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IN2CO - A Visualization Framework for Intuitive Collaboration

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Abstract

*Today, the need for interaction and visualization techniques to fulfill user requirements for collaborative work is ever increasing. Current approaches do not suffice since they do not consider the simultaneous work of participating users, different views of the data being analyzed, or the exchange of information between different data emphases. We introduce **Intu**itive **Co**llaboration (IN2CO), a scalable visualization framework that supports decision-making processes concerning multilevels and multi-roles. IN2CO improves the state of the art by integrating ubiquitous technologies and existing techniques to explore and manipulate data and dependencies collaboratively. A prototype has been tested by mechanical engineers with expertise in factory planning. Preliminary results imply that IN2CO supports communication and decision-making in a team-oriented manner.*

Categories and Subject Descriptors (according to ACM CCS): User Interfaces [H.5.2]: Graphical user interfaces (GUI), Input devices and strategies, Interaction styles, User-centered design—Group and Organization Interfaces [H.5.3]: Computer-supported cooperative work, Synchronous interaction—

1. Introduction

Collaboration in shared interaction visualization environments is increasingly used to design, evaluate, and balance concepts. For example, complex civil engineering or transportation infrastructure designs require the input and information exchange of several peer-designers, to offer diverse viewpoints and bring together the needed different core competences. Especially for decision-making purposes no single person can take sole responsibility - considering and integrating the ideas and expertise from several persons is crucially important.

Real-time simultaneous multi-user software is common in gaming communities, where it is now much more routinely used than in other communities [FSN*14]. Such collaborative software can also be useful and practical in other fields, such as engineering settings with various simultaneous contributors. Here, collaboration is essential to identify and solve design conflicts in an early stage and, consequently to reduce development lead-time and manufacturing costs. Common collaboration technologies are mostly addressing work of distributed teams. There exist a wide range of tools undertaking mind mapping, file sharing, messaging, and so on. Those tools are mainly developed for single desktop applications. Co-located collaboration is often performed by one presenter and several spectators, whereby active participation is strongly limited. Our research focuses on an environmental setup for co-located and distributed collaborative work.

Due to the large size and high resolution, large display devices (LDDs) enable the reproduction of large datasets in one view. However, most LDD's interaction capabilities are designed for single users, so powerful and intuitive visualization and interaction capabilities are needed to support a larger number of users. Smart devices offer a wide range of interaction metaphors, leading to natural and intuitive interaction. In addition, they come with a display that can be used as secondary output device. Complex data often comprises several levels on which different activity emphases exist (e.g., machine energy consumption or production rate). Those emphases can have interdependencies that must be identified and collaboratively solved. Changing attributes in one level might have an unaware or undesirable impact in another level of the same data. With the number of participants, the requirements for the visualization tool and techniques accumulate. Combining different core-competences and supporting intuitive data exploration for and between different activity emphases is still a challenging task.

IN2CO is a human-centric visualization framework for intuitive and collaborative data exploration and manipulation. Specifically, it's contribution is *the integration of ubiquitous technologies and existing techniques to explore data and dependencies in collaborative decision-making for co-located and distributed participants.* A challenging task in designing such a collaborative framework is to support the active participation of each user as well as the design of the underlying architecture, infrastructure, and protocols.

2. Related Work

The Pittsburgh Pebbles PDA Project [sot09] was one of the first projects using mobile devices as remote controllers for PCs. Borchers et al. [BRTF02] demonstrated a software framework that integrates ubiquitous technologies to support collaborative work on large-scale devices. Lee et al. [LESD09] detected that collaborative virtual environments have the potential to improve collaborative work but still lack sufficient communication capability for distributed teams.

SourceVis is a collaborative visualization system for co-located environments based on multi-touch tables developed by Anslow et al. [AMNB13]. The table provides a horizontal display on which one interactable viewport per user is created on opposite sides. The number of active users is limited due to the size of the table. Myers [MPN*01] introduced semantic snarfing, where a region of interest is tracked via pointing devices and copied to a secondary handheld device. Here, latest smartphone technologies can lead to a more natural and intuitive effect of semantic snarfing.

