Eurographics Italian Chapter Conference (2008)
V. Scarano, R. De Chiara, and U. Erra (Editors)

IMPROVE: the experience from a FP6 EU project

M. Witzel and G. Conti and R. De Amicis

Fondazione Graphitech
Via Alla Cascata 56/C, 38050 Povo (TN), Italy, +39 0461 883393

Abstract

This paper aims at introducing the results of the EU FP6 project IMPROVE to the Italian community showing the results and specifically those achieved by Graphitech within its context.
The project aimed at delivering advanced visualization and interaction technologies in the field of design review. In terms of hardware the project has delivered innovative technologies for lightweight near-to-the-eye displays and for tiled stereoscopic large size displays. In terms of software technologies the project has delivered novel interaction paradigms which are suitable for such hardware. The achievements of IMPROVE have been integrated into a collaborative mixed reality product development environment, showcased and evaluated in two application scenarios: collaborative product design in the car industry and architectural design.
Specifically a final user test for the automotive scenario was undertaken at Elasis, Naples which was one of IMPROVE partners.

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [User/Machine Systems]: Human factors H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities H.5.2 [User Interfaces-Interaction Styles]: User-centered design

1. Introduction

Virtual design reviews are extensively used within automotive industries. This is because in the initial phase, not only one design proposal is examined, but multiple variations are elaborated until one design is finally chosen. Virtual design reviews are specifically used in the development phase to discuss and scrutinize styling designs, the placement of components and their properties.

For this reason, the reviewing of a prototype is characterized by a vivid discussion in a group of collaborating engineers and designers. Traditionally the reviewing process is performed by a panel of experts standing in front of a large display while only one user can actually interact with the virtual prototype itself.

An efficient support for communication with the model and in turn with the team members is therefore needed. This outlines that multiple instances of the application and in fact distributed clients have to run simultaneously, giving each participant the possibility to interact with the model and the design review application.

However current industrial systems are often implemented exclusively for single user and single modality interaction. Offering multiple modalities to access embedded functionalities ameliorates the users effectiveness when working with the system. Although multimodal techniques try to activate larger parts of the conceptual bandwidth, they are limited in adapting to the way each user would like to access the application's functionality. Hence, the interaction requirements of users with different professional profiles (engineer, designer, etc.) in relation to the tasks have to be examined in detail.

Using multiple modalities further allows accessing functionality more efficiently when their respective strengths are exploited. For instance, speech enables fast and direct input while gestures allow specifying geometries and sketches with ease. Recognition-based interfaces such as speech and gesture subsystems require handling the continuous flow of input in such way that the users actually perform a natural dialogue with the system. However current multimodal interfaces lack the opportunity to align the user preferences properly to their needs and preferences, taking into account well acknowledged interaction paradigms or conventions.

The project IMPROVE has developed a number of techniques aimed at tackling these issues and the result will be discussed in the following sections.

