

# Nexus—A Global, Active, and 3D Augmented Reality Model

Daniela Nicklas

## ABSTRACT

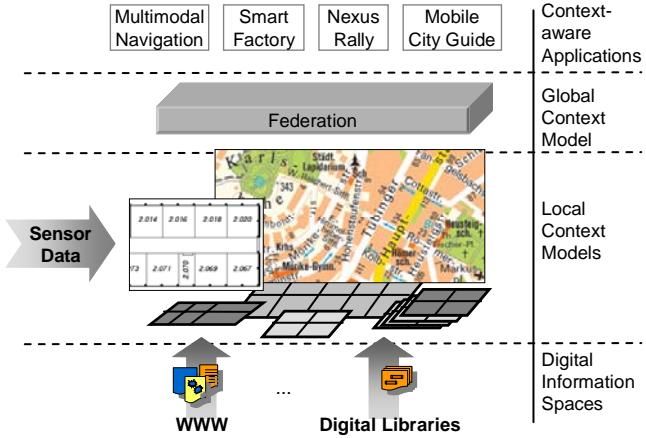
The proliferation of sensor technology, along with advances in wireless communication and mobile devices, allow for context-aware applications. These applications need context information, which should be shared between different applications to reduce the effort of modeling, obtaining, and managing. In the Nexus project, a context sharing platform was developed that allows for global, open context access of different applications. In this paper, different aspects of this work are illustrated: how a global access can be achieved by a federation approach, how these models can be active to support event observation and notification, how the third dimension can be introduced in the modeling and finally, how this leads to advanced applications that augment our reality with virtual information. Finally, an outlook into the vision of the World Wide Space is given.

## 1. INTRODUCTION

Context-aware systems have attracted researchers in the past years starting from location-aware computing. Early work [SAW+94] considered context to be related to the location of users, the people nearby, and resources which can be accessed based on the spatial proximity. Depending on the focus of research projects, further definitions of context have been proposed. Context-aware applications use context information in order to adapt their behavior. Meanwhile, a multitude of applications has been developed. These applications cover different domains, such as tourist guides [CDM+00, AAH+97], indoor information systems [CKW01] and smart environments [KOA+99], to name a few. The different context sources and characteristics of context information, e.g., type and representation, have led to a number of different approaches to supply applications with context information. Besides specialized approaches, e.g., the context toolkit [SDA99] for sensor integration or the location stack for positioning systems [HBB02], a generic approach based on a database-style management of context information has evolved that typically offers interfaces to query context information or to receive notifications on context changes. However, these infrastructures mostly address a distinct application domain, such as context processing based on sensors [SDA99] or providing application-specific context [CDM+00]. Also, when new services, hardware, or environmental information such as maps become available to an application, other existing applications can not automatically use them. Interaction between different applications based on their context, e.g., identity, location, or state, is not possible if they do not rely on a common representation of this context.

For many context-aware applications, the spatial environment of the user is most relevant. So-called location-based applications, or location-based services (LBS), define a specific class of context-aware systems that adapt their behavior to the spatial context of the user, e.g., by providing local maps and navigational information. In this application area, there are already commercial solutions available, e.g., location-based information systems for mobile phones or car navigation services. They rely on spatial data that has previously been gathered and preprocessed to fit their needs. This data is expensive, because in many cases it has to be manually collected, edited and updated. Typically, spatial data is fused with traditional information from databases or web pages, augmented with a spatial reference, to form what is called the context model.

In the context of the Nexus project [SFB], we design and implement an open platform to manage such a context model, called the Nexus Augmented World Model [NM04]. Based on an extensible set of so-called location-based data services, we developed a service-oriented architecture that is built on a federation approach to flexibly and efficiently support location-based applications (see Figure 1).



