A Taxonomy-Based Approach towards NUI Interaction Design

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Abstract. The rapid development in the domain of Natural User Interfaces (NUIs) and the proliferation of the hardware required to implement them places an increasing burden on interaction designers. Designers should be aware of research results relevant to their interaction problem but the increasing volume of NUI related research makes it difficult and thus hinders the development of usable real-world products. To address this problem, we have developed a decision-making tool that uses an interaction taxonomy in combination with definable application requirements. Using our tool, designers as well as HCI researchers can search for existing guidelines for a specific interaction problem fast and easily. In this paper we present the structure of the taxonomy, the decision-making process and tool as well as an evaluation and discussion of the overall approach.

Keywords: Interaction Design, Taxonomy, 3D User Interfaces, Tangible Interaction, Embodied Interaction, Geo-Visualization, Virtual Reality.

1 Introduction

Developing highly interactive and intuitive systems requires fundamental insights from the area of Human Computer Interaction (HCI) and human perception research [5]. Especially for Natural User Interfaces (NUIs) a gap exists between gathering such knowledge from research and transferring it into real-world products. This is mainly caused by the vast amount of results and publications that spread out across countless different publications and websites without a unified structure. Unfortunately, there is no simple reference tool enabling a fast look-up of NUI design guidelines for specific problems.

For the purpose of our research we restrict our definition of NUIs to systems that can be operated by gestures using body parts or the whole body. Our goal is to lower the burden of using new kinds of NUIs, especially within collaborative work settings. Therefore, we here only consider technology that requires low instrumentation, can be used ad-hoc and that does not require complicated setups or calibrations.

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NUIs can be very beneficial for group work (e.g. Computer Supported Collaborative Work - CSCW). Users interacting coactively[1] with NUIs often gain a higher degree of awareness [7], [9], [15]. However, since numerous environmental parameters have to be taken into account (e.g. group size and arrangement, display size, alignment and setup, type and dimension of the visualized data and the degrees of freedom (DOF) controlled by the input technology) coactive and co-local multi-user applications are much more challenging compared to single-user applications. Further more, input technologies can differ strongly in their suitability for coactive setups. E.g. touch-based interfaces are often a good solution because of the somatosensory feedback they provide. However, they are not applicable as soon as a large number of people interact on a large display because some areas get out of physical reach and the system cannot distinguish between different users. Because of these fundamental differences, creating easily accessible guidelines for coactive NUIs seems crucial.

To sum up, many parameters have to be taken into account when designing NUIs. For every single problem a number of alternative approaches might exist that designers have to consider. Solutions that have been proven to be good in one situation may be very poor in another. The number of research outcomes and publications is vast and not organized in an easily accessible and searchable way, hindering a seamless transfer into practice. Therefore, our goal is to make a first step to overcome this gap. In this paper we propose a structured iterative method of collecting, breaking down and evaluating NUI components considering different environmental parameters. Using this approach we have developed a database based decision-making tool that helps designers to find design guidelines for a specific interaction problem using NUIs. Further on, HCI researchers can make use of this tool as a reference database. They can also submit new findings to the database and detect gaps in it that require new interaction and usability studies.

The structure of this paper is as follows: First, we will present our taxonomy of NUI interaction techniques that adapts ideas from the area of Virtual Reality. Based on the taxonomy a decision-making process and the tool we developed are described. Finally, we present an evaluation and discussion of the process as well as of the decision-making tool.

2 A Taxonomy Based Approach

Taxonomies are a useful way to structure interaction tasks in a systematic way. Bowman et al. have developed a popular taxonomy of interaction tasks for the domain of Virtual Reality (VR) [1], [2], [3], [4]. To support the description and design of interaction techniques they have also introduced a hierarchical structure to describe how interaction techniques are composed of components to address specific

[1] According to [11], coactivity *„summarizes the different forms of communication, cooperation, collaboration, coordination, etc.“*

interaction tasks. While they introduced VR interaction techniques like selection, manipulation, travel and system control, we adapted their approach to the heterogeneous field of NUIs. Interaction techniques are much more diverse in this area since multiple kinds of technology offering different DOF control and multiple metaphors may be used.