2. State of the Art

With regards to Human-Computer Interaction most traditional applications adopt menu-based interactions to provide access to the functionalities available within the working environment. The interaction metaphors can vary from traditional 2D menus in standard programs, to more complex 3D widgets in more complex three-dimensional applications or in Virtual Reality (VR) system. Some VR applications make also use of hybrid approaches by using a further abstraction level with elements, such as a tablet or a pen [Se98], which in turn provide access to traditional menu-based commands. New interfaces have gone beyond the mere decoding of users' pointing actions by taking advantage of the information encoded through voice, gestures or gaze. This has led to multimodal VR interfaces where multiple communication channels [Lat01] are used. The resulting interfaces make use of technologies which allow the user to interact through voice recognition and text-to-speech synthesis or gestures. Such interfaces differ fundamentally from traditional GUIs since they adopt a novel, probabilistic approach rather than a simple event-driven command mechanism. In fact the "atomic" nature of the conventional event-based model used in GUI-based systems cannot handle the continuous flow of input streamed for instance by speech or gestures subsystems. In order to take advantage of the natural skills of the designer several authors have fostered the adoption of an integrated multimodal interfaces. In this context the idiom "modality" is used to refer to the syntactic and semantic properties of a signal; on the contrary the word "medium", is adopted to focus on the production and transmission of signals [Coh91]. Since the first system developed in 1980 [Bol70] a number of researches have proved the efficiency of human-computer multimodal interactions [Joh97]. As cognitive scientists have proved, the design experience strongly benefits from the support of multisensorial, or multimodal, interactions [RN00]. As stated by Forbus et al. [FFU01], different modalities can be considered as complementary conceptual channels that can transmit information, not easily acquired spatially, regarding the spatial and semantic nature of the design. One of the main advantages of the integration of different modalities lies in the widened perceptual and conceptual bandwidth [FFU01] available to the user to convey information regarding the object he is reviewing. Furthermore, such integrated approach is founded upon the effective support of human communication patterns [OC00] that can provide, if combined, spatial description and mutual interrelation hardly achievable through other means. Specifically it has been proved [OC00] that the raise in efficiency can be substantial in applications dealing with visual-spatial information. The very nature of multimodal interfaces has fostered a number of works which have adopted modular structure. Several authors have successfully promoted the division in different subsystems [Ce98] where commercial recognizers were successfully integrated into customized applications. Most systems developed for engineering applications [Rei98], for complex assembly and maintenance tasks [SdL03] usually use off-the-shelf engines to recognize user's commands. The Studierstube [Se98] VR/AR platform introduces a new level of abstraction to the multimodal interaction. The system makes use of an open architecture for tracking devices, called OpenTracker [Sch07], which provides high-level abstraction over different tracking devices and interaction modes. Several approaches have been explored in order to assess the best merging of information coming from the different recognizer. These include semantic fusion [WOC99, Je97], the MTC (Members-Teams-Committee) method [OC00] as well as other relevant statistical techniques. The adoption of Multimodal Interface in the mobile devices brings improved ergonomics through adoption of more natural interactions and it allows greater efficiency and naturalness in the way the user interface the machine through the adoption of human communication patterns [OC00]. Research works have brought to the creation of portable multimodal VR/AR environments based on PDAs [GS03]. Voice is used to navigate, annotate, and communicate (through voice-over-IP) with other users and a context sensitive interface shows the available speech commands. Such a multimodal approach, although very promising, however lacks in standardized technologies, interaction paradigm and technologies. The authors in [Ke03] developed an integration of gestures and speech by recognizing signals in parallel, yet unimodal recognizers were used to output lists of speech and 3D gesture hypotheses which were then routed to the time-aware multimodal integrator. The work of [FFU01] proposed an open agent architecture to adapt to available input and output resources in order to provide distributed access to multimodal services. While the aforementioned approaches focused on command input, [Ce99] has extended multimodal techniques to navigation in virtual environments [Lav99]. The author of [Mar98] introduced graphs for binding modalities together. However this was done on a non-semantical level and provided means of customization only via a specification language.

3. The Improve Collaborative Framework

As emerged during the user requirement stage, which has involved car designers at the Fiat Research Center Elasis in Naples, Italy, the different car projects are visualized on a Powerwall where designers can see the virtual car in 1:1 scale. However, this stage is entirely lacking the collaborative dimension of shared design reviews. The team of reviewers consist of junior and senior designers, engineers, stylists. They are involved in activities related to underbody design, car body design and engine bay layout. They relate to CAE, Ergonomics and DMU showing once more the heterogeneity of the group and their respective professional background and domain.

The tasks are performed in experimental laboratories specifically equipped with virtual reality hardware and software. Users usually meet with other departments to share information to their colleagues. This highlights once more the need for a more efficient information exchange. The information is shared amongst the different designers via talking, emailing and videoconferencing. It should be noted that no discrete data exchange exists using a dedicated collaborative design review framework and application.