CEDAR [MSA*13] is a design review tool supporting collaborative tasks by using a CAVE system and handheld devices. Here, cooperative task execution with the system is not provided. Simultaneous work of several users and multi-role perspectives are not considered. Marquardt et al. [MBB*12] demostrated that information exchange between multible users with the use of mobile devices as input and output devices could be facilitated and supports collaborative work. Finke et al. [FKW*10] and Marquardt et al. [MHG12] [HM15] demonstrated the versatility and design space with cross device interaction using handheld devices. Other framework approaches such as *Munin* [BFE15] focus on solving data exchange problem of application and communication data between ubiquitous devices. Even when they provide a software framework used for ubiquitous analytics and visualization, the domain oriented multilevel perspective is not fully adressed.

3. IN2CO

IN2CO integrates the techniques mentioned above with ubiquitous technologies and represents a domain-oriented visualization framework with focus on multilevel data analysis, and multi-role perspectives and interaction capabilities. The framework combines a large screen system, used as output device, and several mobile devices used as input and secondary output devices. All devices are implemented as input devices for the large screen setup to enable co-located cooperative tasks, and as independent clients, offering interactive viewports using semantic snarfing for individual use. Thus, other devices - such as desktop systems, CAVE systems, or smart-devices in distributed locations - can be connected to the main server and join a session.

3.1. Architecture

Based on the scientific literature, we generated a catalogue of general-purpose user needs for collaborative work and environments. Currently, we are working on an innovative approach based on a "quality function" to translate and weight the needs for specific environments, user groups and applications into a quality model for further refinement of our system's components. Together with a transaction model the architecture of that system could be designed (1) and prototypically implemented. Build upon the VR development toolkit VRUI [Kre09], IN2CO provides the user with a large number of input- and output capabilities, and tool interfaces that can be integrated to generate a collaboration application for visual

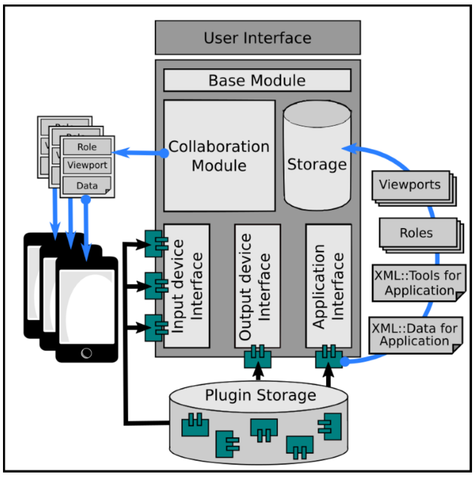

Figure 1: *IN2CO Architecture - User roles and viewports defined in application plugin are transfered to clients*

analysis and data manipulation with different views and roles in an easy way. An existing parser overcomes the task of preprocessing the data to extract defined activity emphases and values, which can afterwards be connected with predefined tools per drag and drop.

The user interface as top layer assists the user to chose and aggregate the needed plug-ins and devices, which triggers the system registry, user registry, and finally the program execution. The system registry links all appropriated resources and plug-ins into the program, while the subsequent user registry associates roles, viewports, and rights to the user. Build upon VRUI, which includes the task of rendering and providing interfaces for common types of input and output devices, our framework has been extended with the following modules:

- **Smartdevice interface:** links smart devices and triggers the exchange of messages
- **Graphical user interfaces:** register smart devices with the environment
- **Basis module:** undertakes supportive activities like parsing for import and export and also creating annotations
- **Collaboration module:** triggers user registry, object distribution, data exchange and transaction handling
- **Application interface:** holds user specific viewports; user roles; tool and functionality collection for the tasks/usable devices
- **Data storage:** collects all application-specific values with impact links between processes, and contains all session logs for recording and recovering

3.2. Smartdevices

Smart devices offer a wide range of interaction metaphors, which can lead to natural and intuitive interaction as well as a broad array of control elements. As users can be explicitly identified, smartphones as interaction devices scale with the number of users. Furthermore, the smart device offers the possibility to use the screen as secondary output capability. Therefore, the overall design objective is to provide two viewports to each user. The LDD represents a shared viewport for all users, on which everyone can track the observation of the others and cooperatively discuss the same scene. Additionally, each user owns a private viewport on the smart device. On this private view users see exclusively the information relevant to their domain. Symbolic input is a usual task of smart devices; notes and markings are made on the private view and synchronized with the shared view if desired. With the latest developments on wristwatch computers, new techniques can be used to make the interaction more natural and intuitive. Next to smartphones and tablet computers with different sizes, smart-watches will be used as well to interact with the model and support decision-making processes.

