A Tractable Hybrid DDN-POMDP approach to Affective Dialogue Modeling for Probabilistic Frame-based Dialogue Systems

Trung H. Bui Mannes Poel Anton Nijholt Job Zwiers

University of Twente, P.O.Box 217 7500AE Enschede

Abstract

Designing and developing affective dialogue systems have been receiving much interest from the dialogue research community [1]. Previous work was mainly focused on showing the *system*'s emotion to the user in order to achieve designer's goals such as helping students practice nursing tasks [7] or persuading users to change their dietary behavior [6]. A more challenging issue is to develop a robust dialogue manager that can infer the *user*'s affective state and adapt the system behavior accordingly. For example, in the automatic call routing domain, if the system detects that the user is irritated, the system should verify the information provided by the user or forward the call to a human operator [2].

Recent work from the literature [5, 12] has demonstrated that Partially Observable Markov Decision Processes (POMDPs) are suitable for use in designing this type of dialogue manager for three main reasons. First, the POMDP model allows for realistic modeling of the user's affective state, the user's intention, and other user's hidden state components by incorporating them into the state space. Second, the POMDP-based dialogue manager is able to cope well with *uncertainty* that can occur at many levels inside a dialogue system from the automatic speech recognition and natural language understanding to the dialogue management. Third, the POMDP environment can be used to create a *simulated* user which is useful for learning and evaluation of competing dialogue strategies [9].

However, solving the POMDP problem (i.e. finding a near-optimal policy) for realistic dialogue systems is computationally expensive [4]. Therefore, almost all developed POMDP-based dialogue management approaches (mainly for spoken dialogue systems) are limited to frame-based, and almost toy like, dialogue problems with the size of only a few slots (e.g., two slots in [10], three slots in [13], and four slots in [8]). Recent work [11] has tried to solve this problem by compressing the POMDP structure. However, the affective dialogue model requires a more complex POMDP structure than that of the spoken counterpart. Compressing the POMDP structure prevents us to incorporate a rich model of the user's affect into the state space and might loose dependencies between the user's emotion, goal, and other hidden state variables.

In this paper [3], we propose a novel approach to developing a tractable affective dialogue management model for probabilistic frame-based dialogue systems without compressing the POMDP structure. The model, based on POMDP and Dynamic Decision Network (DDN) techniques, is composed of two main parts: the slot level dialogue manager and the global dialogue manager. The first part is composed of a set of slots where each slot is first modeled as a POMDP and then approximated by a set of DDNs. The second part is handcrafted. The model has two new features: (1) being able to deal with a large number of slots and (2) being able to take into account some aspects of the user's affective state in deriving the adaptive dialogue strategies.

Our implemented prototype dialogue manager can handle hundreds of slots in real time (i.e., processing time is smaller than one second), where each individual slot might have hundreds of values. The approach is illustrated through a route navigation example in the crisis management domain. We conducted various experiments to evaluate our approach and to compare it with state-of-the-art approximate POMDP techniques and three handcrafted policies. The results showed that the DDN-POMDP policy outperforms the handcrafted policies when the user's action error is induced by stress as well as when the observation error of the user's action increases. Further, performance of the one-step look-ahead DDN-POMDP policy after tuning its internal reward is close to the approximate POMDP counterparts. The method is not only useful for building affective dialogue systems but also applicable for the development of robust dialogue managers for multimodal dialogue systems, in particular spoken dialogue systems.

References

[1] Elisabeth André, Laila Dybkjær, Wolfgang Minker, and Paul Heisterkamp, editors. *Affective Dialogue Systems, Tutorial and Research Workshop (ADS 2004), Kloster Irsee, Germany, June 14-16, 2004, Proceedings*, volume 3068 of *Lecture Notes in Computer Science*. Springer, 2004.

[2] Anton Batliner, K. Fischer, Richard Huber, Jörg Spilker, and Elmar Nöth. How to find trouble in communication. *Speech Communication*, 40(1-2):117–143, April 2003.

[3] Trung H. Bui, Mannes Poel, Anton Nijholt, and Job Zwiers. A tractable hybrid DDN-POMDP approach to affective dialogue modeling for probabilistic frame-based dialogue systems. *Natural Language Engineering*, 2008, to appear.

[4] Trung H. Bui, Boris van Schooten, and Dennis Hofs. Practical dialogue manager development using POMDPs. In S. Keizer, H.C. Bunt, and T. Paek, editors, *Proceedings of the 8th SIGdial Workshop on Discourse and Dialogue (SIGdial '07)*, pages 215–218, Antwerp, Belgium, 2007.

[5] Trung H. Bui, Job Zwiers, Mannes Poel, and Anton Nijholt. Toward affective dialogue modeling using partially observable Markov decision processes. In D. Reichardt, P. Levi, and J.-J.C. Meyer, editors, *Proceedings of Workshop Emotion and Computing, 29th Annual German Conference on Artificial Intelligence*, pages 47–50, Bremen, Germany, 2006.

[6] Fiorella de Rosis, Nicole Novielli, Valeria Carofiglio, Addolorata Cavalluzzi, and Berardina D. Carolis. User modeling and adaptation in health promotion dialogs with an animated character. *Journal of Biomedical Informatics*, 39(5):514–531, October 2006.

[7] Dirk Heylen, Anton Nijholt, and Rieks op den Akker. Affect in tutoring dialogues. *Applied Artificial Intelligence*, 19:287–311, 2005.

[8] Nicholas Roy, Joelle Pineau, and Sebastian Thrun. Spoken dialogue management using probabilistic reasoning. In *Proceedings of the 38th Annual Meeting of the Association for Computational Linguistics (ACL-00)*, pages 93 – 100, Hong Kong, China, 2000. ACL.

[9] J. Schatzmann, K. Weilhammer, M. Stuttle, and S. Young. A survey of statistical user simulation techniques for reinforcement-learning of dialogue management strategies. *Knowledge Engineering Review*, 21(2):97–126, 2006.

[10] Jason Williams and Steve Young. Scaling up POMDPs for dialogue management: the summary POMDP method. In *Proceedings of the IEEE workshop on Automatic Speech Recognition and Understanding (ASRU '05)*, pages 250–255, Cancún, Mexico, 2005.

[11] Jason D. Williams and Steve Young. Scaling POMDPs for dialog management with composite summary point-based value iteration (CSPBVI). In *Proceedings of the AAAI Workshop on Statistical and Empirical Approaches for Spoken Dialogue Systems*, pages 37–42, Boston, MA, USA, 2006. The AAAI Press.

[12] Jason D. Williams and Steve Young. Partially observable markov decision processes for spoken dialog systems. *Computer Speech and Language*, 21(2):393–422, 2007.

[13] Bo Zhang, Qingsheng Cai, Jianfeng Mao, and Baining Guo. Spoken dialog management as planning and acting under uncertainty. In *Proceedings of the 7th European Conference on Speech Communication and Technology (EUROSPEECH '01)*, pages 2169–2172, Aalborg, Denmark, 2001.