game), but it also provides an interesting framework for thinking about coordination problem in a new way.

with regard to his or her beliefs.<sup>16</sup> But how do these two features fit together? The whole result of salience proceeds in two steps that are captured and formalized by the theory. Initially, there is a non-uniform probability distribution on the set of strategies, sometimes known as *primary salience* (Mehta, Starmer, and Sugden 1994), whose role is to disrupt the symmetry of the coordination problem. A natural interpretation of this could be that agents have a psychological propensity to pick some strategies without any incentive and in the absence of strategic reasoning. Such behaviour then exhibits randomization over some strategies that might be particular to a certain cultural background, contextual information, or simply because of their uniqueness and conspicuousness. This part of the story might be sufficient to explain “picking behaviour”, or why there is a concentration of choices in aggregate, as supposed by Schelling (1960), and tested by Bardsley et al. (2010). However, the presence of coordination success on many occasions demands a fuller explanation.

At this point, the second element, belief hierarchy, becomes involved. The theory introduces agents of various levels of reasoning who have the cognitive ability to recognize lower-level agents, and to choose the best strategy (best-response)<sup>17</sup> given their assumptions about other players and their choices (Stahl and Wilson 1995; or Haruvy and Stahl 2007). Therefore, it attempts to establish an apparatus whose expressivity allows us to grasp the intuition that agents have a certain depth of reasoning and the cognitive ability to understand other minds (Ohtsubo and Rapoport 2006). In this respect, there are categories of agents depending on how many steps have been taken, or let us say that each of them is assigned a certain level of reasoning. For instance, a level 0 player (or L0) lies at the bottom of the hierarchy and has no mental model of other players’ choices or reasoning abilities. His behaviour in coordination is fully characterized by the non-

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<sup>16</sup> The origins of this idea can be traced back to Lewis (1969b, 24–36) and his account that coordination is feasible only by means of a system of high-order expectations.

<sup>17</sup> The best-response decision rule is essentially based on the strict dominance principle—a core element of decision-making. It assumes that a rational agent can eliminate all strategies that are, in all respects, worse than the other options.

uniform probability distribution  $p_0$  (i.e., primary salience).<sup>18</sup> Next, level 1 represents an agent who is convinced that all her co-players are L0, and she decides to maximize her chances of a match with the others. The intuitive understanding of the model is that the level 1 player tries to guess what the most probable choice is according to his peers, influenced by primary salience, and then chooses the best response to that behaviour. The same holds for all higher-level reasoners: they expect others to be lower-level agents, and they have particular beliefs about the frequency of these types in the population. In other words, these beliefs express the probability of an encounter with a given type. For example, a level 2 player believes that he may coordinate with someone who is either L1 or L0, and acts in order to maximize his expected utility in anticipation of the respective behaviour of his co-player.

The specific implications of cognitive hierarchy theory for coordination games is straightforward: players—depending on their type—maximize their chance of compliance with others based on generally recognized primary salience (or picking behaviour), which successively leads to a concentration of choices around one of the equilibria. This dynamic process of reasoning sooner or later selects one of the possible alternatives with the support of original non-uniform probability distribution. As an example, consider the familiar game with beverages except now I will analyse it is using the apparatus of cognitive hierarchy theory. The first obstacle emerges with the issue of how to determine the likelihood of choosing a drink, i.e.  $p_0$ . The traditional answer is that we do not have to specify this *a priori* because, essentially, it is a matter of empirical research. The aim of the theory of salience-based coordination is not to enumerate all the sources of salience, but, rather, to demonstrate the formal consequences leading to one solution. Thus, as someone who lives in a country with a famous beer-drinking culture, I will imagine that primary salience in this case highlights

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<sup>18</sup> One idealized assumption is that  $p_0$  distribution is for all agents (even for higher levels) the same. The reason for such simplification is as follows: if theorists want to model salience-based behaviour then they think that the contextual background is commonly shared. Even though this might seem restrictive, as some individuals might display minor variations, the underlying idea is correct, at least for the instrumental purposes of the theory.