**Figure 1** Integration of Different Context Models into a Global View

The remainder of the paper is structured along the various features of the Nexus Augmented World Model as mentioned in the title: the realization of a global federation of context models is described in Section 2. The concept of physical events, which make the Augmented World model active, are illustrated in Section 3. Shortly, the move from two dimensional to three dimensional models is presented in Section 4. Section 5 shows the benefits of using fine-grained 3D context models for augmented reality applications in the Smart Factory application domain. Finally, the paper concludes with an outlook on the vision of the World Wide Space, which realizes a truly augmented reality in Section 6.

## 2. GLOBAL FEDERATION OF CONTEXT MODELS

The goal of the Nexus platform is to offer generic support to context-aware applications. The basic approach is to provide a global context model as a federation of local context models (Figure 1). Typically those local context models provide different types of context information like representations of real world and virtual objects. Our main application area are location-based services, i.e., the most important context in the Nexus platform is spatial information like positions and extents of objects. The Nexus platform offers generic support for different kinds of location-based applications, e.g., multi-modal navigation applications, the Smart Factory [WLJ+06], the NexusRallye [NHMM04], and mobile tourist guides [CDM+00, AAH+97].

Local context models can be provided by various location-based data services. Existing digital information spaces like the WWW can be integrated using discovery services and web robots. Sensors keep local models up to date (e.g., the position of a person).

Here, only a short overview over the architecture of the Nexus platform is given. For more details see [GBH+05].

### 2.1. Context Server

A context server is a location-based data service that stores a local context model. To be a context server, the location-based data service has to fulfill two requirements: it has to implement a certain interface (simple spatial queries and result representations given in a specified XML language) and it is registered with its service area and object types to the Area Service Register (comparable to a spatially enhanced DNS).

There can be many different implementations of a context server. For providing large scale geographical models, we used a spatially enhanced database. We cope with the high update rates of the positions of mobile users using a distributed main memory system. For the Aware Home we adopted a lightweight spatial server as Context Server. Even small-scale sensor platforms like the ContextCube can be used as a context server [GBH+05].

## 2.2. Federation

A federation node mediates between applications and context servers. It has the same interface as a context server, but does not store models (except for caching). Instead, it analyses an application request issued as a query, determines the context servers that could fulfill the query and distributes the query to these servers. Then it combines the incoming result sets to a consistent view and returns this to the application.

For query distribution and service discovery, a Nexus node uses the Area Service Register (ASR). This service is a directory to the available local context models and it stores the address of each corresponding context server, its object types and its extent.

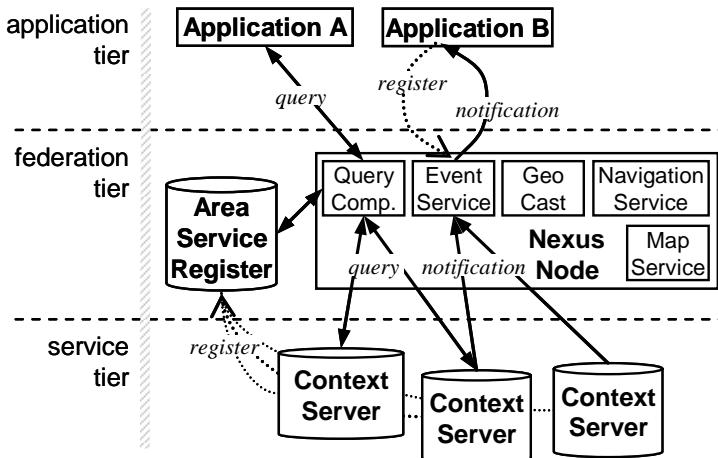


Figure 2 Nexus Architecture

## 2.3. Additional Services

In addition to the query functionality, every Nexus node supports value-added services. They use the federated context model to implement advanced services having their own interface. In Figure 2, you can see three different value-added services of the Nexus platform: The map service renders maps based on a selected area. The navigation service computes multi-modal navigation routes across the borders of local context models. With GeoCast, you can port a message to a geographically addressed area to be sent to every mobile application that is currently in this region.

