# Context-Aware Systems for Complex Data Analysis

Adam Fouse(✉), Stacy Pfautz, and Gabriel Ganberg

Aptima, Inc., Woburn, MA, USA
{afouse, spfautz, ganberg}@aptima.com

**Abstract.** Increasingly there is a need to analyze a large quantity of diverse, multidimensional data in a timely, efficient manner. A computational awareness of context can improve the speed and accuracy of complex data analysis, and promote more effective human-machine collaboration. We describe ongoing work to develop a framework that monitors human-machine interactions, analyzes context, and augments the system (such as prioritizing information, providing recommendations, adapting an interface, adjusting the level of automation, proactively fetching data, managing notifications, sharing context with others, personalizing the system, etc.). We believe that we can facilitate complex data analysis by adapting systems to meet analysts needs based upon the varying demands of the tasks, priorities, resources, time, user state, and environment.

**Keywords:** Context-aware systems · Recommender systems · Complex data analysis · Interactive visualization

## 1 Introduction

The rapid increase in ubiquitous computing devices and the Internet of Things has created interest in computational awareness of context [1, 2]. In these settings, context is often primarily concerned with the social and environment setting in which actions are taking place. We apply similar concepts to support people performing data analysis in complex environments, such as geospatial awareness for disaster response, intelligence analysis, and healthcare. In these settings, useful information about context includes not only the social and environmental setting, but also the collection and characterization of relevant data, the history of interaction, and explicit or implicit tasking given to analysts. To support users working in such environments, we have developed a framework to monitor and analyze context in real-time, and applied this framework to improve interaction with analysis support systems.

Traditional data analysis and decision-support tools lack an understanding of context, such as the semantics of the information, how it relates to tasks, goals, and objectives, and even the workflow or cognitive strengths and limitations of the human analyst. The goal of incorporating these types of contextual information to guide interaction is to intelligently adapt or augment a system or application to best suit a user's current situation and needs.


C. Stephanidis (Ed.): HCII 2015 Posters, Part II, CCIS 529, pp. 503–507, 2015.
DOI: 10.1007/978-3-319-21383-5_84

## 2 Defining and Analyzing Context

Our work with developing context-aware systems for data analysis has been informed by several years of work across a variety of fields, including geospatial analysis, medical data analysis, and open-source intelligence analysis. Based on interviews with expert analysts in each of these fields, we have developed a working definition of context as it can be applied to the design of systems.

We define context as explicit and implicit situational information about entities, the environment, and their interactions which may impact interpretation or decisions [4]. In our experience, an effective context-aware application has three major functions, as illustrated in Fig. 1: First, monitor the context explicitly present within the system's environment and infer implicit context such as user state; Second, analyze and reason about goals and intent (including latent knowledge) within the contextual situation as a whole; Third, augment the environment or situation based on its understanding of the situation.

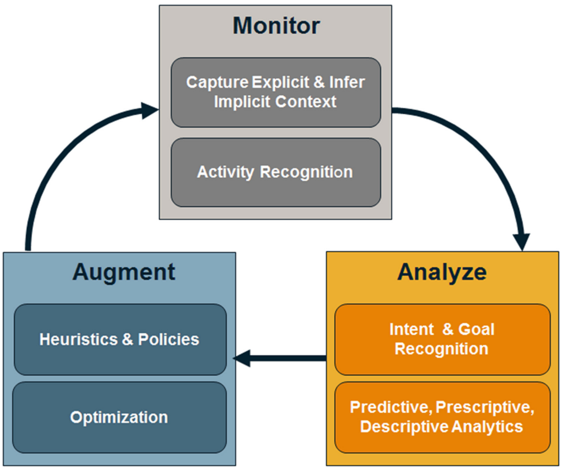


**Fig. 1.** Model for contextual awareness in data analysis systems [4]

Context data comes from a variety of sources, including system data, mobile devices, traditional computer activity tracking (such as keystroke or mouse clicks), instrumented user interfaces, neurophysiological sensors, or from optical and depth cameras. Analysis of context data is domain-dependent, but typically combines low-level activity recognition with higher level predictive analytics to hypothesize goals and intent. Details of this contextual analysis have been previously discussed [4]. Here, we focus on discussion of ways that we can augment the system by making use of the results of context analysis– for example, by proactively taking actions, adapting a user interface, managing notifications and recommendations, or personalizing the tool.

# 3 Applying Context to Interaction with Adaptive Systems

The primary benefit of recording and analyzing contextual information is to augment, adapt, or configure analysis systems to better support users. These online changes to system characteristics have the potential to make analysis faster and better by more directly supporting an analyst's current needs. However, applying these changes also has the potential to frustrate and confuse analysts, so care needs to be taken to design such changes in ways that align with work patterns and expectations.

Our efforts have focused on three ways that context can be applied to improve interaction with complex data: recommendations, adjustable automation, and personalization. In the following sections, we discuss these techniques as used in the general case of knowledge workers performing analysis of text-based documents, a description that can apply to a range of specific roles, from scientific researchers to intelligence analysts. While these roles may differ in their details, they share some common characteristics. Analysts across these domains are faced with collecting documents from a variety of sources, organizing these documents, extracting relevant information from those documents, and forming conclusions based on that information. We use document to refer generally to a range of text-based information, including blog posts, news articles, and scholarly publications.

