Goal Oriented Sensing in Pervasive Computing

Dipl.-Ing. Gerold Hölzl, BSc
Institute for Pervasive Computing
Johannes Kepler University Linz
hoelzl@pervasive.jku.at
Univ.-Prof. Dr. Alois Ferscha, Prof. Anind K. Dey

PROBLEM STATEMENT AND RESEARCH QUESTION

Today's dominating design principles to build context aware systems are based on bottom-up philosophies. The design process begins with selecting the sensors that deliver the necessary data and the associated in-line processing steps. These processing steps, encapsulated in the so called Activity Recognition Chain, allow to interpret the delivered raw sensor data towards semantic meaningful labels (e.g., Walk, Stand, Sit, etc.) using machine learning and reasoning techniques. The major drawback and the Achilles' Heel of systems based on this design metaphor is their static and predefined nature. Systems of that kind are not able to adapt to changes in the sensing ecosystem as sensors may fail, or to integrate newly, unforeseen available ones. Complete system failure can be caused by just the failure of one single sensor. The march goes on towards highly miniaturised sensor platforms that are more and more integrated into various gadgets of daily living. Up until today, these platforms were mostly used in laboratory settings, but recent developments start reaching the global consumer market. Manifested in all forms of *Smart*-X-Devices like smart-watches, smart-glasses, smart-shoes, and of course smart-phones, they will be an essential element for a globe spanning, always on, sensor network. The complexity of this globe spanning distributed, cyper-physical system will reach the limits of today's dominating, bottom-up design principles for pervasive Activity- and Context recognition systems. New methods have to be developed to overcome this complexity crises.

The focus of this thesis is to rethink the traditional bottom-up approaches towards an autonomous, goal oriented and dynamic top-down methodology. This will provide a solution to overcome the limitations of nowadays mostly predefined and static Activity- and Context recognition systems towards their dynamic configuration during runtime.

The main *Research Challenges* of the thesis are divided into four groups:

- Goal Orientedness
- Activity and Context Modelling
- Recognition Goal
- Combining Sources of Information

METHODOLOGY

Being inspired by Weiser's Statement *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"* [7], in combination with autonomic [4] and context computing [1] the research methodologies focus on how *Sensing Goals* can be formulated on an abstract, semantic level in the research area of Activity- and Context Recognition. Goals can be as simple as to detect the modes of Locomotion (i.e., Walk, Sit, Stand, Lie), but can reach an an arbitrarily complex level as shown in [3]. The goal itself is a high level directive that defines and specifies in an abstract way, what a system should do and how it should behave. At each point in time, there can potentially be more than one possible way or strategy to achieve the given goal. Using a goal oriented methodology to direct the configuration of an Activity and Context recognition system is a novel approach, as the sensing ecosystem needs not to be defined at design time of the system. The configuration of the whole system is achieved and directed by using a high level, abstracted goal during runtime. Being aware of the available sensing ecosystem, a goal based sensing system can react on changes in the ecosystem (e.g., nodes appear, disappear, or are malfunctioning) and adapt accordingly to the newly evolved ecosystem and the specified goal. If one strategy to fulfill the goal fails, the system can adapt to a better suited one.

Beside the pure adaptation process regarding changes in the sensing ecosystem, the goal itself can be changed or modified during runtime of the system. This results in a completely autonomous reconfiguration of the system and its utilised components from the sensing ecosystem (in the best case without the need to deploy new, goal specific sensing components thus utilising the already deployed sensing ecosystem).

The envisioned framework has to process and interpret the formulated sensing goal in an autonomous manner. It must be able to understand and handle Activity and Context relations, thus being able to interpret the stated goal and to break it down to the best fitting sensors in the ecosystem of the user. The relations of Activities and Contexts are modelled in an Ontology, a *Network of Relations* that allows to reason [3] about the needed sensors to fulfil the stated sensing goal. Methods have been designed that allow to match and quantify sensor capabilities towards its usefulness for the formulated sensing or recognition goal. The semantic matchmaking approach assures, that at each point in time, the system is able to autonomously identify, select, and instantiate the best set of available sensors according to the stated sensing goal.

After the goal processing was performed, and the best available set of sensor has been identified, the delivered sensor data has to be interpreted and translated to the corresponding semantic classes (e.g., Walk, Sit, Stand, etc.). To achieve this, the framework can dynamically instantiate the needed Machine Learning techniques for each sensor [5], and can dynamically create higher level recognition models (i.e., Hidden Markov Models and Evidential Networks) [2] in utilising the semantic relations stored in the *Network of Relations* Ontology.

To proof and evaluate the feasibility of the approaches and the developed methodologies, a large scale dataset for multi-sensor Activity- and Context Recognition was collected [6]. Utilising the dataset, reproducible results can be gathered and the recognition accuracy of the configured sensor ensembles can be determined.

RESULTS

The developed methodologies of (i) formulating a sensing goal in form of *TexTivity-Predicates* [3], (ii) semantic based goal processing [3], (iii) instantiating of goal related machine learning techniques [2] , and (iv) the dynamic runtime selection, instantiation, and combination of the available sensing ecosystem are implemented in a realtime system in form of the OPPORTUNITY-Framework [5]. The results impressively highlight, that a goal oriented, autonomous, and dynamic sensor selection approach is a suitable solution to overcome the limitations of todays dominant static and predefined recognition architectures. As the goal is decoupled from the subjacent sensing infrastructure, the sensing ecosystem can change as long as sensors are available that match the given goal. This matching is not limited to a *1:1* match of the goal to a sensor. The designed Activity- and Context relation Ontology can be used to substitute TexTivity-Predicats by semantically close Activity- or Context terms if no sensors are available that match directly. This is especially useful if no sensors can be found in the ecosystem of the user that are explicitly designed to detect the stated recognition goal. Using the relations of Activities and Contexts, we can reason semantically closed ones related to the stated recognition goal, and use sensors that can detect these semantically linked Activities and Contexts instead. This allows the dynamic configuration of sensing ensembles and exploits the full flexibility of the goal oriented sensing approach, as the sensing goal can be processed, reasoned, and matching methodologies can be applied at different levels to substitute activities out of related ones.

CONCLUSION AND NEXT STEPS

Rethinking the dominant bottom-up design approach will break new ground and force scientists and engineers to overcome the static design principles of todays Activity- and Context recognition systems. These days, systems are still predefined bottom up at design time of the system and then kept static throughout their lifetime. Although this thesis is only an impulse, a starting point for future large scale sensing systems, it defines basic methodologies to overcome the complexity crises of billions of sensors that deliver an immense and overwhelming flood of data (expected 40 zettabytes by 2020). I see goal oriented approaches as the future of pervasive sensing systems, replacing static bottom-up architectures, as the amount of available devices that can be seen and used as multi-sensor platforms (e.g., smart-phones or smart-watches) will increase dramatically in the future. Sensing on a large scale with millions of sensing devices will need methodologies to select exactly the needed sensing components out of the billions of available ones in the sensing ecosystem, and to combine them in different ways. This will unleash the full potential of the globe spanning sensor networks as we see it today in its initial steps.

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