The requirements analysis undertaken within IMPROVE has therefore outlined the need for the framework to be used as basic development platform. The Advanced Immersive Collaborative Interaction Framework (AICI) was chose as the preferred platform. This is based on the open-source portable scenegraph system OpenSG (www.opensg.org). AICI has been designed in a user-centered way, and high flexibility in usage and extensibility has been considered of high importance. Using OpenSG as base scenegraph library, AICI takes advantage of features such as advanced multi-threading and clustering support.

A crucial factor for a VR/AR framework is how interaction capabilities are offered to the user, and how easily they can be adopted. Not only the range of devices decides on the quality of the framework, but also the way incoming user data is processed and forwarded to the application. AICI uses the tracking library OpenTracker to provide access to a wide range of tracking devices locally and in a distributed fashion when run as a server. In fact, it serves as a tracking device abstraction layer underlying the framework.

We have strived for support of collaboration amongst the users. The shared information consisted mainly of navigation and annotation. A continuous exchange of navigation and thus sharing of OpenTracker data has proven to be ineffective and error prone due to faulty transmission. Further, there is still the need to exchange categorized information amongst the distributed clients.

As visible in Figure 1 the chosen architecture consists of five distributed, autonomous subsystems: communication backbone, interaction, tracking and rendering component and a central repository. Each subsystem, which can be physically located on a separate machine, communicates with the other modules through a high-level message exchange.

Each component is deployed entirely autonomously of the other system components. This gives the system a high degree of flexibility with respect to the physical distribution of the devices as well as robustness. By specifying a consistent well-defined protocol, the components are made independent and replaceable. The number of clients is in fact only restricted by the channel capacity of the communication backbone server. All messages are derived from a common structure which holds attributes such as author, system origin and its location.

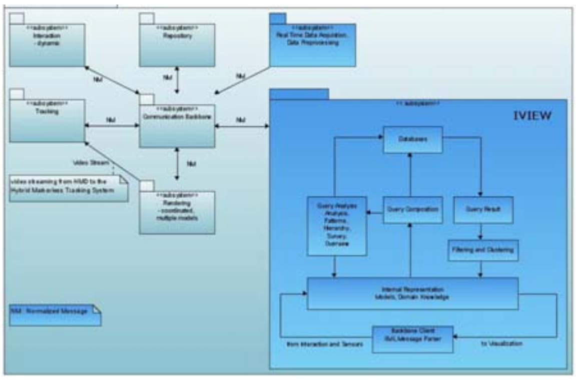

Figure 1: *The architecture of IMPROVE.*

This way any given client does not need to know about the number of clients present within the working system. The information exchange is simply done by publishing and processing only the input data associated with a topic. This approach makes clients independent and it increases scalability, re-configurability, and reuse of components. This it emphasizes the choice of a well defined communication protocol as the one defined within IMPROVE.

The latter is at the base architecture for a distributed VR/AR framework and application which establishes a communication to instances using a Message Passing Middleware (MPM). The information exchange uses XML messages in a channel topic/subscription method to deliver collaborative navigation and scene modification. It has been used to integrate and to visualize time-varying information inside the VR/AR application. This is especially important when working with distributed data providers such as sensors where the frequency of the information update is high.

4. Multimodal Interaction

Much effort has been spent during the last years in developing environments dedicated to virtual design review. However, many approaches are very limited with respect to the range of used input devices and, more importantly, in the way the users are enabled to interact with the product and the system itself. Specifically, in the field of design review, the reviewing group consists usually of users with a very heterogeneous professional background, potentially having different interaction preferences. This problem is further complicated when the application has to address multiple scenarios and hardware configurations. Additionally, such sessions naturally require a frequent switching between navigation and scene manipulation, for example to examine a particular part of the prototype while taking an annotation. The methodology developed within IMPROVE builds onto these requirements and proposes an approach characterized by the elevated user-friendliness based on the development of a customized multimodal interaction dialogue.