## 2.4. Information Access

A context-aware application can use the Nexus platform in three different ways:

- **Pull Mode.** An application can send queries to the federation to get all kind of information about its surrounding including infrastructure, points of interest (POIs), mobile objects (friend finder) and so on.

- Push Mode. An application can register to the Event Service [BR05] to get a notification when a certain state in the world models occurs, e.g., the user has entered a building, the temperature in a room exceeds a certain value, or two persons meet. This concept is described in more detail in Section 3.
- Value Added Services. An application can use value added services like the map service or the navigation service to shift basic functions into the infrastructure of the platform.

### 3. ACTIVE CONTEXT MODELS

The last section introduced a global management of context modeled, realized as an open federation over distributed context servers. Now, we give more details on the realization of active context models, where applications get notifications from the context management platform when a certain real world event occurs.

A typical example for such an application is a RememberMe-Service: the user may specify something she ought not to forget (e.g., buying tickets when passing the theater) and her mobile device notifies her when she's there.

There are three different types of physical world events that are the basis for such reminders:

- *OnEnterArea* event: *Pick up the theater tickets.* There is a predefined area (around the theater), and a mobile user. When the user enters this area, the system sends out the notification. For this type of event, only the position of the user is dynamic.
- *OnCloseTo* event: *This shop has a DVD-player under offer.* Here, only the type and some constraints of the spatial object are defined (a shop with a certain offer). The system notifies the user when she comes near to that kind of a shop. For this event, the system needs to have knowledge about shops and their properties which can be retrieved using the context management described in Section 2.
- *OnMeeting* event: *Your friend Harry is close by, you wanted to talk to him.* This event happens, when two or more mobile objects are within a given radius, which can happen anywhere.

The main challenge in realizing active context models is to cope with the distribution of event source and event sinks. As we have seen, information from different sources has to be combined to find out whether an event has occurred. Also, the uncertainty of sensor data implies a sophisticated handling in the system: how do you determine an *OnMeeting* event within a radius of 20 meters if the positions of the users have only an accuracy of 50 meters due to bad sensor readings? For this, suitable methods working with threshold probabilities were developed.

Figure 3 shows the general system model of the distributed event and notification service [BR05]. In the local case (a), real-world events (like the change of the position of a user) are observed by sensors, which update a local context model. Here, an event observation component checks whether these basic events trigger a registered (complex) event of the user (e.g., the user's position is close to a shop with a DVD player offer). In this case, a notification is sent to the client.

In the distributed case, the sensors also update different local context models. However, the observation of a complex event is only possible at the global view. Therefore, the local context models have to update the global context model. From there, a notification can be sent to the client.