Our taxonomy consists of multiple graphs, where each graph represents a single Interaction Task (ITA, see Fig. 1). A task describes an overall goal a user has to fulfill, e.g. a 2D movement of a graphical object, a rotation of a 3D graphical object or the input of text. Many ITAs are suitable for different applications but some are also very domain specific (e.g. zooming may be very different in a document management system than in geo-visualization applications). ITAs can be realized using one of the available Interaction Techniques (ITQ) as can be seen in Fig. 1. ITQs may differ in their technical realization (e.g. multitouch, tangible interaction or optical hand tracking in midair) and the metaphor they represent. ITQs can be split up into Subtasks (ST) that represent the workflow of the interaction and the order of actions (e.g. selection - manipulation - confirmation). STs therefore represent a high level view on the realized metaphor and many of them occur multiple times in the overall taxonomy. Finally, Interaction Components (IC) as the leaves in the graph represent a concrete action a user has to perform (e.g. a freehand grabbing gesture in midair or the rotation of a physical object). Since they may occur multiple times in the taxonomy STs and ICs can be realized as re-useable software components. These components can then be used for rapid prototyping and testing of new interaction techniques.

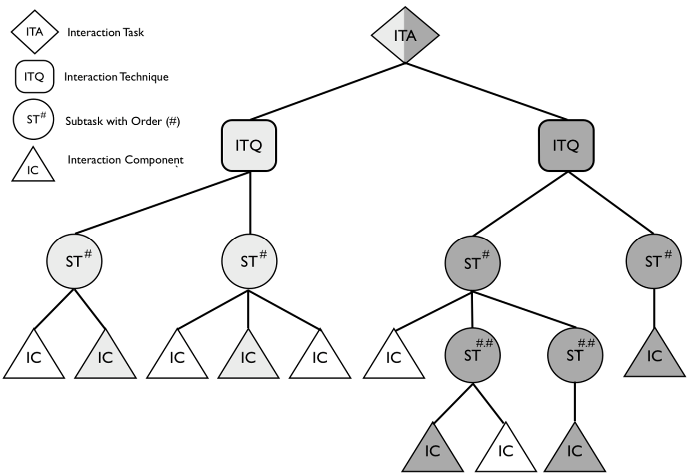

Fig. 1. Structure of an Interaction Task

Fig. 1 shows the structure of a single ITA. It shows how designers can make use of the taxonomy by choosing one of multiple available ITQs. Each ST of this ITQ has to be realized while only one of the available ICs has to be chosen. The light and dark grey shaded nodes in the graph (Fig.1) show two different possibilities for the realization of the ITA. Using the hierarchical data structure of the taxonomy decisions regarding ITQs and ICs can be automated. However, decision-making requires some kind of qualitative evaluation towards the suitability of ITQs and ICs for a specific application context. Such evaluation requires the definition of requirements that consists of ITAs, characteristics and measurable parameters.

2.1 Characteristics and Measurable Parameters

While the taxonomy in the form proposed by Bowman et al. is well suited to structure the design space of interaction techniques for VR applications, it is not quite suited as a design tool for NUIs. To enable tool support in the identification of potential interaction techniques for a task we have therefore extended the taxonomy by defining characteristics and measurable parameters. According to the idea of defining *User, Task, System and Environment Characteristics* [4] for interaction techniques, we decided to categorize characteristics for NUIs into *User, System and Application*. *User* characteristics describe the group of users and their capabilities. *System* addresses hardware characteristics while *Application* describes the software-side characteristics of the system. The categories and the definition of specific characteristics are easily extendable. We have identified some important ones that have already been addressed in research studies. Table 1 introduces some of the so far defined characteristics.