When designing interaction techniques for software systems, developers naturally look at an application from their particular point of view, typically biased by their background. For this reason they often implement interaction techniques that are appropriate for daily use by people with similar mind set. However during design reviews several people with different professional backgrounds are working collaboratively and each user has potentially his/her preferred way of working with software systems. Review panels are made by car engineers, designers, architects and 3D modelers. An architect may want to use a sketch for invoking an action like taking a visual bookmark (his natural interacting way) while other users may prefer traditional dialog-based interaction. The greatest challenge of collaborative design reviews, in terms of interaction, is then to give users access to the same functionality through customized user-centered modalities. For this reason it is essential to tackle the problem of distinct modality configurations according to each user's needs. This includes customization of gestures, voice commands as well as the graphical user interface (GUI).

The whole interaction infrastructure in fact needs to be highly customizable according to the user's specific needs, to the design review scenario itself as well as his/her aesthetic taste to improve the users' efficiency and perception of the application. For example, the interface should allow a designer to define his personal interaction process to load a 3D model regardless of whether he wants to use a circular gesture, to select a specific icon on the GUI or to use a speech command in his native language. The problem becomes more complex when applications need to address distinct industrial products as it has been the case in of IMPROVE. For instance, during a car review session, the vehicle resides always in the focus of interest while in an another context, the surrounding environment may become crucial criteria for the final product.

The essential requirement was that the interaction metaphors should seamlessly integrate with the traditional tasks at hand. It is obvious that the users should be supported at all times when using new multimodal interaction schemes, because they are provided with a previously unknown degree of freedom. While the tasks at hand can be complex, interactions should be clear and simple to always keep the goal of the work in focus. This leads us to a further requirement: user interactions should be specifiable in patterns (building blocks) and thus made reusable in other scenarios. As we will show in the next chapters, the solution to this problem should be independent from the technical domain.

For this reason, on the interaction design level, we propose a novel paradigm customizing user interaction for multiple modalities using a graph-based approach. The user is enabled to design interaction patterns using a graphical authoring tool. The so called interaction graph is persistent and thus it can be re-used and applied in other graph enabled applications. It should be noted that of course it is necessary to find away how to activate specific functions within the application itself using the stored graph. We achieve this by attaching attributes to functionalities which are meant to be used by our approach. The functions are triggered when the attributes match the user's stage of dialogue with the system. To validate our proposed approach, we will show its applicability to two distinct design review scenarios: virtual automotive design review under real industrial conditions and hybrid outdoor large-area VR/AR environment.

The details of the developed approach have been extensively detailed in previous works by the authors [GMR08, WCdA08]. This is based upon the use of the so-called interaction graph. The graph, as described in [GMR08, WCdA08], forms an interaction mechanism where the user is enabled to tailor the application to his personal interaction preferences. Besides this, it is possible to customize the application itself by reducing the graph to a sub-graph. It has to be highlighted that we have defined the interactions independently from the application. This way we have freed ourselves from any hard-wiring modalities to the offered application functionalities. Patterns of user interactions can be specified and reused, potentially using them in other interaction graph-enabled applications, too. A major benefit of this approach is that interaction mechanisms are defined only once for different modalities outside the application. To a certain extent, this technique could be called "anticipatory", since only reasonable, context-aware commands are accessible. Figure 2 shows an example of customization of user interaction using Dynagraph. Here, the user inserts a new node into the graph, enabling him to access a mouse navigation scheme during a review session.

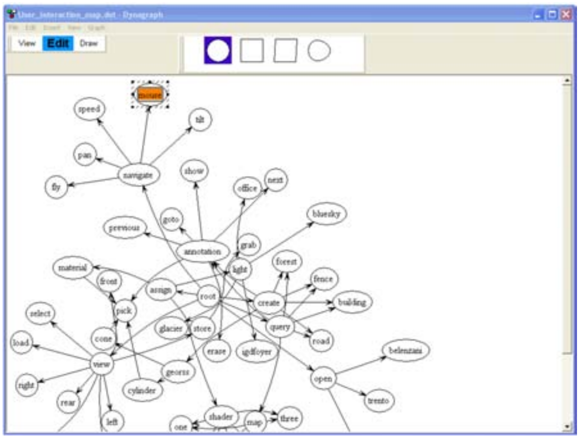

Figure 2: *An example of interaction graph being edited by the user.*

Through incremental navigation in the graph based on edge attributes, the user is enabled to specify precise modalities for interactions. The nodes and edges of the graph represent the dialogue of the user with the system and furthermore reflect the application scenario through the used node names. Using such a flexible approach to interaction configurability has made it necessary to resolve the application functionalities in a flexible manner because of the complete separation of user interaction and application response.