one of the alcoholic drinks. Whatever an individual's choice is, let me assume a stable, reliable, and population-wide pattern of primary salience, for instance  $p_0 = \{0.15 \text{ whisky}, 0.2 \text{ wine}, 0.1 \text{ water}, 0.4 \text{ beer}, 0.15 \text{ sherry}\}$ . This describes a feature of what some individual picks if he or she would not consider others, but simply follow non-reflective inclinations. Although this behaviour occurs in coordination, the theory predicts some agents will strategize and focus on limited strategic thinking. A level 1 agent expects her co-player to behave in accordance with primary salience, and therefore she will choose pure strategy  $s_{11} = \{\text{beer}\}$  since it gives her the highest expected utility ( $u_{11}(s_{11}, p_0) = 0.4$ ). A Level 2 player believes that he may encounter either level 1 or level 0 with corresponding probabilities  $q_1$  and  $q_0$  (where  $q_1 + q_0 = 1$ ), and he also forms beliefs concerning their behaviour ( $s_{11}, p_0$ ). But how should and will a boundedly rational L2 agent act? Even if he imagines the scenario in which his co-player is certainly either type 1 or type 0 (i.e.,  $q_0 = 1$  or  $q_1 = 1$ ), his best strategy is always to choose  $s_{12} = \{\text{beer}\}$ .<sup>19</sup> Therefore, cognitive hierarchy theory describes coordination behaviour in this interaction as a gradual increase of the concentration of choices around one specific alternative.

To summarize, cognitive hierarchy theory explains salience by other means. Coordinating behaviour emerges rather as the result of the expectation of which option is most likely to be selected (given the various types of agents who may or may not think strategically). It is accepted that some players might be choosing blindly, but, overall, coordination is a result of a convergence of choices (in the example, it is convergence to the most popular drink). In comparison to variable frame theory, agents do not have to think as team members, and salience does not create a direct structural transformation. But let us pause for a moment and think more about what the analysis of the beverage game further reveals. The case clearly demonstrates the somewhat disturbing and striking result of divergent predictions provided by each of these theories in the very same game-setting. Whereas one theory ends with the selection of water, the second would suggest beer, and the question—*What would you like me to drink?*—seems to have no definite answer for now.

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<sup>19</sup> Expected utility for L2 player is  $u_{12}(\text{beer}) = q_1 + 0.4q_2$ , therefore  $1 \geq u(s_{12}) \geq 0.4$ .

Of course, in many other cases, the practical implication of the models would be identical, since one needs no more than to suppose that primary salience points in the same direction as a particular frame, keeping in mind that theoretical explanations and underlying assumptions differ (Bacharach and Stahl 2000). But the value of test cases such as the game with beverages rests more on the promise of assessing experimentally which theory is supported by the data, and the identification of a correct explanatory model. Unfortunately, the alleged behavioural litmus test did not provide results as promising as had been expected (Mehta, Starmer, and Sugden 1994; Bardsley et al. 2010; Colman, Pulford, and Lawrence 2014), and the problem seems to be, rather, that two parallel modes of reasoning are possible, and may influence individuals' decision-making in this type of situation. The question, then, is how to reconcile these dual processes?

#### 4. Correct beliefs and belief in rationality

My proposal for a solution will be based on the idea that modes of reasoning in coordination with salience sustain certain epistemic standards which must be implicitly recognized by the interacting agents.<sup>20</sup> Hence, even before it comes to establishing the coordination outcome, every involved and strategically thinking agent makes some estimates concerning possible interaction scenarios, his or her co-player's behaviour, and beliefs (similarly Janssen 2001). Therefore, one can consistently claim that variable frame and cognitive hierarchy theory together provide an explanation of the coordination problem because each theory relies on different epistemic standards. In a nutshell, different epistemic background induces a distinctive coordination mechanism.

As we have seen with cognitive hierarchy theory, this approach of restricted reasoning belongs to a broader class of theories known as bounded rationality. And, as such, it makes rather less demanding epistemic assumptions, which are embedded into the concept of agent. First of all, cognitive

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<sup>20</sup> In this spirit, I follow in the footsteps of the established programme of epistemic game theory, aiming to clarify solution concepts and their underlying epistemic principles. See more on this in de Bruin (2009) or Perea (2012).

hierarchy theory violates *correct beliefs assumption*. This is an important point in my argument I will specify later, but for now, it is sufficient to say that violation of correct beliefs means that even if coordination has been achieved by salience, we cannot say that individuals have correct beliefs about themselves. Thus, an inevitable consequence of cognitive hierarchy model is that every strategically thinking agent is, in fact, acting rationally (he decides for the best option with regard to his or her beliefs and level), even though he has an incorrect belief about his partner in coordination (there is an epistemic disharmony between individuals). The problem, therefore, is deeply rooted in the fact that an agent believes that a co-player is systematically mistaken in what *behaviour* the co-player attributes *to the agent himself*.

