Services for Context Prediction and Proactive Adaptation in Ad-Hoc Environments

Arkady Zaslavsky
Department of Computer Science & Electrical Engineering,
Luleå University of Technology, Sweden, arkady.zaslavsky@ltu.se

Context-awareness has evolved from a research challenge in pervasive computing to a solid mainstream research activity that enables run-time knowledge of the application environment. The complexity of dealing with context- and situation-awareness increases manifold, when the application environment is partially or fully based on an ad-hoc wireless communications and networking topology. Ad hoc environments have additional complexity compared to traditional infrastructure-based networked environment be it wired or wireless. This complexity is primarily due to more uncertainty, faster changes, greater needs for abundant computational resources, greater needs for smart, robust and flexible software.

In recent years much of European (FP6 and FP7) and worldwide research effort have been directed towards and invested into study and design of context-aware systems. Examples of such efforts include: **Context Builder** (Context-Aware Computing Group, MIT) - a system designed to allow context aware systems to be built easily and rapidly without requiring any user programming; **ICAA** (HCI Institute, CMU) - Intelligibility of Context-Aware Applications -aims at improving the usability of context-aware applications and designing interaction techniques and programming tools that will help application designers make their systems intelligent; **Nexus** (U Stuttgart) – managing context in a global-scale architecture. Context quality is addressed as well as history, current context, and context prognosis. Adaptation in pervasive computing is addressed by a number of European projects (e.g. MADAM, MUSIC in FP6, ALLOW, FRONTS, REFLECT, SOCIALNETS in FP7). Projects financed under FP7 are bundled in the **Pervasive Adaptation Initiative (PerAda).** While these projects address different aspects of adaptation, including network adaptation and adaptation of workflows, they concentrate mostly on reactive adaptation and offer very limited support for proactive adaptation. Turning to research literature, the paper by Cook and Das (2005) gives a thorough overview of context prediction with focus on smart home environments and location prediction. Pichler et. al (2004) provide a context prediction overview with focus on artificial intelligence-based techniques and discuss not only the examples, but further possibilities. Ziebart et. al. (2008) present context prediction overview with the focus on user behaviour modelling, while Hong et. al. (2009) concentrate on inferring user preferences and utilizing the context history. Cook et. al. (2009) survey the area with the focus on ambient intelligence systems. A comprehensive review of general approaches to context prediction is done by Mayrhofer (2004). Some of the use case scenarios can be summarised below (Nurmi et. al., 2005).

- **Reconfiguration**. Some configuration-related tasks take a while to complete. Those tasks include installation of updates, loading and unloading libraries, starting new applications, handling infrastructure changes related to node mobility, searching in large databases. If the system can predict requests for those tasks in advance, they can be performed beforehand and avoid causing unnecessary delays.
- **Device power management**. Devices that are not currently in use and will not be used in near future can be shut down or switched to a sleep mode. Another example describes a situation whereby if the user attempts to send large multimedia message MMS while being in a region with bad radio reception, the system can predict that the user is going to enter better reception area soon, avoid repeated retransmissions and delay the sending of MMS (and therefore save the power).
- **Early warning of possible problems**. Context prediction can determine whether the system is about to enter a problematic state and act to prevent it or issue a warning. For example, a pervasive system can predict that it is going to run out of memory or computational resources soon and act proactively to counter that problem, eg, discover resources to balance the load or offload the data from the storage. Or,

for example, a pervasive system can predict that the user is running into a traffic jam and find the way to avoid it. Different cases of accident prevention also fall under that category.

- **Planning aid**. If the user's needs can be predicted reliably enough, the system can meet them proactively. For example, in smart home systems air conditioner can be started in advance to reach a certain temperature when the user returns from work. In a smart office, the door can be opened right before the person enters.
- **Inference of another entity's future context**. User can actually be influenced by future context of another user. For example, user may have the confidential information on the screen. Therefore, when someone passes by, the screen could be temporarily blacked out. Prediction of other people's activities enables the system to act proactively and within acceptable time constraints.
- **Early coordination of users**. If the needs of several users in a group can be accurately predicted, the system can act to meet the interests of the group as a whole.