5. Evaluation and Assessment

Specifically when dealing with user interaction, it is of utmost importance to a project to perform a validation of the achieved results. The development of our application was at all times marked by collaboration with the industrial users at the FIAT research center Elasis who provided us with inspiring and constructive feedback. We have undertaken two extensive test sessions during which advantages and shortcomings of our approaches became evident.

The first user test at an early stage of the project realized a collaborative user interface, which was tightly wired to the application. Further there were no means available for any customization with respect to devices and their scenario and user dependent use.

Following the first test and early feedback, we have striven for a high configurability in all areas of the application. As follows in the next sections, we have received a very positive feedback during the final user test that verifies our developed approach in an industrial environment.

5.1. Users

The test session was run throughout a working day at ELASIS, Italy with users being asked to assess the system in groups of two during their working activities. None of the users had been previously informed of the event in order to avoid cross influencing. The test involved 9 users from ELASIS, 7 men 2 women, all from Italy, aged on average 25-34, with different profiles and with an average good experience with CAD/CAS (3.3 in a 1-5 range). Previous experience with VR system was also assessed; this showed that the majority of users had very good experience with VR while 30% of users had no experience at all. Four users had used IMPROVE during the first test session. Their feedback has been essential to assess the evolution of the system as it was perceived by the final users.

5.2. Process

At the beginning of the test, users were invited to enter the VR lab and were given a short 2 minutes introduction to the system and to the hardware configuration. During the following 5 minutes staff from Graphitech introduced the collaborative session and the concept of "master" application. Staff from Graphitech explained the concept of the interaction graph, being used by the system, and how it is possible via a simple configuration to change the entire interaction architecture following the motto "Configure once, interact in any way". For this it was shown to each group consisting of two users how to customize the interaction metaphor by creating the most appropriate combination of gestures/spoken commands/action. Specifically it was shown to each user how to use the interaction graph viewer and how to change the interaction dialogue. Specifically users were briefly taught that:

- Nodes of the graph define the actions.
- Connections define commands.
- Edges are used to define the interaction mechanism.
- Edges have properties.
- Actions/handlers are identified by path/order of user interactions.
- User interactions can be fully rearranged and customized according to the application context and user-tailored.
- Separation between application and interaction definition.

An example of change in the configuration was carried on together with the user group. In particular, it was shown to users that it is possible to have seamless integrations of modalities by using nodes as definitions of actions/domains where edge attributes specify how to access them and gestures and speech are defined as attributes with a list of allowed items (how to advance in the graph). An example of this was handed out to the users.

5.3. Evaluation

Data was collected through the use of two questionnaires (see relevant section). As in the previous test each of these categories included a number of different sentences which could receive a ranking from 1 to 5 (from strong disagreement to strong agreement) with a further "no opinion" option. The user was also asked to record the importance of each of this sentence through a similar ranking from 1 to 5 (from strong disagreement to strong agreement) with a further "no opinion" option. Finally, following each sentence, the user was free to provide a concrete example where he/she does not agree with the statement.

For each questionnaire the rating provided by the users was used to calculate mean values and standard deviations. Mean values of the ranking was also calculated

The first questionnaire contained a set of 47 questions organized in the 5 macro groups: ergonomics factors, hardware and setup, scenario and test, human factors, psychomotorial factors

Additionally an ISOMETRIC questionnaire was prepared according to International Standard ISO 9241. Users were asked to fill in the ISOMETRIC questionnaire after completing the first (heuristics) questionnaire. According to ISO guidelines, and similarly to the previous test, the assessment has been done based on the categories as described in the following sections.