To illustrate this point, let me use the before-mentioned beverage-choosing game (Section 3). For instance, imagine a situation of two friends, John and Isaac, who want to order the same drink in a crowded bar with loud music. The only thing that matters is to have the same drink because they do not want to drink more than one type of beverage. Unfortunately, they have been separated by the crowd and each has to make an order independently of the other's decision. They face a typical coordination problem. How can they solve it? Cognitive hierarchy theory predicts that each will choose or pick a drink depending on his cognitive level. The crucial aspect now, however, is what beliefs they have about each other. Let say that John believes that Isaac will choose beer because he believes that John himself is randomly picking one of the drinks, and beer seems like the most attractive option (primarily salient). Given that, John chooses beer too, though he does that knowing that Isaac is mistaken about his actual beliefs. Remember, John believes that Isaac thinks that he is randomly picking. Coordination in this case will be successful despite the obvious epistemic discord.

Now, I will illustrate the issue of incorrect beliefs more formally, which allows me to capture this feature of the theory in a precise manner. I will assume that both agents (John and Isaac) are of the same level, say L2 players. Both expect that the partner will be L1 or L0 (with respective probabilities); and if their partner is L1, L2 player will also think that the co-player (as a L1 agent) has some beliefs about him, namely that L1 will think she is paired with an L0 player. However, we need to know not just

the agent's relevant level, but also information about his strategies. Then, it may be useful to represent formally by means of a simple notation such as  $t_{i2}^{\text{beer}}$  that each individual has a certain epistemic type for a given depth of reasoning and chosen strategy;  $t_{i2}^{\text{beer}}$  indicates that Isaac's (agent *i*'s) epistemic type is specific for an L2 player who is choosing the strategy *beer*.<sup>21</sup> Epistemic type in a nutshell is a convenient way to express the beliefs an individual has, and how they are structured. Bearing this in mind, it is not very difficult to describe an agent's type for the game as follows:

$$t_{i2}^{\text{beer}}: t_{j1}^{\text{beer}} \rightarrow t_{i0}^{\text{alcoholic}}$$

$$t_{j2}^{\text{beer}}: t_{i1}^{\text{beer}} \rightarrow t_{j0}^{\text{alcoholic}}$$

In this display, you can see a case of how two agents of the very same level, on the one hand, have false expectations regarding the other player's level. Isaac ( $t_{i2}^{\text{beer}}$ ) believes that John is L1, whereas, in fact, he is  $t_{j2}$ . This trivial result, though, can be easily avoided simply by stipulating that John is actually  $t_{j1}$ , and then it would prevent this type of incorrectness, which is not my direct concern here. On the other hand, a much more important implication of the model lies in what Isaac ( $t_{i2}$ ) thinks about John's expectations about him. As previously stated,  $t_{i2}$  believes that he is interacting with John of L1.<sup>22</sup> Or, more precisely, he believes that co-player *j* is a  $t_{j1}$  player who chooses *beer* because John expects that Isaac is an L0, who randomizes amongst alcoholic drinks (in accordance with  $p_0$ ) and has no model of his co-players. And conversely, the same holds for  $t_{j2}^{\text{beer}}$ . Thus, a crucial consequence of cognitive hierarchy theory is that the agent ( $t_{i2}$ ) assumes that his co-player is fundamentally wrong in her belief about how he will behave. This kind of incorrectness is different from the first, concerned with the hypothetical versus the actual level of the agent, and, furthermore, is a profound feature of the theory that helps outline its epistemic coordination roots.

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<sup>21</sup> Type-space notation is suitable here for the reason that it allows us to comprehend an aspect of nested beliefs in a simple and elegant way. Cf. Sillari (2008) or Geanakoplos (1992).

<sup>22</sup> This is a harmless simplification, as I assume that  $q_1=1$ .