Table 1. Examples for characteristics

Group	Characteristic	Description
User	User:Cnt:2, User:Cnt:3-5, User:Cnt:5+	Describes the number of users that is coactively using the system
	User:TaskExperience:Low, User:TaskExperience:High	Describes the average experience of all users with the interaction task
System	System:DisplayAlignment:Vertical, System:DisplayAlignment:Horizontal	Describes the alignment of a single display
Application	Application:Data:2D, Application:Data:3D	Describes the dimension of the visualized data

Besides Characteristics also measurable parameters like speed, precision, intuitiveness or awareness are important for interaction designers that plan to create a specific application. These parameters can be measured within user studies either automatically (e.g. speed, precision) or using usability methods (e.g. for intuitiveness, awareness). The next section shows, how characteristics and measurable parameters are used in order to create qualified evaluations from existing user studies that address NUI interaction techniques.

2.2 Evaluating Interactions

Given the wide variety of possible interaction techniques in NUIs it would be desirable to support interaction designers with tools that allow the identification of suitable techniques and provide easy access to existing knowledge on their characteristics.

Using extendable structures like the taxonomy as well as the characteristics and measurable parameters, arbitrary application scenarios can be defined (e.g. a horizontal display setup for five users that offers precise input). After describing such a scenario using characteristics a designer or developer might further define ITAs that the application needs to offer to its users as well as a number of preferred and technically available interaction paradigms and devices. These combined descriptions are termed *requirements* (see Fig.2). Given this formalized information it becomes possible to develop a systematic procedure that is able to search for design guidelines based on the given requirements.

To enable the automated identification of suitable interaction techniques evaluation results from existing research studies must be made accessible. It is impossible to rate ITAs from the taxonomy with respect of different characteristics and measurable parameters since they represent different NUI technologies and interaction types. Therefore, the evaluation has to take place deeper in the hierarchy of the taxonomy. Evaluating ITQs and ICs on the other hand is possible and matches the choices the structure of the taxonomy offers. Therefore, we created a database-based tool that allows the evaluation of ITQs and ICs in combination with one or more characteristics and measurable parameters. All characteristics in the evaluations are described with an additional factor ranging from 1 to 3 in order to define the importance of every single characteristic. Further more, it is also possible to rate the coexistence of ICs. This is extremely useful to avoid media disruption (switching from on interaction technology to another) or to force the usage of specific ones (e.g. the use of digital pens for text input even though all other input is done without pens). Each evaluation gets a rating that can be either X (impossible to fulfill requirements), - (not recommended combination), * (good solution), ** (very good solution / best practice). The following combinations are evaluated:

- IC [1], Charakteristics [1..n] and measurable parameters [0..n] (IC eval.)
- ITQ [1], Charakteristics [1..n] and measurable parameters [0..n] (ITQ eval.)
- IC [1] and IC [1] (IC-IC eval.)

Every evaluation needs at least a reference or written defense that justifies the evaluation. Further on, technical requirements may occur for specific combinations. For example, some multitouch techniques in multi-user setups might require user identification or authentication. This is later presented to the designer along with the results. Therefore, they have also to be described while entering an evaluation using our developed tool. Fig. 4 shows some examples of evaluations that have been entered into the tool.

3 The Decision-Making Process and Tool

We have developed a decision making tool, that allows to enter and edit characteristics, measurable parameters, technical requirements, evaluation results as well as the creation of new and editing of existing ITAs. The overall decision-making process, involved roles and the input of data can be seen in figures Fig. 2 and 3. At the moment we are using an algorithm that looks up every entered evaluation for the given requirements (ITAs, characteristics, measurable parameters) and creates the best-rated overall solution for all ITAs. However, it does not simply present one solution but a number of *design alternatives* with good overall-ratings in order to present guidelines from which a designer may choose. A *design alternative* consists of a specific ITQ but only one single IC for every ST. The most interesting point here is that the resulting ITQ can be a newly created and never tested combination of ICs. Therefore, our tool creates new combinations that result in completely new NUI interaction techniques. Further more, within a design alternative, additional characteristics are given that have not been part of the requirements but are needed to design the system. Whenever needed or existing also technical requirements, annotations and existing discussions are presented within a design alternative. Our tool creates discussion threads automatically whenever conflicting evaluations are detected. Besides positive results also design alternatives with bad evaluations are presented to the user in order to give insights about bad influences to the system.