## 3.1 Recommendation

Contextual information can be highly valuable for identifying information that could potentially be useful for an analyst's task at hand. Traditional keyword-based search techniques are limited by the analyst's skill in choosing the correct set of search terms, and potentially iterating through multiple sets of search results by using variations of the terms. When presented with long lists of search results, users may miss information that shows up beyond the first several results. Developing a model of the context of an analyst's work can help to find relevant information more quickly, and discover information that may be missed.

A key enabling technology for forming recommendations is modeling of information at a semantic level. We make use of third-party semantic entity extraction tools to process documents, and build a *semantic knowledge graph* that represents the documents and information in the system. This knowledge graph creates links between documents based on common reference to entities. We then make use of a range of algorithms, such graph analytics techniques used for collaborative filtering, to extrapolate from a current context to identify data accessible to the system that may be relevant to the analyst's current activity. For example, this may include documents that are related to those an analyst has already read, rated, or annotated.

While identifying related documents can help with finding more relevant information, pro-active recommendations require additional context information. In combination with identification of related documents, we also make use of models of analysis process to identify where additional reading and analysis would offer the most benefit. For example, if an analyst has created a collection of documents about a topic that are all from a single type of source, the system may suggest documents that are related, but from sources with different characteristics. Other recommendations could be to include information that will lead the analysts down new paths and broaden their perspectives, or information that is similar to information that has been rated highly or marked as relevant.

### 3.2 Adjustable Automation

Several analysis tasks are too difficult for either a human or automation to complete successfully alone with current techniques. Even when tasks can be independently completed, cooperation is likely to improve performance when the strengths of current automation are complementary to those of human analysts. A common goal of adjustable automation is to minimize training time and reliance on the adaptability of humans, and to design systems that are manageable by a wide variety of users in varying conditions. Automation can also assist human teammates to facilitate coordination and collaboration activities. There are several existing scales [3] that describe levels of automation, and in general they range from fully automated, to fully manual, to systems that require users to confirm or reject decisions the automation makes.

Context can be used here to automatically adjust automation levels depending on state, user preferences, and other constraints in the environment. Context can also be used along with resource allocation and constraint optimization algorithms when formulating and solving the problem of optimizing what information or tasks should be assigned at any given time, creating an adjustable automation policy. For example, documents can have a variety of tags and ratings, such as topic themes, source credibility, and topic relevance. Contextual information can be used to infer these values based on the knowledge gap, but whether the system should infer values or let an analyst manually determine the values is determined by the context of the analysts' activities. These applications of context also intersect with recommendations, allowing the system to better understand *when* and *how* recommendations should be presented.

### 3.3 Personalization

A critical challenge for designers of analysis support systems is designing tools that are flexible enough to support a wide variety of analysis tasks but don't overwhelm analysts with interface complexity. One area where this challenge is particularly relevant is the creation and configuration of visualizations. For complex data analysis, powerful visualizations are needed to navigate the data and form initial hypotheses. A variety of views may be needed to understand the development of information, including temporal visualizations for understanding events, geospatial visualizations for understanding spatial relationships, and node-link visualizations for understanding semantic relationships.

In the absence of context, creating and manipulating these visualizations can be a complex task in itself. By leveraging context, interaction with complex visualizations can be customized to the current context so that they can be simplified but remain powerful enough to improve the analyst's ability to do his or her job. For example, given the amount of information that is available, visualizations can quickly go from showing too little information to be useful to showing too much information and causing cognitive overload. Context information can be used to pre-select relevant data or automatically adjust filters so that a manageable amount of information is shown.

## 4 Discussion and Future Work

We have presented our ongoing work to incorporate context into systems supporting analysis of complex data. We believe this approach has great potential to create analysis systems that are tightly coupled to the needs of analysts and enable faster and better quality analyses.

Our primary goal for future work in this area is validation of the described approach. The goal is to improve the speed and/or quality of analysis, and application of context-aware system design has potential to achieve that goal, but as of yet we have no empirical evidence that this approach provides the expected benefits. Several evaluation efforts in multiple domains are at various stages of planning and execution.

In addition, while we have described our current framework for creating context-aware applications for analysis of complex data, we have also identified several paths for future work in this area. Many of these are related to the question of how to best adapt an interface based on an analysis of context. For example, we discussed possible ways for the system to suggest changes to context, some of which were implicit and some of which were explicit. An area for further research is to determine when different approaches should be used.

## References

1. Abowd, G.D., Dey, A.K.: Towards a better understanding of context and context-awareness. In: Gellersen, H.-W. (ed.) HUC 1999. LNCS, vol. 1707, pp. 304–307. Springer, Heidelberg (1999)
2. Dourish, P.: What we talk about when we talk about context. Pers. Ubiquit. Comput. **8**(1), 19–30 (2004)
3. Parasuraman, R., Sheridan, T.B., Wickens, C.D.: A model for types and levels of human interaction with automation. IEEE Trans. Syst. Man Cybern. Part A: Syst. Hum. **30**(3), 286–297 (2000)
4. Pfautz, S.L., Ganberg G., Fouse, A., Shurr, N.: Leveraging context to improve human-system performance. AI Magazine (to appear)