Hintikka's World: scalable higher-order knowledge

Tristan Charrier[1*] , **Sébastien Gamblin**[2] , **Alexandre Niveau**[2,3] and **François Schwarzentruber**[4]
[1]First Affiliation
[2]Second Affiliation
[3]Third Affiliation
[4]Fourth Affiliation
{first, second}@example.com, third@other.example.com, fourth@example.com

Abstract

Hintikka's World is a tool that shows how artificial agents can reason about higher-order knowledge (agent a knows that agent b knows that...). In this demonstration paper, we present symbolic models that enables to implement in *Hintikka's World* large examples such as real card games.

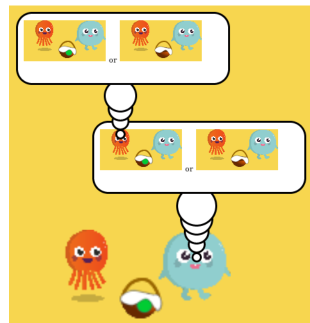
1 Introduction

The current trend is to construct programs that play games with imperfect information, for instance Hanabi [Bard *et al.*, 2019], but also video games such as Starcraft 2 [Hu *et al.*, 2018]. An important ingredient is to reason about higher-order knowledge (an agent knows that another agents knows that...). In these systems, epistemic logic and its dynamic extension, Dynamic epistemic logic ([Baltag *et al.*, 1998], [van Ditmarsch *et al.*, 2008]) may offer formal tools for providing explanations in such AI programs. needs to be understood is relevant in AI, especially in strategic reasoning [Aumann, 1999].

The only pedagogical tool we are aware of that explains such models is *Hintikka's world* and was presented at ECAI-IJCAI 2018 [Schwarzentruber, 2018]. *Hintikka's world* is a proof of concept of a graphical user interface that represent Kripke models by comic strips, as shown in Figure 1. It enables to explore mental states of agents. The tool is available at the following address: http://hintikkasworld.irisa.fr/.

Kripke models are graphs, represented explicitly in memory in the first version of the tool. Explicit models are useful to learn how dynamic epistemic logic works by means of toy examples: muddy children, Sally and Anne [Wimmer and Perner, 1983], etc. However, in real card games, such as Hanabi, there are an exponential number of possible configurations of cards. For instance Hanabi has 50 cards total and each player has 4 cards and the order of the cards is important. Therefore with 4 players, the initial Kripke model features $50 \times 49 \times 48 \times \cdots \times 38$ configurations, that is 2.2×10^{21}. Thus, it is impossible to represent explicitly the full graph in memory: the first version of Hintikka's world does not *scale*.

That is why, in this demonstration, we propose to represent Kripke models symbolically by using the approach in [Charrier and Schwarzentruber, 2017] and [Charrier and Schwarzentruber, 2018]. The implementation relies on Binary Decision Diagrams (BDDs) [] as it was done in the tool DEMO[1] [van Benthem *et al.*, 2015].



TODO ajouter le modèle de Kripke

Figure 1: Graphical user interface of *Hintikka's world*.

2 Symbolic models

Symbolic Kripke models aim at representing succinctly so-called pointed Kripke models. A pointed Kripke model is a graph whose nodes are *possible worlds*, edges are labeled by agents and an edge $w \rightarrow^a u$ means that agent a considers world u as possible in world w. Each world w is equipped with a valuation telling which atomic propositions is true in w. A special world is called the pointed world and represents the true situation, while the other possible worlds are worlds imagined by the agents. The tool shows that graph in the right-part of the screen (in the example of Figure 1, the Kripke model has two possible worlds).

A symbolic model consists in a description of the model in a more succinct language. Such representations already exist for other formalisms, such as boolean circuits for searching for Hamiltonian paths in graphs [Papadimitriou, 2003], or BDDs for temporal logics [Burch *et al.*, 1990].

In the demonstration we use the symbolic description of [Charrier and Schwarzentruber, 2018] for dynamic epistemic

*Contact Author

[1]The current implementation does not rely on DEMO since their work is not well-suited for a web application.

logic [2], and use the reduction to first-order logic of [Charrier *et al.*, 2017] to implement this approach with BDDs.

Take for instance any card game. The initial model is described by BDDs for the following boolean formulas: formula χ_W whose valuations are the possible configurations and formula χ_R to describe which configurations agents do not distinguish. The formula χ_W actually describes legal configurations according to the rules of the game, and χ_W reflect the fact that agents do not see the hand of other agents, so they may imagine as possible any possible dealing.

Dynamic epistemic logic also provides so-called *event models* for describing actions (public announcements, public actions, private announcements/actions, etc.). The reader may refer to the textbook on DEL [van Ditmarsch *et al.*, 2008] and to [Charrier and Schwarzentruber, 2017] for symbolic event models, that we do not detail here.

3 Demonstration Outline

In the demonstration we show a play of the game Hanabi. In this game, each agent has cards with a color and a number, but cannot see his own hand. In each turn, an agent can either give the information to some other agent about a number or a color, or play a card. The goal is to play the cards in increasing order for each color.

TODO expliquer la démo. Je me suis peut etre trompé sur le nombre de cartes ici et si on gère les jetons pour les infos il faut le mettre dans le paragraphe.

4 System Description

TODO Expliquer comment c'est FAIT

4.1 Class Architecture

Figure 2 shows the main part of the architecture of *Hintikka's world*. The interesting part is the fact that the graphical user interface (GUI) is independent from the current example that is running (muddy children, Sally and Anne, etc.). In particular, adding a new example only requires to add a new class that inherits from `World` and to implement the method for drawing the scene from data (valuations, numbers, etc.) that are members of the class.

4.2 Model Checking

The tool highly rely on model checking. Indeed, for instance, performing the public announcement of ϕ requires to compute the subset of worlds in which ϕ holds and to prune the current Kripke model. We chose to write the model checking procedure in Javascript. Since model checking is in PTIME – thus is an easy task – and is used intensively, it suitable to run run it on the client-side for performance reasons.

4.3 Satisfiability Problem

5 Future Work

TODO implémzenter d'autres exemples etc.

TODO d'autres façons de "scaler"

[2] Which is actually a rewriting of the description of [Charrier and Schwarzentruber, 2017]

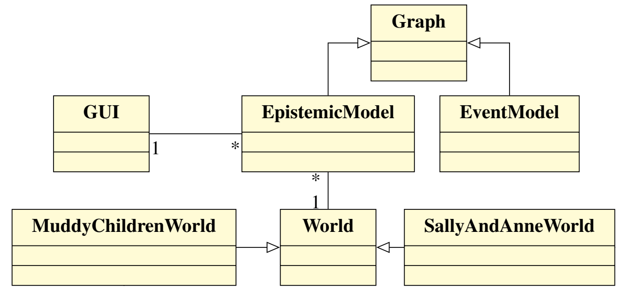


Figure 2: Architecture for the symbolic approach in *Hintikka's world*

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