A MAS Approach to Fusion of Heterogeneous Information

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Abstract

Distributed Perception Networks (DPN) are a MAS approach to large scale fusion of heterogeneous and noisy information. DPN agents can establish meaningful information filtering channels between the relevant information sources and the decision makers. Through specification of high level concepts, DPN agent organizations generate distributed Bayesian Networks, which provide mappings between the observed symptoms and the hypotheses relevant to the decision making. In addition, DPNs support robust distributed inference as well as decentralized probabilistic resource allocation.

1 Introduction

Recent advances in technology resulted in large quantities of heterogeneous information, which can be obtained through sensory systems, databases, GSM networks, world wide web, etc. Such a large body of information can be very valuable in the context of complex controlling and decision making processes. Particularly interesting is the situation assessment, where hidden events of interest are inferred from large quantities of heterogeneous and noisy evidence. This, however, requires adequate world models which provide a mapping between the evidence and the hypotheses of interest. In addition, we assume that the information sources relevant to a particular estimation task are not known prior to the operation. In this context we can identify the following challenges:

- The relevant information sources must be discovered at runtime.
- Large quantities of heterogeneous symptoms often require complex world models.
- Adequate world models must capture relevant information sources. Since the constellations of information sources are not known in advance and they can change frequently, the world models cannot be generated prior to the operation. Consequently, we must assemble such models at runtime.
- We deal with large amounts of information, and consequently, a central model might not be appropriate due to the processing and communication bottlenecks.

In order to be able to cope with these challenges, we introduce Distributed Perception Networks (DPN), a MAS approach to the distributed situation assessment.

2 Distributed Perception Networks

DPNs are multi-agent systems that implement a logical layer on top of existing sensory, communication and processing/storage infrastructure. DPN agents wrap heterogeneous, spatially dispersed information sources and integrate them into complex inference systems. Each DPN is specialized for a specific fusion task, i.e. it estimates the probability distribution over a single random variable. A DPN is essentially an organization of agents which map large quantities of evidence to the hypotheses of interest through cooperation. A society of DPN agents can support several DPNs simultaneously, each corresponding to a particular fusion task. In addition, a single DPN agent can participate in several different DPNs simultaneoulsy.

At the lowest level different Sensor agents with a direct access to the information sources interpret raw data while at the higher levels Fusion agents use local world models for high-level information fusion. Such local world models are encoded through Bayesian Networks (BN) [2] and represent basic modeling building blocks. At runtime DPN agents organize autonomously and integrate local Bayesian Networks into complex causal models, which provide mapping between different symptoms and hypotheses about events, that cannot be observed directly. Each DPN agent estimates the probability distribution over a single random variable corresponding to its service concept. Such belief updating is based on inputs corresponding to the so called input concepts, which in turn are identical to service concepts of other

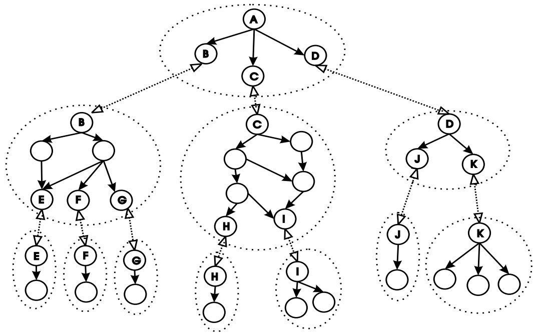

Figure 1. A DPN network. Dashed ellipses denote the agents participating in a particular DPN fusion service. Each of these agents contributes a local Bayesian Network, which supports a partial fusion service.

DPN agent types. The distribution over the service concept can either be supplied directly to the decision maker or it can be used as a soft evidence by other agents.

Bayesian Networks facilitate distribution and sharing of fusion processes through communities of agents. In this way we can often prevent processing and communication bottlenecks as well as single point of failure. In addition, through the DPN modularity the design and maintenance of fusion systems is simplified. Namely, complex models can be assembled out of smaller and simpler partial world models which can be obtained from different experts or machine learning processes.