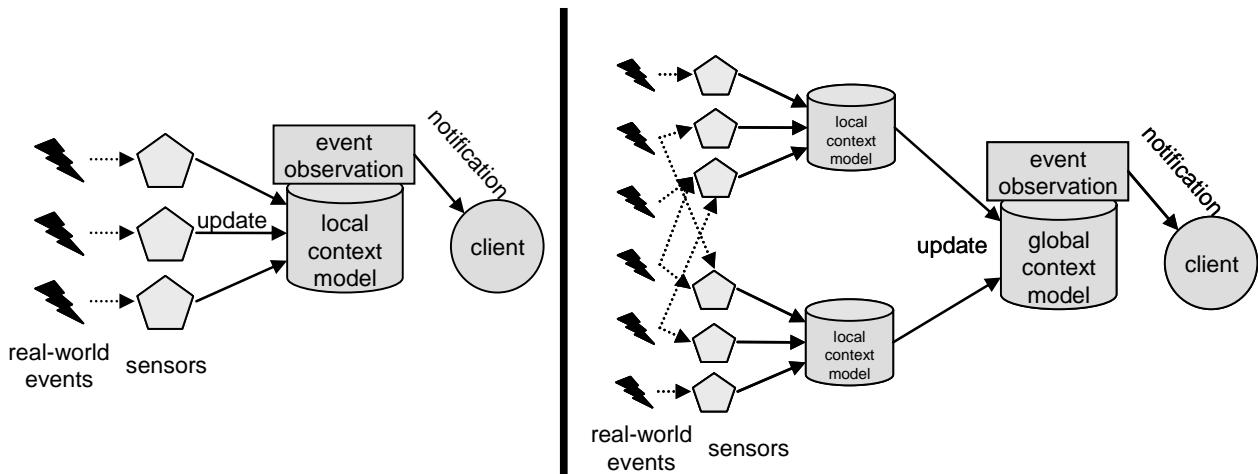


Figure 3 System Model of the Event Service – a) local case, b) distributed case (according to [BR05])

In typical event-based systems like publish/subscribe services or active databases, all events that happened are propagated to the system. Their goal is often to efficiently deliver notifications to the clients. However, in the case of global active context models, it is clear to see that this approach would not be scalable because of the huge number of real-world event that happen.

Therefore, the observed events are stored in local context models. Only if a client registers for a complex event, the system registers for the corresponding basic events at the local context models, so that the updates in Figure 3 (b) are only delivered if needed.

Also, all event registrations do have a time-out. If a client does not renew its registration at the system, the event observation will eventually stop. This prevents orphaned event observations from wasting resources.

This event services was implemented and evaluated with a high number of observations. In the next step, we also plan to support continuous queries and stream-based context information delivery. In this case, applications not only register for a certain event but for update for a given subset of the model, specified by a query. Whenever the result set of the query changes due to changes in the real world, updates and result set differences are sent to the client. This leads to stream-based processing of context information, where sensor data streams are merged with static model data and delivered to the client applications.

#### 4. THE THIRD DIMENSION

With the ongoing three-dimensional digitalization of whole cities along with the advance of mobile visualization methods, the need for modeling, managing, and retrieving of three-dimensional context models is increasing. It is a pre-requisite for many innovative context-aware applications, e.g., mobile augmented reality, enhanced navigation, or disaster management. These three-dimensional models are needed both for visualizing and context derivation.

In [EHS+06], several requirements for 3D data modeling in Nexus are composed:

- There should be support for both outdoor and indoor models. While for indoors, full 3D models are necessary, for outdoors sometimes 2,5D is enough.
- Models can be composed of several objects, which can have their own coordinate system.
- The accuracy should be within centimeters.
- Additional to the position, an object should contain optional information about texture, normal vectors, and characteristics of the material.
- Additional to the geometry, topological information should be stored.

It is the goal of the Nexus project to exploit existing standards whenever suitable. Since version 3.0, the Geographic Markup Language (GML3) [CDL+04] supports the modeling of three-dimensional geodata and is widely supported by GIS and spatial databases. Additional, the Nexus Augmented World Model uses GML for the representation of two-dimensional data. GML is an abstract XML-format that does not contain object definition. This is done by a GML application schema.

The CityGML project [KGP05] develops such a GML application schema and strives for its standardization. The goal of this project is to provide a commonly used, interoperable data format to represent three-dimensional city models. CityGML is structured into five levels of detail (LoD) as depicted in Figure 4:

- LoD0 is a 2,5D (two dimensions plus height information) digital terrain model, over which an aerial image or a map may be draped.
- LoD1 represents buildings as simple blocks without any roof structures or textures.
- LoD2 adds these roof structures and textures.
- In LoD3, fine-grained architectural models with detailed wall and roof structures, balconies, bays and projections may be represented.
- Finally, LoD4 completes a LoD3 model by adding indoor structures like rooms, stairs, or furniture.

In [EHS+06] we show that GML3 supports almost all the requirements mentioned above and can be easily extended to fulfill all of them. These extensions cover e.g. the modeling of material types and normal vectors.