5.3.1. "Suitability for the task"

The assessment shows, if compared with the result from the first test session, users have a more positive result and, interestingly, a much clearer view on the "suitability for the task" group as no user expressed a "no opinion". If compared with the previous test the amount of neutral judgment has grown.

At a glance, looking at the result from the second test, the result never diverges too much from the average value. The largest difference is to be found in the fact that now users feel that the software forces to perform tasks that are not related to the actual work. Positively the users perceive that the software let them completely perform their tasks, that the arrangement of the elements is sensible for the work to be carried out and that the way data is output reflects the task the users want to perform with the software.

Positively a higher share of users considers that it is easy to adapt the software to perform new tasks and that the majority of the commands required to perform the work are easy to find.

5.3.2. "Self descriptiveness" and "Controllability"

The results in this group reflect show a better tendency if compared with results emerged in the first test. Results, albeit always close to average and much better than in previous test, never get very high ranking. According to the users' feedback during the de-briefing, this was due to the fact that, all communication between the interface and the users, entirely lies on the graphical language with virtually no text.

This is an extremely interesting point as, although this makes the entire interface much more compact, and once accustomed, much faster to use, at the beginning this requires interpretation by the user. A positive point is that the user feels that it is possible to understand immediately what is meant by the information display by the software however, poor results are scored in terms of support for concrete examples, rather than using general explanations. This is not surprising as there is currently no way to invoke example in the use of the interface.

5.3.3. "Suitability for individualization"

Extremely good results have been collected in terms of suitability for individualization. The user perceive that:

- The software lets them adapt forms, screens and menus to suit their individual preferences.
- The software can be easily adapted to suit their own level of knowledge and skill.
- They are able to adjust the amount of information (data, text, graphics, etc) displayed on-screen to their needs.
- The software lets them change the names of commands, objects and actions to suit their personal vocabulary.
- They can adjust the attributes (e.g. speed) of the input devices (e.g. mouse, keyboard) to suit their individual needs.

These very good achievements are the result for the high degree of customization provided by the authoring of the interface, which allows every user, if required, to define a customized interaction multimodal dialogue.

5.3.4. Video analysis

During the analysis of the video following the test session a few issue emerged. The most important benefit highlighted by the users was the responsiveness of the system. The previous version was very slow during use. This caused a sense of unease since the entire interaction process became slower. The final version allowed a much more fluent interaction.

A major improvement, according to users, would be the implementation of a proper "undo-redo" mechanism. This in fact is considered a limit and it generates a general sense of anxiety to the user who is aware that no potentially bad action can be recovered.

6. Conclusion

This work has presented the results of the IMPROVE project with specific attention to the novel approach developed for user-centered customizable multimodal interactions. The system integrates voice commands, gestures and traditional dialog elements which can be tailored to the users interaction preferences and scenario requirements.

This is achieved by binding modalities together via a bidirectional graph. The nodes and edges of the graph represent the dialogue of the user with the system. This way the users are enabled to specify precise modalities for interactions through navigation through the graphs. The dialogue of the user with the application and in fact the behavior and functionalities of the application are designable using a graphical authoring tool.

For this reason we have developed a command interpreter which provides the end user with intuitive but powerful means to control the application. Our two-tier model decouples the application's functionalities from the actual user interactions and offers an exceptional degree of freedom for customization with respect to gestural and voice input.

The result of the work has been implemented in a very complex prototype which allows concurrent users to interact with a collaborative virtual environment specifically thought for design review sessions. This has been done in the context of the EU project IMPROVE.

The resulting prototype has been successfully validated within a real-life scenario. Specifically two extensive test sessions have been run at ELASIS (Fiat research center) in Naples to assess the usability and user-friendliness of the final interface. The effectiveness of the prototype was assessed through specific ISO-compliant questionnaires that all final users of the system were asked to fill in.

The results have been very positive and show how the approach pursued has lead to a sharp increase in usability. As demonstrated during the tests the application can be configured to a wide range of input and display devices using mapping artifacts which normalize and redirect the incoming data. As stated by the testing users, this is essential in a daily workflow with the high priority of non-fatigue navigation through the scene and around the reviewed car model.