2.1 DPN Self Configuration

Each DPN specialized for a particular fusion task requires a specific world model that maps the currently available evidence from the relevant information sources to some hypothesis. Since we deal with applications where the information sources are not known in advance, the DPN agents must assemble local probabilistic world models into a distributed BN at runtime. The top-down self configuration process is based on local domain knowledge and hierarchical service discovery. Configuration is initiated by a specification of a high level concept corresponding to some hypothesis. The configuration process is driven by the overlap in service and input concepts. Agents A and B can integrate their local models if the service concept of one agent intersects an input concept of the other agent. In other words, through the ontologies encoded in local BNs used by different fusion agents, we specify beforehand *what* types of agents can exchange information. But, we never know in advance *which* agent instances are actually going to participate in the distributed BN (see [4]). Thus, each distributed world model assembled by DPN agents can be viewed as a function of the available information sources, fusion agents and the hypothesis of interest.

A local BN in a DPN fusion agent can have an arbitrary topology. However, each agent supports only one service concept, which means that it can share with other agents only a single distribution over a single root variable. With this restriction we limit the topologies of assembled BNs and avoid loops between the local world models (see Figure 1). Despite this limitation we can model a significant class of domains.

The discovery of the relevant service concepts is based on the Yellow Pages, where all DPN agents in the community register their service concepts. Also, DPN sensor agents support integration of heterogeneous information sources, such as sensors, databases, etc. Information sources are wrapped by the DPN sensor agents, which provide the communication interface and register the service at the Yellow Pages. In this way, the information sources are made visible to the DPN agent community and can be integrated into arbitrary DPNs if relevant.

2.2 Distributed Information Fusion

DPN agents support retrospective inference (see [5]) based on distributed BNs. The DPN approach to exact distributed belief propagation is (i) independent of the order of evidence instantiations, (ii) does not require any centralized fusion control and (iii) it can cope with changing network structures at runtime. We achieve this with a combination of algorithms for local inference whose partial results are combined via an inter-agent messaging process [1]. This approach exploits the limited DPN structures resulting from the DPN self configuration process.

In order to obtain large quantities of information relevant to a particular fusion task, DPN agents support active querying of humans. DPN agents can generate relevant queries from the concepts encoded in their local BNs integrated into DPN structures. Concise queries can be replied with simple yes/no, which is used as evidence about different symptoms in DPN agents that generated the queries. The communication between the DPN agents and humans can be based on SMS messages, appropriate Web-interfaces or email.

2.3 Resource Allocation

Often information sources cannot be used by more than one DPN agent at a time. For example, several DPN agents can send different queries to a person, which can reply to only one query at a time. Therefore, we introduce a probabilistic approach to resource allocation, which exploits the Bayesian Network framework as well as the DPN fusion structure [3]. DPN sensor agents that wrap scarce information sources compute the entropy change that their information will cause at different hypothesis nodes. The DPN sensor agents supply the information to the DPN sub-system associated with the greatest entropy change (i.e. information impact). The entropy change is determined in a fully decentralized way through cooperation of all DPN agents in DPN fusion structures that provide mappings between the information source and the hypothesis nodes.

3 Example

We illustrate the basic DPN features with the help of a simple example. We consider DPN systems for estimating the presence of phenomena (e.g. toxic gases) causing different observable symptoms. We assume large numbers of noisy information sources, such as different types of simulated sensors and humans who can observe and interpret very heterogeneous symptoms. The information originating from the humans can be obtained from databases, web-pages or through interactive querying. In particular, some DPN agents specialized in the fusion of human information can query humans in the area of interest via concise SMS messages. In addition, several DPN agents wrap different simulated information sources, such as sensors, databases and web-pages.

By wrapping information sources and using active querying, the presented DPNs can discover huge numbers of relevant information sources quickly. In addition, the information filtering channels established on the fly support efficient distributed processing and the resource allocation mechanism determines the most relevant queries. Consequently, the decision maker is quickly supplied with the relevant information (i.e. the presence of the toxic gas), distilled from a huge body of noisy information.

References

[1] P. de Oude, B. Ottens, and G. Pavlin. Information fusion in distributed probabilistic networks. In *Artificial Intelligence and Applications*, pages 195–201, Innsbruck, Austria, 2005.

[2] F. V. Jensen. *Bayesian Networks and Decision Graphs*. Springer-Verlag, New York, 2001.

[3] J. Nunnink and G. Pavlin. A probabilistic approach to resource allocation in distributed fusion systems. In *proceedings of AAMAS, Utrecht, The Netherlands*, 2005.

[4] G. Pavlin, M. Maris, and J. Nunnink. An agent-based approach to distributed data and information fusion. In *IEEE/WIC/ACM Joint Conference on Intelligent Agent Technology*, pages 466–470, 2004.

[5] J. Pearl. *Fusion, propagation, and structuring in belief networks*, volume 29. Elsevier Science Publishing Company, 1986.