An important lesson here is that such description reveals a general tendency built into the theory: a rational agent (of sufficiently high level)<sup>23</sup> believes that the partner is fundamentally mistaken in his expectation about whom he is interacting with. And because of this, it is consistent to say that one might observe coordinating behaviour despite the fact that the beliefs the agents have about others contain an internal error. This finding, furthermore, is robust since there is no change in the result even if we admit some variations in the expected composition of a population, or in the depth of reasoning.<sup>24</sup> To shed more light on this epistemic aspect of the theory is just the first step in my analysis, but I believe it delivers a non-trivial philosophical finding regarding how decision-making individuals reflect mental states and the reasoning processes of others, and what they might justifiably ascribe to them in coordination by salience. Since correct belief assumption plays a further crucial role, I need a precise notion of it, which may also bring some understanding of what exactly is violated by the cognitive hierarchy model.

*Correct belief assumption:*

An agent's beliefs—that is, agent's epistemic type ( $t_i$ )—for a particular (coordination) interaction are such that she believes that other agent involved in the situation has beliefs ( $t_j$ ) about her behaviour such that it holds that these beliefs are accurate and correct.<sup>25</sup>

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<sup>23</sup> This condition assumes that the agent has a 'theory of other minds', which holds when he or she is L2 or higher.

<sup>24</sup> Imagine a more sophisticated case: a person who is an L3 player and has an expectation that she may interact with an individual of each level with some positive probability ( $q_0, q_1, q_2$ ). Then we can express her relevant epistemic type for the beverage-choosing game in the following manner:

$$\begin{aligned}
 t_{i3}^{\text{beer}} &: q_2 \times t_{j2}^{\text{beer}} + q_1 \times t_{j1}^{\text{beer}} + q_0 \times t_{j0}^{\text{alcoholic}} \\
 t_{j2}^{\text{beer}} &\rightarrow t_{i1}^{\text{beer}} \rightarrow t_{j0}^{\text{alcoholic}} \\
 t_{j1}^{\text{beer}} &\rightarrow t_{i0}^{\text{alcoholic}}
 \end{aligned}$$

Formalization like this allows us to see the profound basis of epistemic asymmetry of cognitive hierarchy theory concerning one strategic aspect (choice of strategy in particular).

<sup>25</sup> The correctness simply implies that it is the case that, in the belief hierarchy, agents assume their beliefs about actions and beliefs of their partners are the same

Now this definition and formal description allow us to see one aspect of cognitive hierarchy theory that results from the hierarchical structure and underlying assumptions.<sup>26</sup> But we should not lose sight of the fact that *correct belief assumption* expresses a more general idea of coordination and its epistemic context. The case of cognitive hierarchy theory has merely shown at what costs the assumption can be violated if we want to achieve coordination anyway.

How does this analysis help us with variable frame theory? Is there any difference or similarity with respect to the correctness of the agents' beliefs? In section 3, I have briefly explained that variable frame theory proceeds by two distinct steps: structural transformation, and team-coordination. Both make different demands on the individuals involved, yet they are fully adaptable to the formal framework presented and, are, therefore, easy to comprehend and compare. The major difference between the theories lies in the concept of frame that makes salience-based coordination more refined and subtle because it introduces partitions on the strategy set (instead of rather coarse primary salience). If we state that individuals in interaction have the same frame according to which they look upon the coordination problem, then the theory predicts, in this idealized case, that their choices will intersect in a Pareto-optimal result.<sup>27</sup> All of this we know already from above, but the question is whether the outcome is in line with correct belief assumption, or against it. We are already familiar with the answer to the question "What would you like me to drink?"—It is water (the single member of *non-alcoholic* group). Nonetheless, it is better to show the epistemic

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throughout the nested structure of beliefs (Perea 2012, 145–46). It does not imply that those beliefs are true because there might be many consistent and correct belief combinations, for instance in a game with many Nash Equilibria.

<sup>26</sup> To be entirely clear, authors of cognitive hierarchy theory briefly acknowledge this conclusion. (Camerer, Ho, and Chong 2004, 869) My concern relates more to other applications and experiments where this issue is often disregarded.