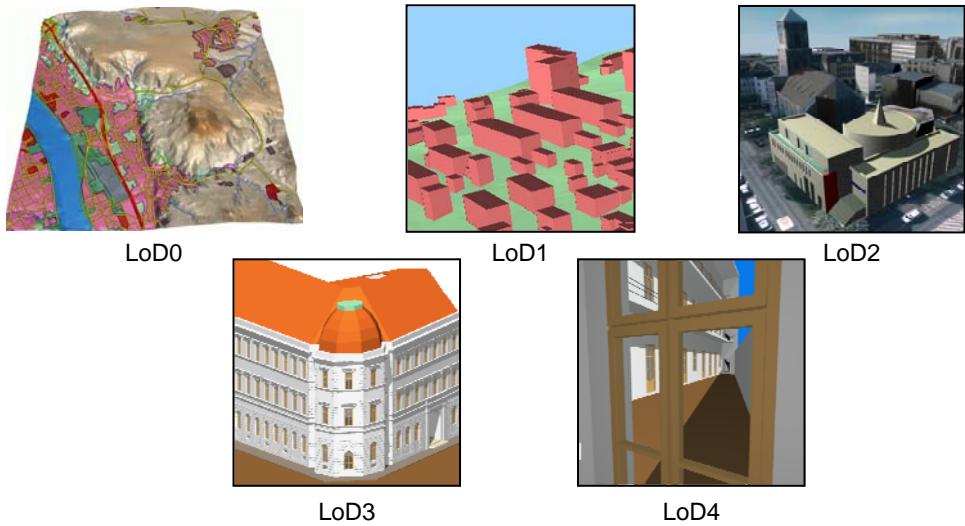


Figure 4 The five Levels of Detail (LoD) defined by CityGML [KGP05]

## 5. AUGMENTED REALITY IN THE SMART FACTORY APPLICATION DOMAIN

The realization of active, three-dimensional, and fine-grained context models enables new and innovative applications. One example is the Smart Factory [WJEE05], where the proliferation of sensor technology and communications technology (ICT) systems in machinery, work pieces and tools leads to the adoption of ubiquitous computing and mobile computing techniques in the production area.

For example, the exact tracking of tools and mobile items allows for a smart resource management, which significantly decreases the amount of overstocking in the factory [BJS04]. Also, maintenance tasks can be supported by task-oriented, context-aware applications that dynamically assign tasks to mobile workers [WKNL07, WLJ+06]. However, these applications are already possible with the two-dimensional context model management described in sections 2 and 3.

A challenging yet very promising application area is the usage of so called augmented reality techniques in the production environment. Milgram et al. [MTUK94] introduced the Reality-Virtuality Continuum to classify these types of applications (see Figure 5): between the real environment (the physical world) and the virtual environment (the world of data and documents) there is a continuum containing Augmented Reality applications, which overlay an impression of the real world with digital objects, and Augmented Virtuality applications, where a virtual environment is augmented with representations of objects from the real world. Virtual reality applications are also located at this side of the continuum.

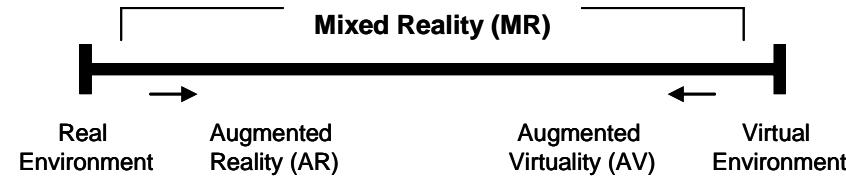


Figure 5 Milgram's Reality-Virtuality Continuum (according to [MTUK94])

In [ESE06], a context-aware application is introduced that allows a transition between mixed, virtual and augmented reality. The goal is to support an assembling task of a worker by different modes, like a virtual reality training mode, the actual task with 3D documentation in an augmented reality manual, and the final inspection of the work with an augmented virtuality (AV) review. The user study with this prototype application show that the combination of multiple reality stages clearly indicated valuable benefits: lower assembly times and error-rates and thus a higher quality, e.g., through the AV review as a final inspection.