7. Acknowledgments

The work presented has been developed within the EU project IMPROVE. Additionally the authors wish thank Alessandro Milite from Elasis for his valuable insight, support and feedback during the user tests.

References

[Bol70] BOLT R. A.: Put-that-there: voice and gesture at the graphic interface. *ACM Computer Graphics 14*, 3 (262-270), 262–270.

[Ce98] COHEN P., ET AL.: The efficiency of multimodal interaction: a case study. In *International Conference on Spoken Language* (1998).

[Ce99] COHEN P., ET AL.: Multimodal interaction for 2d and 3d environments. *IEEE Computer Graphics and Applications* (1999), 10–13.

[Coh91] COHEN P.: The role of natural language in a multimodal interface. In *UIST'92 conference* (1991), pp. 143–149.

[FFU01] FORBUS K. D., FERGUSON R. W., USHER J. M.: Towards a computational model of sketching. In *6th international conference on intelligent user interfaces* (2001).

[GMR08] G. C., M. W., R. D. A.: A user-driven experience in the design of a multi-modal interface for industrial design review. In *Proceedings Human Factors in Telecommunication* (Kuala Lumpur Malaysia, March 2008).

[GS03] GOOSE S., SCHNEIDER G.: Augmented relity in the palm of your hand: A pda-based framework offering a location-based, 3d and speech-driven user interface. In *Workshop on Wearable Computing* (2003).

[Je97] JOHNSTON M., ET AL.: Unification-based multimodal integration. In *8th conference on European chapter of the Association for Computational Linguistics* (Madrid, Spain, 1997), pp. 281–288.

[Joh97] JOHNSTON M. E.: Unification-based multimodal integration. In *35th Annual Meeting of the Association for Computational Linguistics ACL* (1997), pp. 281–288.

[Ke03] KAISER E., ET AL.: Mutual disambiguation of 3d multimodal interaction in augmented and virtual reality. In *5th Internation Conference on Multimodal Interfaces* (2003), pp. 12–19.

[Lat01] LATOSCHIK M. E.: A gesture processing framwork for multmodal interaction in virtual reality. In *1st international conference on computer graphics, virutal reality and visualization* (2001).

[Lav99] LAVIOLA J.: *A Multimodal Interface Framework For Using Hand Gestures and Speech in Virtual Environment Applications*. Lecture Notes in Artificial Intelligence. 1999, ch. Gesture-Based Communication in Human-Computer Interaction.

[Mar98] MARTIN J. C.: *TYCOON: Theoretical Framework and Software Tools for Multimodal Interfaces Intelligence and Multimodality in Multimedia Interfaces*. 1998.

[OC00] OVIATT S., COHEN P.: Multimodal interfaces that process what comes naturally. *Communications of the ACM 43*, 3 (March 2000), 45–54.

[Rei98] REINERS D. E.: Augmented reality for construction tasks: Doorlock assembly. In *International workshop on Augmented Reality* (1998).

[RN00] REEVES B., NASS C.: Perceptual user interfaces: perceptual bandwidth. *Communications of the ACM 43*, 3 (March 2000), 65–70.

[Sch07] SCHMALSTIEG D.: Studierstube project: Open tracker. Online, October 2007. http://studierstube.icg.tugraz.ac.at/opentracker/.

[SdL03] SCHWALD B., DE LAVAL B.: An augmented reality system for training and assistance to maintenance in the industrial context. *WSCG 11*, 3 (2003), 425–432.

[Se98] SZALAVÁRI Z., ET AL.: Studierstube - an environment for collaboration in augmented reality. *Virtual Reality: Research, Development and Applications 3* (1998), 37–48.

[WCdA08] WITZEL M., CONTI G., DE AMICIS R.: User-centered multimodal interaction graph for design reviews. In *IEEE Virtual Reality* (Reno, Nevada, USA, March 2008).

[WOC99] WU L., OVIATT S., COHEN P. R.: Multimodal integration: a statistical view. *IEEE Transactions on Multimedia 1*, 4 (1999), 334–342.