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# Interaction-in-the-large vs interaction-in-the-small in multi-device systems

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## ABSTRACT

In this paper we analyze how interaction develops in multi-device environments by distinguishing two layers: an *interaction in the large* layer defines an interactive experience across different devices and locations, where roles and tasks evolve and intertwine; an *interaction in the small* layer defines the actions done and the interaction techniques used to execute a specific, self-contained task on a device. We present a notation to describe interaction in the large and demonstrate how it can be useful to understand the interaction layers perceived by the users during an interactive experience. We finally report about a user experiment in the context of a real application scenario to evaluate concretely which interaction layers the users observe and if they are able to recognize the boundaries theoretically identified through the notation.

## CCS CONCEPTS

• **Human-centered computing** → **HCI theory, concepts and models**;

## KEYWORDS

Distributed interaction, in-the-large, in-the-small, interaction trajectory, interactive experience, multi-device.

## 1 INTRODUCTION

Multi device environments (MDE) are receiving increased attention due to enhanced display technologies, spread of public displays, augmentation of ambients with embedded devices, and spread use of mobile technologies and personal devices. Moreover, the growth of information available for immediate access contributes to the improvement of contemporary use of a wide range of computing devices according to the user context, the amount and type of information, the degree of information sharing vs privacy, etc. Such interactive environments can be found in many application domains such as public transport, museums or even just in the streets [22]. They are mostly used to display information [19] because so far no dedicated device can efficiently and effectively cover MDE requirements: smartphone [5], tactile [21] and gesture [25] based interaction are recently considered solutions but acceptability and robustness remains to be established. Furthermore, users take control of different devices during the execution of a complex procedure by changing location, role, attention and task in several seamless or discrete trajectories along an interactive experience. Thus, an emerging challenge in such a scenario is the ability to analyze and compare different multi-device configurations along many dimensions.

To contribute to this challenge, we first distinguish between two different interaction types in the execution of a complex task spanning many devices, many locations and a long time: a fine level and a coarse level. In the fine level, interaction is performed with a limited set of devices used sinergistically to achieve a self-contained task in a short span of time, focusing on a precise aspect of the interactive experience. In the coarse level, the interaction performed is intended to support a sequence of tasks executed on a greater timescale and in a wider location or set of locations, involving the use, at different times, of several devices in a coordinated way to get the final goal. At the coarse level, the user's physical activity (e.g., moving, switching devices, changing visual focus) contributes to the global process of the interactive experience.

Borrowing the terminology from a classical paper by DeReimer and Kron on software development [6] we call the two

types, respectively, *interaction in the small* (ItS) and *interaction in the large* (ItL). This distinction aims at improving the design of complex interactive procedures by considering the different scopes of two activities: the design of the interaction techniques covering a specific aspect of the interactive experience (ItS) and the design of a more global view including the relations between tasks and devices in a procedure (ItL). More precisely, the interaction in the large layer defines the sequence of tasks and activities a user does moving from one phase to the next of a complex procedure across different devices and locations, where roles and tasks evolve and intertwine. In a multi-display and multi-device environment the devices' physical layout could lead the user to displace, implying: (1) a physical trajectory in space along which the interactive experience develops; (2) the possibility that some displays/devices be sometimes not in sight or occluded; (3) in case of multiple users with different roles, the spatial relations between the user and the distributed equipment could impact the ability of the users to effectively join the experience in a continuous way.

The interaction in the small layer defines the sequence of operations a user does on each local device in a unitary way, i.e., with no or limited displacement, (e.g., around a large touch table), in a short and non interrupted span of time, with a limited and well defined goal. With the expression "unitary way" we refer to Aristotle's classical units defined in his *Poetics*, i.e, the unity of action, unity of time and unity of space [2]; unity of action refers to the self containment of an interactive task.

While the ItS layer has received great attention and has a solid theoretical and technical background, the ItL layer still needs to be explored at depth. In this paper, our approach to better understand and use the distinction between the two layers relies on the discovery and definition of *interaction trajectories* at both levels. The user motion in a spatially distributed environment, the change of attention and access to sparse devices, the temporal delays between different phases of a procedure define the trajectory of an interaction in the large [3, 24], that in the following will be called simply *trajectory in the large*. On the other side, the transitions between different ways of use of the same device, such as the activation of a new window, the switch of a data representation or data content, evolve along a trajectory in the small [8, 13] contributing to the continuity, fluidity, naturalness, etc. of the interaction [10, 18].

In this paper, we first review the literature about MDE, interaction spaces and interaction trajectories. Then we introduce a concrete scenario for an MDE and three different running configurations. Based on this scenario and configurations, we introduce the elements of a notation to describe the trajectory in the large, and produce a conceptual comparison of these three settings. Finally we report about a

user experiment in this environment: it reveals that user's change of location is more disruptive than a change in visual attention or interface. It also reveals that a change of device helps in differentiating subgroups of activities, contributing to the clear identification of the two interaction layers.

