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Hidden protocols: Modifying our expectations in an evolving world

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ABSTRACT

When agents know a protocol, this leads them to have expectations about future observations. Agents can update their knowledge by matching their actual observations with the expected ones. They eliminate states where they do not match. In this paper, we study how agents perceive protocols that are not commonly known, and propose a semantics-driven logical framework to reason about knowledge in such scenarios.
In particular, we introduce the notion of epistemic expectation models and a propositional dynamic logic-style epistemic logic for reasoning about knowledge via matching agents' expectations to their observations. It is shown how epistemic expectation models can be obtained from epistemic protocols. Furthermore, a characterization is presented of the effective equivalence of epistemic protocols. We introduce a new logic that incorporates updates of protocols and that can model reasoning about knowledge and observations. Finally, the framework is extended to incorporate fact-changing actions, and a worked-out example is given.

1. Introduction

Talking about knowledge and protocols, some questions come to our minds: *What do we mean by knowing a protocol*? *How does this protocol knowledge affect our knowledge of facts about the world*? The literature abounds with various formal models answering these questions from different angles [1–5], and the proper representation and formalization of knowledge and knowledge dynamics is a core interest in the area of artificial intelligence [6–9]. In some situations, agents have partial knowledge of the underlying protocols that guide the behaviors of other agents. Based on their incomplete knowledge of protocols and their observations, the agents try to reason about other agents' epistemic attitudes as well as about hard facts. Protocols play a role, for example, when agents communicate using full-blown secret codes (see [10] for many intriguing historical examples). Our daily communications provide more mundane protocols that may help to hide information from part of the participants.

Example 1 *(The voice of Kathleen Ferrier).* Consider a café in the 1950s, with three persons, Kate, Jane and Ann sitting across a table. Suppose Kate is gay and wants to know whether either of the other two is gay. She wants to convey the right information to the right person, without the other getting any idea of the information that is being communicated. She

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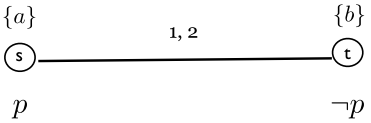
states, 'I am musical, I like Kathleen Ferrier's voice'. Jane, who is gay herself, immediately realizes that Kate is gay, whereas, for Ann, the statement just conveys a particular taste in music.[1]

Example 2 *(Valentine's day).* Coming back to the present day, consider a similar café scenario with Carl, Ben and Alice. Carl and Ben are childhood friends and know each other like the back of their hands. Carl says to Ben: 'On Valentine's day I went to the pub with Mike and Sara. It was a crazy night!' This immediately catches the attention of Alice, who is in love with Mike. She asks: 'What happened?' Carl winks to Ben and says: 'Nothing'. Knowing Carl very well, Ben immediately realizes that indeed nothing has happened, whereas Alice becomes unsure of that, as she saw the wink that Carl has given to Ben.

This paper presents a dynamic epistemic logic (DEL, [12,13]) that can suitably describe such scenarios. Knowing a protocol can mean 'knowing what to do according to the protocol' [1]. It can also correspond to 'understanding the underlying meaning of the actions induced by the protocol' [2]. Here, we follow the latter interpretation, which appears to capture the notion of a protocol in the types of situations we want to model. Kate's making a statement like 'I am musical, I like Kathleen Ferrier's voice' corresponds to the fact that 'Kate is gay'. In the second situation, 'Nothing' (even if accompanied by a wink) corresponds to the fact that 'Nothing has happened'.

Our work is inspired by two lines of research: the work relating dynamic epistemic logic (DEL) and epistemic temporal logic (ETL) [3,5,14] and the work on protocol changes [4,15]. In [14], Pacuit and Simon model protocols as tree compositions, basically equating protocols with plans. Hoshi et al. [3,5] propose the notion of 'state-dependent' DEL-protocols (sets of sequences of *event models* [13]) in order to handle protocols that are not common knowledge. Consider an epistemic scenario wherein the agents are not only uncertain about the factual state of the world but also about the protocol that can be executed given some factual state, depicted as the model:



In this model, s, t are possible worlds, p is a proposition, and a, b are expected actions. The uncertainty of the agents about the protocol is denoted by a state-dependent protocol assigning singleton action sets $\{a\}$ to s and $\{b\}$ to t. Note that we have omitted the reflexive arrows for agents 1 and 2 for the sake of compact representation, and we will follow this convention throughout this paper. A system wherein the protocol can be different in any state is clearly more complex than a system wherein the protocol is a background parameter, and thus can be assumed common knowledge to all agents. But in the example model above, we can still reclaim some form of common knowledge of the protocol, namely by describing it intuitively as follows: **if** p **then** a and **if** $\neg p$ **then** b. In order to discuss the knowledge of protocols formally, we need to first fix a protocol specification language, which will then enable us to represent such protocol models in a more informative way.

Given a protocol language, how do we obtain such epistemic models with protocol information from specifications of conditional protocols, and vice versa? Similar questions are addressed in [4,15], in which Wang presents a logical framework that incorporates protocol specifications in epistemic models and introduces the idea of matching observations to expectations. However, there, protocols are assumed to be common knowledge. We do not assume that here.

Our work is based on the logic developed in [4] but in the current article we use epistemic models with procedural information as in [3,5] to deal with uncertainties about protocols, an agent's knowledge of underlying protocols, and her current observations affecting factual uncertainty. In our framework, the protocols can be viewed as 'given by nature', so the framework does not cover interesting aspects such as how and by whom the protocols have been designed and how agents have come to agree to use them.

The ingredients of our work are:

1. epistemic models encoding state-dependent expected observations;
2. an update mechanism for eliminating impossible worlds according to the observation of agents and their expectations;
3. a formal language for specifying observations and protocols;
4. protocol models that represent agents' incomplete information about the 'real' protocols;
5. an update mechanism for incorporating protocol information (as protocol models) in epistemic (observation) models;
6. a notion of equivalence between protocol models;
7. a logic for reasoning about knowledge based on protocols;
8. fact-changing actions and factual change systems, in order to investigate how we modify our expectations in an evolving world.

[1] This example has been inspired by the interviews in [11], from which it appears that in 1950s Amsterdam, 'musical' was indeed a code term for 'gay', known almost exclusively by gay people. The additional mention of singer Kathleen Ferrier strengthened this 'gay' hint. Among gay women, Ferrier's low contralto voice, for example in her performance as Orfeo in Gluck's Orfeo ed Euridice, was widely popular.