## 6. THE WORLD WIDE SPACE—AN AUGMENTED REALITY

The research and applications illustrated in this paper are outcomes of the Center of Collaborative Studies (SFB) 627 “Spatial World Models of Mobile, Context-Aware Applications” (Nexus). The project started in 2003 and continuous at least to 2011. More than 30 researchers from different disciplines collaborate to further increase the knowledge in this area.

In analogy to the WWW we envision a World Wide Space, which provides the conceptual and technological framework for integrating and sharing context models. It is open in the sense that any commercial and non-commercial provider can "place" context models into this space. The collection of context models is federated and leads to a large scale context model, offering a global and consistent view on the context data. The federation allows for complex spatial queries, including continuous evaluation and stream-based processing. If the context model is enriched by temporal concepts, applications can query not only the current model state, but also states of the past or even predicted ones.

To protect context data, application-specific views can be defined for individually controlling model access. This World Wide Space will be the common basis for future context-aware applications. And as we have seen in the last section, this World Wide Space will allow for different kinds of overlapping realities. The so-called Cyber world will not longer be a separated field of experience (as communities like Second Life suggest) but will be integrated with both our everyday life and our workplaces.

## 7. REFERENCES

[AAH+97] Gregory D. Abowd, Christopher G. Atkeson, Jason I. Hong, Sue Long, Rob Kooper, and Mike Pinkerton. Cyberguide: A mobile context-aware tour guide. *Wireless Networks*, 3(5): pages 421–433, 1997.

[BJS04] M. Bauer, L. Jendoubi, and O. Siemoneit. Smart Factory–Mobile Computing in Production Environments. Proceedings of the MobiSys 2004 Workshop on Applications of Mobile Embedded Systems (WAMES 04), 3, 2004.

[BR05] Martin Bauer and Kurt Rothermel. An architecture for observing physical world events. In ICPADS (1), pages 377–383. IEEE Computer Society, 2005.

[CDL+04] S. Cox, P. Daisy, R. Lake, C. Portele, and A. Whiteside. OpenGIS Geography Markup Language (GML 3.1), Implementation Specification Version 3.1.0, Recommendation Paper, 2004.

[CDM+00] Keith Cheverst, Nigel Davies, Keith Mitchell, Adrian Friday, and Christos Efstratiou. Developing a context-aware electronic tourist guide: some issues and experiences. In CHI, pages 17–24, 2000.

[CKW01] W. Steven Conner, Lakshman Krishnamurthy, and Roy Want. Making everyday life easier using dense sensor networks. In Gregory D. Abowd, Barry Brumitt, and Steven A. Shafer, editors, Ubicomp, volume 2201 of Lecture Notes in Computer Science, pages 49–55. Springer, 2001.

[EHS+06] Mike Eissele, Nicola Hönle, Thomas Schwarz, Steffen Volz, Martin Kada, Lamine Jendoubi, and Susanne Bürklen. 3D-Daten in GML 3.0. SFB 627 Bericht 2006/03, Universität Stuttgart: Sonderforschungsbereich SFB 627 (Nexus: Umgebungsmodelle für mobile kontextbezogene Systeme), Germany, Universität Stuttgart, Institut für Parallele und Verteilte Systeme, März 2006.

[ESE06] M. Eissele, O. Siemoneit, and T. Ertl. Transition of Mixed, Virtual, and Augmented Reality in Smart Production Environments–An Interdisciplinary View. Robotics, Automation and Mechatronics, 2006 IEEE Conference on, pages 1–6, 2006.