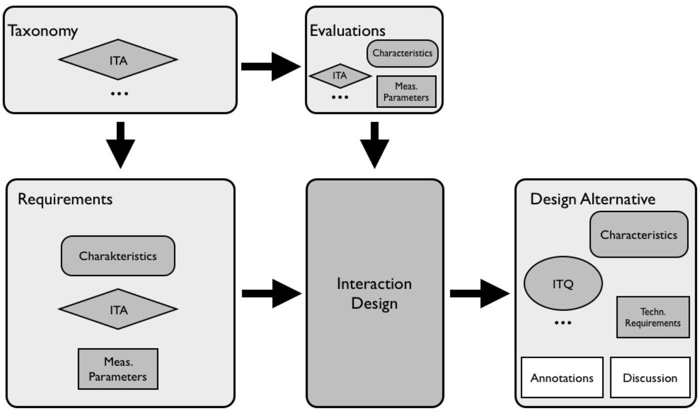

Fig. 2. The decision-making process

In summary, the tool we have created allows to enter new data and to request design guidelines based on given requirements. Guidelines consist of multiple design alternatives a designer may choose from. Designers can hence use the tool to get insights about existing knowledge about a specific interaction problem. On the other side, HCI researchers can use the tool for archiving their research results and for a fast look up of existing studies as well as for gaps in NUI research. Therefore, the tool is ideally usable in preparation of new HCI studies.

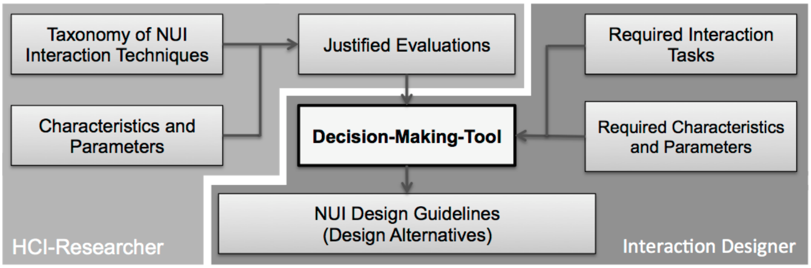

Fig. 3. Roles in the decision-making process

4 Evaluation and Discussion

In this section we present an evaluation and discussion of first tests of the developed concept and tool. The tool was implemented as a web application on an Apache web server and it uses PHP and a MySQL database.

In order to test the approach we entered data from three interaction studies that we performed in our lab into the database using the tool. Within these studies we analyzed single user 6 DOF multitouch interactions on a large tabletop display [12], 3D selection, manipulation and travel tasks using mid-air gestures in front of a large wall projection [13] and tangible interactions for 3D tasks in single and coactive user setups [14]. The decision-making tool could easily be used to describe all characteristics of the study settings. Further on, the developed interaction techniques from all studies have been entered. We therefore created two ITAs: 6DOF Object Manipulation (that also includes prior selection) and 2D Camera Control (using an avatar mounted virtual camera in a 3D environment). Since multiple interaction techniques and metaphors have been tested in the study, the result was a taxonomy that consisted of 2 ITAs, 7 ITQs, 34 STs and 27 ICs. These values demonstrate the multiple occurrences of ICs since the number of STs is higher than the number of ICs. At least one IC is required for every ST and almost every ST in our taxonomy possesses two ICs or more.

After defining characteristics and the taxonomy, the study results have been transformed into evaluations and entered into the database using our tool. Different measurable parameters have been taken into account and in summery we entered 34 ITQ evaluations (some of them can be seen in Fig. 4, right), 112 IC evaluations and 9 IC-IC evaluations.

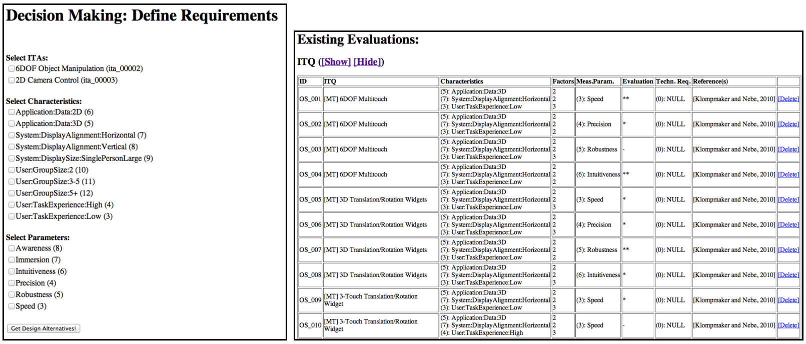

Fig. 4. Screenshot of the decision-making tool: defining requirements (left) and overview of existing ITQ evaluations (right)

