Reconfiguration of Large-Scale Surveillance Systems

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Abstract

In [2] we introduced a theoretical framework for modelling scalable *information-aggregation systems*. The framework is exposed on the background of a description of METIS, a system prototype aiming at supporting maritime safety and security by facilitating continuous monitoring of vessels in national coastal waters. Among the main problems of deployment of large-scale surveillance systems like METIS lies their *scalability* with respect to a potentially large number of monitored entities. One of the solutions to the problem is a decomposition of the system into a number of fragmentary configurations combined with a *continuous reconfiguration* according to the changing environment it operates in. The proposed continuous reconfiguration algorithm relies on standard results from *abstract argumentation* [1] and corresponds to computation of a grounded extension of the argumentation framework associated with the system.

METIS is a large-scale surveillance system operating in a mixed physical and software environment. It aims at detection of ships suspected of smuggling illegal contraband during their approach to the port under surveillance. To determine whether a vessel is suspect, the system accesses various information sources and subsequently processes the extracted information by a hierarchy of information-aggregators so as to finally identify vessels which require operator's attention. In the prototype scenario, the individual aggregators are represented by various information-fusion components operating over a shared data warehouse, but could include also external agents, such as human experts. The system comprises a number of cooperative agents serving as information sources and aggregators. Typically, these would be either situated physical agents, such as cameras, satellites or human patrols, or software components interfacing various public, or proprietary databases, web resources, etc.

Querying information sources and subsequent information-aggregation incurs non-negligible computational and external (financial) costs. For instance, the bandwidth of satellite communication links used on board of a ship where the system is deployed is limited, accessing external industrial databases costs money and utilisation of physical agents, such as aerial drones, imaging satellites, etc. incurs significant operational burden. Hence, using all available information sources and information-fusion components is not always feasible and in turn one of the problems central to development of such large-scale surveillance multi-agent systems is their *scalability*.

The problem of configuration and dynamic reconfiguration according to the current system's needs can be formulated as follows: *Which information sources and aggregators should be active over time so as to maximize the likelihood of early detection of malicious intents in the most cost-efficient manner?* More precisely, given an information-aggregation system, a query of interest the system aims at answering and an initial snapshot of the database it operates over, the *information-aggregation system configuration problem* $\mathfrak{C}$ is to find a set of agents, a *configuration*, such that 1) together these are able to derive the query of interest; 2) their intermediary conclusions are justified in that the input they are using is also computed by agents

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from the solution configuration, or are pure information sources; and finally 3) there is no doubt about the query solution in that there is no other larger configuration concluding a different answer to the query.

The problem of *continuous reconfiguration of information-aggregation systems* extends upon the configuration problem: given embedding of a system in a dynamically changing environment, upon any change of it, reflected in a modified state of the underlying database, we require the system to always reconfigure itself into an optimal solution. The changes of the environment, such as movements of vessels in the zone of interest, changes in data provided by the external information sources or physical sensor readings or even their possible failures over time, are captured by the execution of pure information-source agents. That is, information-aggregators without any input from the system's database, and non-empty output corresponding to the state of the external environment.

An information-aggregation system is modelled as a network of inter-dependent reasoning agents, each representing a mechanism for justification/refutation of a conclusion derived by the agent. Dung's theory of abstract argumentation [1] provides a natural model of computation of such systems, in that individual arguments represent system fragments encapsulating inter-related knowledge supporting a conclusion. We propose an approach to solving (re-)configuration problems rooted in *sceptical semantics* of argumentation.

Arguments of a configuration argumentation framework $CAF = \langle \mathcal{A}, \prec \rangle$ correspond to information-processing agents of the system ($\mathcal{A}$) and embody a set of interrelations among variables of the underlying database schema. The input variables of an argument (agent) provide the basis for inferring the conclusions of the argument. The attack relation $\prec$ corresponds to a conflict between two agents concluding different values for the same variable in their respective outputs. A *grounded extension* GE_{CAF} of an argumentation framework corresponds to a set of arguments which, starting from some initial set, cannot be further extended without producing a conflict. More formally, GE_{CAF} is the least fix-point of a function $F_{CAF} : 2^{\mathcal{A}} \rightarrow 2^{\mathcal{A}}$ defined as $F_{CAF}(C) = \{A \mid A \in \mathcal{A} \text{ is acceptable to } C\}$, where acceptability of an argument to another set of arguments loosely corresponds to non-attacking any argument from the set, and basing its conclusions solely on values already supported by the arguments from the set.

The core result of our paper is a proposition establishing the correspondence between solutions to configuration problems for stratified systems (those, agents of which can be decomposed into layers according to their input/output characteristics) and grounded extensions of their corresponding configuration argumentation frameworks. In particular, given a configuration problem $\mathfrak{C}$ with a query ϕ and a configuration argumentation framework $CAF_{\mathfrak{C}}$ corresponding to $\mathfrak{C}$, we prove that in the case the ϕ belongs to the output variables of the configuration characterised by the grounded extension $GE_{\mathfrak{C}}$ of the argumentation framework $CAF_{\mathfrak{C}}$, $GE_{\mathfrak{C}}$ is the optimal solution to $\mathfrak{C}$.

The main technical contribution of our paper [2], is an algorithm for continuous reconfiguration of information-aggregation systems building upon the established relationship between the argumentation theory and the configuration problem. In particular, the algorithm combines features of a naive approach to computation of grounded extensions, together with several improvements geared towards reduction of execution costs. The core idea of a naive configuration algorithm utilising the above proposition is to iteratively proceed in three steps. In each i-th iteration it should 1) execute the agents from layer $\mathfrak{A}_i$ of the most compact stratification of the system, 2) select the non-controversial ones, and finally 3) add them to the candidate solution. Additionally, the algorithm operates only on agents relevant to the derivation of the query of interest, checks for safe derivation of the query so that it does not execute irrelevant information-aggregation agents after it is not necessary any more, and finally checks for early termination in the case the query is not computable any more due to derivation of a non-reparable conflict in its derivation tree.

References

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