<sup>27</sup> I assume that there is a commonly shared context of interaction which allows the formation of a particular frame. It is not very controversial to proceed in this way because I have already accepted that salience-based coordination involves external factors. Obviously, there are some additional conditions to be fulfilled to secure a clear result (e.g., symmetry disqualification, trade-off principle), for more details see Bacharach (1997).

background of the solution of the game in a similar fashion as before, with only a slight modification in subscripts. Instead of representing cognitive level (which is irrelevant information for variable frame theory), numbers in the agent’s epistemic type help us to specify the frame available to him. For instance,  $t_{i01}^{\text{water}}$  states that both  $F_0$  and  $F_1$  as defined in  $\Gamma_{\text{beverages}}$  are families of predicates that agent  $i$  (Isaac again) takes into account when he chooses water. Then it is straightforward to express the agents’ epistemic types for variable frame theory accordingly:

$$t_{i01}^{\text{water}}: t_{j01}^{\text{water}} \rightarrow t_{i01}^{\text{water}}$$

$$t_{j01}^{\text{water}}: t_{i01}^{\text{water}} \rightarrow t_{j01}^{\text{water}}$$

What we can see immediately is that the epistemic condition of correct beliefs is fully satisfied in this setting, since Isaac (in the first row) expects his partner John will not be mistaken in her beliefs about the Isaac’s actions, and vice versa (in the second row). In other words, if Isaac is choosing the beverage with the goal to coordinate, his choice of water is fully justifiable—taking for granted particular frames and team-rationality—by his expectations that John will choose exactly the same, and that he also expects Isaac to choose water.

Variable frame theory predicts that whenever there is a coordination solution induced by salience, agents have beliefs that preserve correctness.<sup>28</sup> This result is also consistent for different variations in the structure of a frame. To show a general implication, let me assume a somewhat complex case of a similar game in which one of the agents is aware of an additional family of predicates, say  $F_x$ , and he or she recognizes its availability  $v(F_x) = p$ , where  $0 < p < 1$ . This describes an aspect of uncertainty, as there is an agent now who may apply some predicates but cannot be sure that the other will do so as well (Bacharach and Stahl 2000, 224). Assume two predicates  $a$  and  $b$  such that  $a \in F_x$ ,  $b \notin F_x$  and for simplicity also that  $E(a) \cap$

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<sup>28</sup> One explanation for these results invokes the well-established theorem that Nash equilibrium in principle rests on correct beliefs, see Tadelis (2013, chap. 5) or Perea (2012, chap. 4). Therefore, variable frame theory as an equilibrium refinement programme carries the same epistemic load.

$E(b) = \emptyset$ .<sup>29</sup> And strategy  $s$  based on expected utility calculation (more specifically based on Bacharach's (1997) trade-off theorem) where  $s = \textit{choosing } a$  if  $EU(a) > EU(b)$  and  $s = \textit{choosing } b$  if  $EU(a) < EU(b)$ .<sup>30</sup> For this reason the epistemic type of the agent  $i$  is as follows:

$$t_{i01x}^s: p \times t_{j01x}^s + (1 - p) \times t_{j01}^b$$

$$t_{j01x}^s \rightarrow t_{i01x}^s$$

$$t_{j01}^b \rightarrow t_{i01}^b$$

Even in this general case of framed decision-making, agent  $i$  has correct beliefs regarding his co-player's possible choices. Notwithstanding the fact that the agent believes with probability  $p$  that the other will be aware of the same frame, and with probability  $1 - p$  that  $j$  will not notice  $F_x$ , the choice of the agent is such that she expects her co-player to think that the same choice is being selected. The result is consistent with correct belief assumption.<sup>31</sup>

Now, I move on briefly to the second epistemic aspect of theories, which is better known and has been already analysed—the issue of *belief in rationality*. The rationality assumption is a cornerstone of decision theory, and from a concise description of both theories, it is intuitively obvious that they depart from the game-theoretical standards. However, I would prefer to show how theories treat the epistemic aspect of rationality, and, thus, to address the question: What does an agent expect regarding the rationality of a co-player? And does the co-player believe in the rationality of the other? It should be evident that I am not dealing with the nature and comparative analysis of rationality requirements which I consider fixed for the respective theories and I have set aside as a separate research agenda.

<sup>29</sup> Here I straightforwardly suppose that either choosing  $a$ , or choosing  $b$  is the team-optimal choice under a condition of the validity of the relevant frame.

<sup>30</sup> In the case whereby  $EU(a) = EU(b)$ , the symmetry disqualification principle rules out both options. Unfortunately, this principle has not been confirmed empirically; see Bacharach and Bernasconi (1997).

<sup>31</sup> The fact that  $t_{i01x}$  might think that the other individual expects her to be  $t_{i01}$  does not interfere with the conclusion concerning choices. Moreover, it was my assumption, in this example, to introduce some uncertainty about the other player's frame.

My focus here is fully on the distinction that relates to the epistemic aspects of rationality.