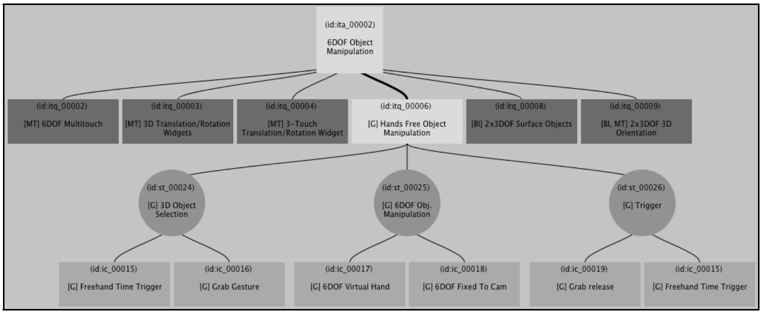

Fig. 5. Screenshot of the decision-making tool: Taxonomy view

To evaluate the concept and its usage it was presented to eight researchers, mostly PhD students in the area of HCI, within two seminar lectures. All of them stated that the concept is easily understandable and allows the transformation of arbitrary NUI interaction techniques into an interaction taxonomy, the description of interactive systems using characteristics as well as entering evaluations based on study results and measurable parameters. However, at the moment it is not yet clear if designers are able to easily understand the concept. Since design alternatives consist of the description of an ITQ based on our taxonomy, they need to understand this concept.

Using the test data from the three studies we analyzed if the decision-making tool behaved the way we planned. During multiple different search queries we came to the conclusion that the programmed algorithm resulted in good as well as bad rated design alternatives as expected. Further on, also new interaction techniques have been found by combining previously untested ICs of the different STs. The test queries showed that the algorithm considered all entered evaluation data. However, it has to be investigated whether the algorithm parameters used to evaluate different combinations for the design alternatives are a good choice or whether they can be optimized in order to produce better usable results. Finally, it is still unclear, how good the results of the process are in practice since only theoretical combinations based on different user studies are combined. With our test data the algorithm needed less than two seconds to process every search query. Since we do not expect that queries with more than two ITAs will occur in practice that often, we state that the algorithm run-time is quite scalable even if the amount of data drastically increases while entering further study results.

5 Conclusion and Future Work

In this paper we presented a taxonomy-based decision-making process and tool for NUIs. This tool can be used by interaction designers in order to search for existing design knowledge for a specific interaction problem. HCI researchers can use the tool to search for existing studies, to archive their own results and to enter new Interaction Techniques. Existing ones can be extended by new taxonomy components like ITQs, STs and ICs allowing the definition of arbitrary interaction processes with different NUI technology and using different metaphors. In addition, new characteristics and parameters that describe the conditions of an interactive systems and evaluations from user studies can be defined and entered easily.

We entered data from three user studies that have been performed in our laboratory and presented results and a discussion based on our experiences with the tool. We have established that the tool allows the identification of design alternatives that are relevant to a specific interaction task in a specific context and thus aids interaction designers in making informed design decisions. We think that the combination of the taxonomy with an interactive tool is a very suitable approach of enabling a more effective transfer of NUI research results into practice.

Building on experience in collecting and hosting community portals about interaction technologies from the AMIRE project[2], as a next step we plan to make the decision-making tool available online for the NUI community. This will be done after running some usability tests and redesigning the tool in order to make it usable for designers and researchers as well. Hopefully this will result in a larger number of data from different domains. Further on, we plan to allow the community to discuss on evaluation conflicts and extensions of the overall approach. We therefore hope to get feedback and input from domain experts and HCI researches as well regarding the concept presented in this paper.

[2] http://www.amire.net/index.html

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