3.3. Multilevels and Multi-Roles

Complex data often comprises multiple levels containing information. Different participants have different focus or even varying activity emphases on the data. Interdependencies between those activity emphases can exist and lead to unaware and potentially undesirable impacts on each other. To avoid unauthorized data manipulation by non-experts, multiple user-roles are used. Here, domain specific tasks and interactions had to be defined and coresponding viewports designed. Ontological designed user-roles together with task defined viewports and interactions are assigned to the participating users.

4. Prototype

The setup of the current prototype consists of a four-sided CAVE system and several smart-devices ranging from smart-watches over smartphones to tablet computers in different resolutions and sizes. A smart-device interface is implemented, which interprets the input of the different devices and initiates specific functionalities. The collaboration module handles concurrent transactions and creates log recordings. All devices act as independent clients that communicate via TCP across a local Wi-Fi connection. The application domain exemplarily used is factory layout planning, characterized by several collaborative tasks and different participating experts.

4.1. User-Centric Design

The IN2CO-prototype followed user-centric design methodologies, starting with a user and task analysis involving engineers from factory planning, which represents an appropriate application to demonstrate the usefulness and benefits of the desired system. Factory planning is characterized by the parallel consideration of multiple aspects such as production resources, production process and technology, and products, while anticipating uncertainty and future developments over the factory life-cycle [TCE*10]. These aspects usually result in different partial-models with specific information content (e.g., layout model, material flow model) and components of the factory (e.g., building, machinery, foundation, media), which need to be analyzed in combination. The different partial solutions are usually developed by various stakeholders, but typically interfere and require each other [SSC12]. The major tasks regarding collaborative factory planning are [WGC*14]:

- Assembling multiple, domain-specific points of view
- Bilateral problem introduction
- Joint discussion and integrated decision making

Appropriate visualization tools to support collaborative factory planning must be able to coordinate different layouts and viewpoints on the factory as well as exchange and manage information and models from different domains. The functions are summarized in the following:

- **Creation:** Combination of different part models and information content.
- **Perform:** Adjustments on the layout to develop optimizations (e.g., manipulate models).
- **Coordination** of various models, information sets and planning perspectives.
- **Verification** of layout through immersion and analytics.
- **Consideration** of efficiency, usability and extendibility constraints.

VR-supported workflows are proposed to foster collaboration, establishment of a joint problem understanding, and exchange of different points of view [WGC*14]. The CAVE system is used to provide an overall picture of the underlying manufacturing system, consisting of the building, storage areas, machines, human resources, and conveyors (see Figure 2 right). The smart-devices are used to control the scene and execute the functionalities in the large screen setup. They are also used to solve tasks individually and independently like distance measurements, navigation in the scene, and information-display of selected objects. For this purpose the underlying model is displayed on the mobile devices resp. textual output on the smart-watch (see Figure 3). Depending on the underlying functionality, the modifications of each user will be synchronized with the large screen in real time, or merely logged for later use.

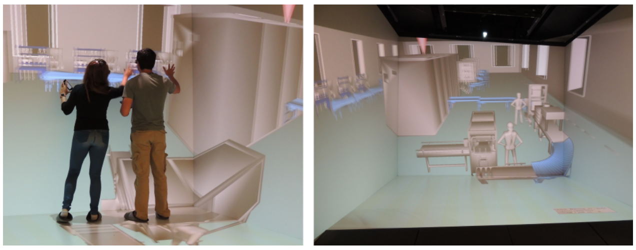

Figure 2: *Left: Collaborative planning process - Right: Virtual manufacturing system*

4.2. Functionality

The following shows all realized functionalities on a desktop/CAVE setup and mostly on mobile devices, which derive from factory layout planning functions and collaboration needs:

- **Manipulation:** rotate, pan, and zoom of single objects
- **Navigation:** rotate, pan, and zoom of the whole model; selection of predefined views; hiding/unhiding of object-groups
- **Examination:** measurement of distances and dimensions, textual output of object-information
- **User feedback:** highlighting and vibration
- **Collaborative features:** making annotations, insert comments, mark areas, and create a visual snapshot

Manipulation functionalities are synchronized with all devices in real time. Functionalities of the category navigation have merely an effect on the underlying device and are not synchronized, except of the modifications that are executed to control the scene on the large screen, which have an effect on the large screen exclusively. User feedback is realized in various forms. If a user selects an object, the object will be highlighted in the user's color. If objects clash with others during object manipulation, the objects will be colored in red. When a configuration on the metadata on a specific level or object has an impact on others, this impact is visualized.