[GBH+05] Matthias Großmann, Martin Bauer, Nicola Hönle, Uwe-Philipp Käppeler, Daniela Nicklas, and Thomas Schwarz. Efficiently managing context information for large-scale scenarios. In Proceedings of the 3rd IEEE Conference on Pervasive Computing and Communications: PerCom2005. IEEE Computer Society, 2005.

[HBB02] Jeffrey Hightower, Barry Brumitt, and Gaetano Borriello. The location stack: A layered model for location in ubiquitous computing. In WMCSA, pages 22–. IEEE Computer Society, 2002.

[KGP05] T.H. Kolbe, G. Gröger, and L. Plümer. CityGML–Interoperable Access to 3D City Models. First International Symposium on Geo-Information for Disaster Management GI4DM, 2005.

[KOA+99] Cory D. Kidd, Robert Orr, Gregory D. Abowd, Christopher G. Atkeson, Irfan A. Essa, Blair MacIntyre, Elizabeth D. Mynatt, Thad Starner, and Wendy Newstetter. The aware home: A living laboratory for ubiquitous computing research. In Norbert A. Streitz, Jane Siegel, Volker Hartkopf, and Shin’ichi Konomi, editors, Co- Build, volume 1670 of Lecture Notes in Computer Science, pages 191–198. Springer, 1999.

[MNG+05] Bernhard Mitschang, Daniela Nicklas, Matthias Großmann, Thomas Schwarz, and Nicola Hönle. Federating location-based data services. In Theo Härdter and Wolfgang Lehner, editors, Data Management in a Connected World, volume 3551 of Lecture Notes in Computer Science. Springer, 2005.

[MTUK94] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino. Augmented Reality: A Class of Displays on the Reality–Virtuality Continuum. Proceedings of Telemanipulator and Telepresence Technologies, pages 282–292, 1994.

[NM04] Daniela Nicklas and Bernhard Mitschang. On building location aware applications using an open platform based on the nexus augmented world model. Software and System Modeling, 3(4):303–313, 2004.

[SAW+94] B.N. Schilit, N. Adams, R. Want, et al. Context-aware Computing Applications. Xerox Corp., Palo Alto Research Center, 1994.

---

- [SDA99] Daniel Salber, Anind K. Dey, and Gregory D. Abowd. The context toolkit: Aiding the development of context-enabled applications. In CHI, pages 434–441, 1999.
- [SFB] Sonderforschungsbereich 627: Nexus project site. <http://www.nexus.uni-stuttgart.de/>. retrieved at 2007-06-13.
- [SHG+04] Thomas Schwarz, Nicola Höhle, Matthias Grossmann, Daniela Nicklas, and Bernhard Mitschang. Efficient domain-specific information integration in Nexus. In Hasan Davulcu and Nick Kushmerick, editors, Proc. of the 2004 VLDB Workshop on Information Integration on the Web: IIWeb-2004 ; Toronto, Canada, August 30, 2004. online, August 2004.
- [WJEE05] E. Westkaemper, L. Jendoubi, M. Eissele, and T. Ertl. Smart factory—bridging the gap between digital planning and reality. In Proceedings of the 38th CIRP International Seminar on Manufacturing Systems, pages 44–44. CIRP, Mai 2005.
- [WKNL07] Matthias Wieland, Oliver Kopp, Daniela Nicklas, and Frank Leymann. Towards Context-Aware Workflows. In Proc. of the Ubiquitous Mobile Information and Collaboration Systems (Caise’07 Workshop). Springer Verlag, Juni 2007.
- [WLJ+06] Matthias Wieland, Frank Leymann, Lamine Jendoubi, Daniela Nicklas, and Frank Dürr. Task-orientierte Anwendungen in einer Smart Factory. In Thomas Kirste, Birgitta König-Ries, Key Pousttchi, and Klaus Turowski, editors, Mobile Informationssysteme - Potentiale, Hindernisse, Einsatz. Proceedings MMS’06, volume 76 of LNI, pages 139–143. GI, 2006.