At the start, I need to clarify the epistemic principle I will rely upon in the next analysis.

*Belief in rationality:*

An agent believes that his co-player is rational, and that the co-player also believes in his rationality.

If we look closely at the scheme of epistemic underpinnings of the solutions to each theory, contrasting features emerge. Variable frame theory explains coordinative behaviour in accordance with the hypothesis that all individuals believe in their co-player's rationality and believe that each partner in coordination believes in their rationality. For instance, epistemic type  $t_{i01}^{\text{water}}$ , who chooses (team) rational option, expects her co-player to be (team) rational because  $t_{i01}^{\text{water}}$  think  $t_{j01}$  will act in line with the recommendation of the theory: i.e., she will also choose water.<sup>32</sup> The result is self-evident from the characterization of her type:

$$t_{i01}^{\text{water}}: t_{j01}^{\text{water}} \rightarrow t_{i01}^{\text{water}}$$

On a more general level of analysis, one may easily see that the theory respects the traditional axiom of the common knowledge of rationality (Tadelis 2013, 64-65). What does it imply about the epistemic background of coordination? A common feature is built into each solution based on variable frame theory implying that players are *epistemically symmetrical* in this important respect. A team-rational player is convinced that she is interacting with someone who also expects the other's actions to be team-rational.

But a contrasting conclusion arises whenever we examine *belief in rationality* in cognitive hierarchy theory. Clearly, it is not that surprising because we recognize that belief hierarchy is based on the gradual nature of rationality. A player at a certain level  $k$  is expecting interaction with an individual who is  $k-1$  or lower. She also believes that her colleague will

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<sup>32</sup> Team rationality operates as a criterion for strategy selection in Hi-Lo game, but it is actually belief in rationality that secures equilibrium selection since it is necessary to consider another agent's behaviour and its basis.

expect coordination with someone who is below her actual level, and so on, until L0 is reached. The entire level-based reasoning process is, thus, in principle, grounded in the bounded rationality paradigm, which, as a matter of a fact, means that *belief in rationality* is violated. The following epistemic type scheme captures this result more accurately:

$$t_{i3}^{\text{beer}}: t_{j2}^{\text{beer}} \rightarrow t_{i1}^{\text{beer}} \rightarrow t_{j0}^{\text{alcoholic}}$$

One might raise an objection, pointing to the fact that all types of agents higher than L0 are genuinely rational because they make the best response to their alleged conception of the other's type. However, it is important to bear in mind that *belief in rationality* across different levels is not of the same nature, though all these types are best-responding agents. It is absolutely dissimilar when the agent *i* expects an encounter with  $t_{j2}$  or  $t_{j1}$ . The first believes that her colleague is rational (L1-rational), while the second does not. After all, it seems that both theories rely on an entirely different epistemic background. In my opinion, the difference could be elegantly depicted in terms of epistemic symmetry and epistemic asymmetry.

## 5. Epistemic (a)symmetry

The paper raised a thorny question: How can coordination be achieved by salience? I introduced salience as a key factor in establishing a desirable outcome in a coordination game in which communication and precedent are absent, and I presented two recognised explanatory pathways for this phenomenon. The subsequent analysis of the epistemic components of theories has identified remarkable differences regarding correctness of beliefs and belief in rationality. Now, I would like to reveal the last piece in the puzzle by means of which it will be theoretically possible to say that there are two parallel ways of coordinating by salience.

My view of the coordination process via salience respects the fact that the two theories are equally suitable and comprehensible. However, their application is conditioned by specific circumstances affecting the relevant reasoning and decision-making. As we are already well acquainted with the epistemic scaffolding of the theoretical apparatus, I can explain the difference between these two theories by using simple epistemic terms—*epistemic*

*symmetry* and *epistemic asymmetry*. Also, I argue that they aptly elucidate why both processes of coordination by salience may occur and under what circumstances. Let me explicate these notions as follows:

*Epistemic asymmetry in coordination interaction:*

In a strategic interaction of a coordination kind, there is epistemic asymmetry if, for every actively participating agent, it holds that he or she does not satisfy correct belief assumption and does not have belief in a co-player's rationality.

Analogically, the notion of epistemic symmetry can be defined in the very same way, except these two essential requirements do hold.