Figure 3: *Input and secondary outputdevices: iPad (left), AppleWatch (center), iPhone (right)*

4.3. Collaborative Features

To connect mobile devices with the general environment provides the basis for collaboration of several users in the same environment. Collaborative work will be enabled as each user has his own control device and everyone can track the changes of others. The main scene is running on a server, which records all transactions and handles requests. Collaboration features are implemented to work cooperatively. Artifacts like annotations or even measurements can be marked as public or private. Private ones are visualized on the private viewport exclusively. Public ones are synchronized to the main scene and can be shown or hidden if desired, and also are tracked from the collaboration module for session recording purpose.

5. Experimental Evaluation

We have conducted a preliminary evaluation of our prototype virtual manufacturing system with 12 subjects, see 2 (left). In the first part of the evaluation, the main capabilities were introduced and subjects had to perform several tasks such as navigation, manipulation, marking areas, and insertion of comments to become acquainted with the setup. In the second part, two subjects had to design a new factory layout collaboratively. The virtual manufacturing system's initial layout had been prepared in advance. Later, users were asked to rearrange objects' positions, so that an additional machine could be integrated. A subject performing this task was monitored in great detail to gather information about the the subject's use of the system and its supported tools.

5.1. Results

In the default setup the user obtained textual and graphical visual feedback about the selected object on the smart devices, a second version of the setup did not provide this visual output. All participants preferred the default version. Especially small objects were difficult to track exclusively on the large screen, so the smart device served as facilitating device. Additionally, some users with a solid factory layout planning background were more intensively confronted with the setup and collaboration features. The majority of the users provided encouraging feedback: On a likert scale from 1 to 5, 75 % of the users estimated that the way in which the team worked together had been most adequate, the way in which data had been visualized was suited to the task they wanted to perform, and that the setup met their requirements.

Overall, all participants evaluated the prototype positively and as helpful. However, their way to use and comment on our system gave us also valuable hints for further improvement. The underlying interaction mechanisms have to be enhanced in terms of accuracy and improvement suggestions for further visualizations could be collected.

5.2. Discussion

IN2CO was successfully applied to an exemplary factory-planning problem. The intuitive interaction that is provided by the smart devices allowed users to focus on the problem description itself, instead of concentrating on interaction issues. Thus communication and decision-making based on the virtual representation of the factory could be achieved in a team-oriented manner. The co-located teamwork is facilitated well, as the provided functionalities enable planners to examine and modify the given factory layout immediately. In contrast to traditional planning tools no privileged master-controller is defined, the participants can perform tasks in parallel which implements an equal balance of power. Hence IN2CO empowers a creative and collaborative factory planning process.

6. Conclusion and Future Research

The first goal of this work was to create a visualization framework for co-located collaborative data exploration and manipulation. Factory layout planning as application domain is ideally suited to address collaboration requirements. Therefore, the current development status is suited to support co-located planning teams. Based on the results, we could identify additional requirements for the framework. In our next development stage, support for distributed planning teams will be considered. The evaluation results have shown that the usage of smart devices is a beneficial approach to enable joint interaction with the model and also does not impair the natural personal interaction between users. Nevertheless, we must support spatially distributed planning teams, implement more natural interaction for even more complex requirements, and design adequate visualizations for different emphases. The contribution noted in the introduction could be tackled in a first step, but there is room for improvement. Therefore, the next steps will be:

1. Enhancement of smart device interfaces and plugins
2. User/task taxonomy of a complete production system
3. Realization and adjustment of the transaction handling model
4. Development of user-centric visualization and interaction techniques
5. Testing and evaluation of the enhanced framework

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