Self-Organization of Sensors for Answering Information Needs*

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Abstract. In our modern society, more and more data is becoming available through technological advances like sensor technology, social media and smartphones. This data can concern a wide variety of aspects of our society, for example environment data like air quality, wind direction, temperature and rainfall, or data about cities like traffic density and parking availability. The scientific challenge that we aim to address in the SHINE (Sensing Heterogeneous Information Network Environment) project aims at using self-organization techniques for gathering, processing and interpreting this data for answering information needs.

Keywords: sensing, self-organization, heterogeneous resources

1 Introduction

In our modern society, more and more data is becoming available through technological advances like sensor technology, social media and smartphones. This data can concern a wide variety of aspects of our society, for example environment data like air quality, wind direction, temperature and rainfall, or data about cities like traffic density and parking availability. The scientific challenge that we aim to address in the SHINE (Sensing Heterogeneous Information Network Environment) project aims at gathering, processing and interpreting this data for answering information needs. More specifically, we address the following research question: *How can heterogeneous resources (people, mobile sensors, fixed sensors, social media, information systems, etc.) self-organize for answering information needs?* In this abstract we describe the aims and approach of SHINE, which will start in the first quarter of 2012.

If a system is able to self-organize, this means that structures and patterns emerge without central control. Many systems exhibit characteristics of self-organization, like a flock of birds, Wikipedia, traffic streams and self-organizing teams in human organizations. An important advantage of self-organization is flexibility. Structures and networks can be formed dynamically according to what is needed and available at a particular moment. In this project we will develop

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techniques that support the formation of such structures and networks among heterogeneous information resources, aimed at answering information needs.

Self-organization should be *robust and dynamic*. That is, the techniques for self-organization should be able to handle failures, for example sensors that get disconnected or deliver faulty information, and it should be able to respond in a timely and flexible manner to continuously changing information needs. Moreover, it needs to take place *across multiple levels* ranging from the lowest in which resource coordination takes place to the highest organization coordination level in which the information need is interpreted and an answer is presented. Finally, self-organization is aimed at organizing *heterogeneous resources*. This gives rise to challenges concerning aggregation and interpretation of information in a reliable manner.

2 Approach

We address the research challenge of SHINE by focusing on six main themes. These range from challenges concerning *data collection*, in particular in the areas of sensor technology and information retrieval, to those in *sensor control and reconfiguration* as well as *interpretation and visualisation*. In the following sections we describe each of these six themes.

2.1 Information Processing for Sensor Swarms

This research will tackle the processing challenges related to sensor swarms operated to extract useful information from the environment. A sensor swarm is a collection of mobile or moving sensors that together aim at collecting a particular kind of data. The processing issues we aim to study are two-fold: localization [7] and data gathering, with the ultimate aim to form 2D/3D images at a desired resolution using a mobile 2D/3D sensor configuration, possibly augmented with a fixed sensor network. We aim for adaptive resolution, where the swarm can autonomously decide to gather more data in certain areas of interest (e.g., where a large transient occurs), i.e. sample more dense in space and time for locations where higher resolution is needed.

2.2 Integration of Social Data

This research will focus on the question of self-organization in information retrieval (IR). Users often express their information needs in queries and answers come in the form of a ranked list of results [2]. Complete self-organization without a radical decrease in quality or performance is still beyond the state-of-the-art. In order to remain scalable without reying on central servers it is natural that each participant in the network could never manage more than a partial view of the whole. An unsolved research question is how to create robust partial views, maintain them over time, tolerate device failure and exclude malicious actors. We will develop what we call 'semantic overlays' which organise the cloud

of information based on similarity and relatedness. The semantic overlay will be organised according to multiple levels, from low-level to high-level semantic properties. This view introduces an optimization problem where information organisation involves a notion of predicted relevancy: the global semantic overlay should be partitioned in local views such that it best fits each participants' local needs. Ideally, each partial view of the complete cloud would define a local copy of the relevant information for that specific device (implicitly defined by the information requests it issues).

2.3 Adaptive Coordination and Collection for Mobility

This research addresses the design of self-organizing algorithms [5] for distributed information dissemination, data collection, (sensor) coordination and (sensor) configuration in a mobile network involving sensors, mobile phones and end-users. The challenge in this work package is that the configuration of such a network (and, in general, of large-scale distributed systems) changes continuously for many different reasons, the most important being that the availability of individual systems and their connections cannot be guaranteed.

2.4 Resource Negotiation

A network of autonomous systems can pursue several goals at once (possibly even combining some of the results). These goals are based upon requests by the resource owners. We assume that there are more requests than what actually can be achieved. In this work package we study how automated negotiation [1] can be used to best select requests for pursuit, acceptable to the resource owners.

2.5 Organization Formation

As information needs arise, new transient organizations should be formed across existing organisations [3] with the goal of answering the respective information needs. This requires that participating actors (sensors, people, or autonomous agents) coordinate their actions and cooperate towards the goal. At the same time, participants belong to existing organisations, have their own requirements and goals, and are bound by specific (institutional) constraints. We aim to develop modelling techniques for describing such transient organizations, together with techniques for creating them on-the-fly. The main challenge is to determine the rules and structure of the new organization while acknowledging and complying to the norms and expectations of the existing organisations to whom participants belong.

2.6 Interpretation and visualization of heterogeneous environmental sensor network data

This research will focus on new analysis and visualization methods that are required to understand and interpret environmental data and represent it to

the end user [6]. It includes information analysis techniques, visual representation of model output and observational data. The framework will be able to represent heterogeneous data streams dynamically: fixed sensors generating time-dependent measurements of physical environmental parameters, user-contributed data streams from for example social media, including natural language text, images and video and so forth. In addition, these measurements will be used in support of environmental models and near-real time simulations for making predictions on the underlying physical phenomena, e.g., extreme urban rainfall.

3 Application for Smart Cities

An important application area of the techniques that will be developed in SHINE, is *smart cities*. Cities are increasingly expected to deliver solutions to citizens that are not only economically sound but environmentally and socially responsible [4]. At the same time, developments in sensor technology and intelligent control and information processing have the potential to create solutions that provide the "right" information in real-time to citizens upon demand, allowing them to act responsibly with respect to their environment. Such techniques will combine large amounts of data from a wide variety of sensors with community-based sensing in which citizens themselves participate in making information about their living environment available, e.g., through social media. Such Smart Cities will be better equipped to address the challenges of the future, ultimately providing a better quality of life for their citizens.

The case study that we will focus on in this project relates to two important future trends: 1) climate change will lead to more extreme rainfall, and 2) the world population movement towards cities, where already its majority lives since 2008 (according to UN). The combination of these two trends poses huge challenges to mankind, ranging from enhancing our understanding of the climate system and its impacts at different scales, to the development of new technologies to safeguard society and flexible governance systems to act and react optimally.

This program will therefore focus on urban rainfall, related pluvial flooding and the community engagement. Already, cities are prone to flooding due to rainfall, and it is very likely that this will increase due to climate change. Without proper precautions such pluvial flooding will reinforce the strain on urban societies and lead to huge financial damage, while also an increase of fatalities may not be discarded.

We aim to involve the community in coping with the consequences of urban rainfall and floods. This is important for the following reason. The data upon which decisions are based should be timely, cover the whole urban area, and be of good/acceptable quality. While operational networks are of good quality, they often lack the flexibility to 'zoom in' on specific events and the areas where the "things happen". This can be overcome with mobile sensors and community involvement. In order to incentivize community involvement, people should see

that their efforts are used and rewarded: it requires a sense-of-purpose and sense of the problems' ownership.

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