The purpose of these definitions is to build on earlier reflections and to demarcate the relevant context of coordination. In the previous section, I demonstrated several epistemic-type structures as an example of different relationships in the foundation of theories. In light of the above, it is clear that a coordination game with salience allows a number of diverse but parallel procedures. Either I assume that I and my co-player are symmetric in important epistemic aspects, or I expect asymmetric conditions to be valid. In the first situation, correct beliefs and belief in rationality, are prerequisites for the use of subsequent framing and the application of team reasoning. Whereas in the second, the epistemic type of agents is such that they rather anticipate some level of incorrectness in beliefs and uneven standards of rationality, which leads to the utilization of best-response reasoning based on each agent's cognitive efforts.

Imagine we are back in the bar with John and Isaac. How can epistemic conditions affect the resulting coordination? From what I have said, it is quite clear that John and Isaac may end up with the same drink (coordination is achieved) but as a result of different salience-based coordinating mechanism. For instance, If Isaac believes that John considers him to be tired and not caring too much about appropriate reasoning, then Isaac might reliably assess the situation as epistemically asymmetrical. In a sense, "John will think I am tired, and so he will choose beer because he thinks I will just pick something." Moreover, epistemic asymmetry might be even bigger if we assume that John and Isaac are just colleagues from work who rarely meet, and they do not know each other very well. In this scenario,

application of the cognitive hierarchy reasoning looks plausible. On the other hand, by assuming that John and Isaac are close friends who trust each other, we can get an epistemically symmetrical context. John's thoughts might be the following: "Isaac wants us to have the same drink and he knows that I want that too. Isaac will choose water because he thinks that I will be rational, and Isaac will believe that I think water is the best choice for both of us because it is a unique choice of non-alcoholic beverage." Here, it is reliable to say that reasoning described by variable frame theory influence Isaac's and John's decisions. Of course, these two scenarios are just simple stories, but I hope they, at least, illustrate the major point of the paper—the epistemic context matter for coordination by salience.

Another implication of my reflections concerns the relationship between symmetrical and asymmetrical perspective. Based on epistemic grounds, it is more than plausible to say that variable frame and cognitive hierarchy theory are like two sides of the same coin. Under suitable epistemic circumstances, it is likely that an agent is well equipped to use the respective coordinating principle determined by the one theory without ruling out future use of another principle. Thus, I think that this epistemic ramification can help us understand the diversity of coordination procedures and to recognize its contextual value. There might be coordination cases in which individuals consider strategic interaction favourable for epistemic symmetry: they trust their partner or have a positive evaluation of the group, or social bonds are tight and firm, etc. (Bacharach 2006, chap. 3; Colman, Pulford, and Rose 2008; Hindriks 2012). For all these factors influencing our perception of the epistemic environment of coordination games it seems legitimate to predict the outcome in accordance with variable frame theory. On the other hand, some conditions—payoff bias (Crawford, Gneezy, and Rottenstreich 2008) or prudential thinking (Cooper et al. 1990)—seem to fit with epistemic asymmetry, and favour cognitive hierarchy theory.

Finally, what does my conclusion say about the impact on experimental research? In most situations these theories imply the same result, yet when it comes to test cases predictions may diverge in various ways. My claim is that although we observe similar results (Mehta, Starmer, and Sugden 1994; Bardsley et al. 2010; Colman, Pulford, and Lawrence 2014) it proves little,

as we can still defend both theories. In my view, coordination by salience is a result of the involvement of two processes whose active impact on the final outcome is fundamentally—but not solely—determined by the epistemic niche of a given interaction. The challenge for future research might be to test experimentally factors entrenched in the epistemic conditions which interfere with coordinating decisions and cause behavioural variations.

## 6. Conclusion

In this paper, I have shown that if one wants to properly understand coordination by salience, it seems necessary to take into account the epistemic restrictions that are imposed on reasoning in different coordination procedures. Consequently, the two well-known and prominent theories, variable frame theory and cognitive hierarchy theory should be regarded as complementary ways of explanation of salience-based coordination. Besides, I have suggested that the criteria of epistemic symmetry and epistemic asymmetry comprehensively specify tacit assumptions of theories and shed a light on the important difference build into their foundations. In variable frame theory, correct beliefs and belief in rationality, are prerequisites for the use of subsequent framing and the application of team reasoning. Whereas in cognitive hierarchy theory, the epistemic type of agents is such that they rather anticipate some level of incorrectness in beliefs and uneven standards of rationality, which leads to the best-response reasoning based on epistemic asymmetry.

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