Context prediction methods can be classified as:

- **Sequence prediction approach**. This approach is based on sequence prediction task from theoretical computer science and can be applied if the context can be decomposed into event flows.
- **Markov chains approach**. Context prediction techniques based on Markov chains are quite popular. Markov chains provide easily understandable view on the system and can be applied if the context can be decomposed into a finite set of non-overlapping states.
- **Bayesian network approach**. Bayesian networks can be viewed as generalization of Markov models. They provide more flexibility, but require more training data in turn to perform well.
- **Neural networks approach**. Neural networks are biologically-inspired formal models that imitate the activity of interconnected sets of neurons. Neural networks are quite popular in machine learning.
- **Branch prediction approach**. Branch prediction based approaches initially come from the task of predicting the instruction flow in a microprocessor after branching commands. Some context prediction systems use similar algorithms.
- **Trajectory prolongation approach**. Some context prediction approaches treated the vector of context data as a point in multidimensional space (Padovitz et al, 2008). Then context predictor approximated or interpolated those points with some function, and that function was extrapolated to predict future values.
- **Expert systems approach**. Expert systems and rule-based engines have been used in some context prediction related projects. The goal of the approach is to construct the rules for prediction. It provides very clear view on the system.

In our research efforts we are embarking on developing context prediction and proactive adaptation middleware, that is, offering context prediction and acting on predicted context as a set of services. We aim at developing middleware services, which *discover, predict, validate and supply relevant* context to applications and/or entities requesting it. Moreover, the proposed middleware will offer *cost-efficient adaptation strategy and optimization services* at run-time through adaptation services, environment monitoring and evolutionary learning. This will enable applications to focus on their functionality, greatly reducing application development cost and time. The concept of *Act-Ahead-Adaptation* will enable applications to proactively adapt both themselves and their environment to future, predicted context by scheduling future adaptation activities before they actually occur. This allows context aware applications that react to context changes much faster and more intuitively than existing systems (Boytsov et al, 2009). The core functionality of the proposal is depicted in Fig.1. **(a)** First, we discover and analyze current context, predict future context, and compute various metrics related to it. **(b)** After that we proactively adapt the system's behavior, structure and running parameters. **(c)** Then we use predicted context to enable various features of pervasive computing systems, **(d)** We selected two application domains to demonstrate the effectiveness of our middleware services to develop future context aware applications: the healthcare/ageing gracefully domain and social networks supported by telecommunications.

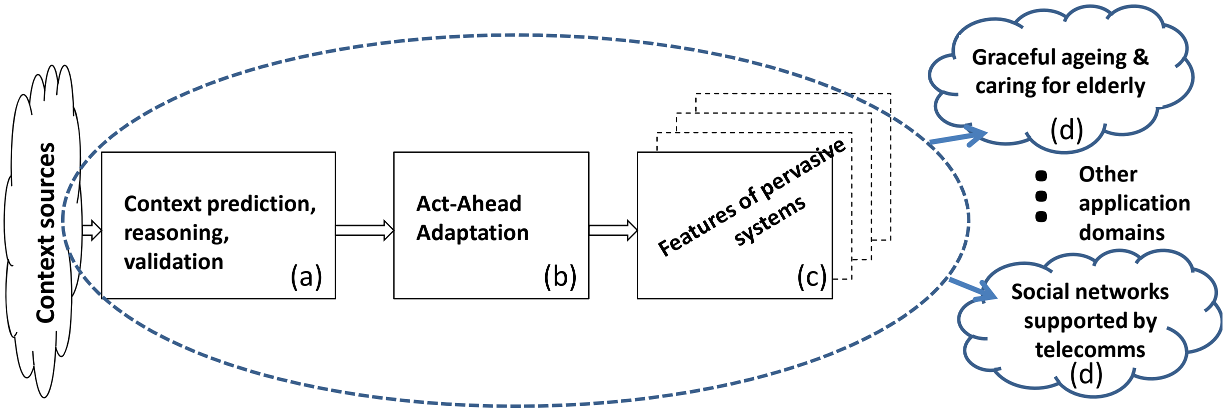

Figure 1. Core functionality of the proposed middleware

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