## 2 LITERATURE REVIEW

### Multi-device environments

A large literature exists on the domain of multi-device environments. Elmqvist's review [9] defines a reference framework for distributed user interfaces whose components are examined along five dimensions: input management, output display, platform in use, space layout, and time of execution on different devices (i.e., synchronous vs asynchronous). Paternò and Santoro [20] describe several design dimensions for multi-device environments in a framework addressing the issues of interface distribution and granularity, facing also multi-user environments and interface migration across devices.

With a different perspective Luyten and Coninx [15] discuss how measures of completeness and continuity can be defined on a distributed interaction space. Completeness means that the user is able to access all the interaction tasks needed to reach a goal regardless of the devices available in the environment. Continuity means that the user is able to interpret the behavior of the whole interactive system regardless of the devices used at a specific time. The two concepts play a role mainly in the context of ambient computing. Vanderdonk [23] develops a conceptual framework about the distribution of elements and functions of UIs across devices according to task, users, domains of use, contexts, etc., with a focus on the class of data access applications.

Usability of MDE is addressed by Majrashi and Hamilton [16]. The authors refer to cross-platform systems where services can be offered by several platforms (classes of devices, e.g., desktop, tablet). The paper investigate the domain of cross-platform systems and multiple user interfaces, referring different views of the same information and allowing access from different computing platforms. The authors discuss twelve usability factors in a formulation adapted to cross-platform, covering properties like efficiency, effectiveness, learnability, satisfaction, visibility, understandability, etc.

These different works address important issues about MDE features and design principles, but do not discuss how the presence of a multi-device environment could favor or contrast the user in executing his/her tasks, leaving space to more specific descriptions, models and notations. Indeed, in

this paper we do not aim at discussing multi-device combination, multimodal interaction, adaptation of devices, middleware, user's collaboration, but rather focus on a description of the user's flow of activity in such context.

### Interaction spaces and trajectories

The interest in distributed interaction is growing towards interaction spaces related to new embodied forms of interaction, based on mobile and embedded interfaces, gestures, wearable devices, that change the understanding of how people interact with the environment [4]. As the complexity of the tasks grows, involving many actors along time and in large physical spaces, the correspondence between the interfaces, the activities and the places where they happen become articulated and needs to be analyzed at several level. Proxemic interaction, occurring in the space close to the users, is analyzed in [14] as the new locus where interpersonal interactions with other people and proactive interaction with devices occur.

The term interaction in the large has been used by Alan Dix et al [7] to denote interaction developing in time through many discrete phases involving many users in a collaborative scenario; his paper suggested to widen the concept of interaction to include the processes typical of a CSCW environment. We agree with such definition, but it was issued when the availability of multi-device environments for one user was still far, and in our opinion should be reformulated. Recently the expressions *in the large* and *in the small* have been used to denote different interaction techniques suitable for large and small screens [11]. Interacting with very large screens, where simple touch gestures are unsuitable, is discussed by Ardito et al in [1].

The analysis of complex interactive activities involving a distributed and spatially wide space is at the basis of the concept of *interaction trajectory*, developed mainly in the field of embodied performances, collaborative gaming and interactive exhibitions [3]; in such contexts, a trajectory is the set of states of a user in a rich interactive experience where the relations between the physical world and the digital world are complex and dynamic.

In [8] we defined an interaction trajectory as the set of interactive steps a user does in order to complete an activity and reach a goal. Each step requires information display and input operations on some device and produces a result as an output on some (same or other) device, thus refining the "interaction in the small" layer introduced in this paper. A different approach, still close to the idea of interaction in the small, is given in [17], where a trajectory is defined as a set of steps during the user's interaction with an application, but limited to the perception of the interface. At a lower level, Gorgan and Duce [13] define a trajectory as the evolution of interface objects (e.g., widgets, icons, windows) due to

the change of their properties (aspect, position) during the execution of an application.

The concept of trajectory applied to the description of interaction is thus only partially explored and needs further refinements to fit a multi-device environment, and specifically our concept of interaction in the large.

### 3 A SCENARIO FOR A CASE STUDY ON MDE

A typical MDE scenario involves a distributed equipment and several activities related to a set of coordinated goals: for example, to present a large multimedia or multidimensional information to many users, each with proper role and executing different actions; to split information between public and private devices, according to various sharing and privacy requirements; to augment interaction with dedicated devices; to share work in a CSCW environment, and so on. In all such cases variants occur in interaction needs as the scenario develops along a series of procedures, activities, phases, tasks and operations at different time paces and with evolving spatial relationships.

To address the issues about interaction in the large and in the small, we present a scenario based on an actual project carried on at the University of Toulouse involving a large set of needs, people, roles and equipment.

#### The concrete scenario of the neOCampus project

The *neOCampus* project is a multidisciplinary approach towards the definition of a smart, sustainable and innovative university campus, gathering ecologists, computer scientists, material scientists, electricity specialists, thermal and acoustics experts together to combine their expertise and offer new services. Their work should contribute to reduce the ecological footprint of the campus and to provide a support for better management of the energy consumption.

The project relies on a huge information system storing data captured by a network of sensors installed in the campus. The information system records instant and historical energy consumption values related to different resources: gas, electricity, heating, water, etc. Information is grouped at different levels of granularity, from buildings and floors down to rooms and devices.

A frequent procedure in the project context involves the campus managers and technicians during the evaluation of the energy management policies. An operator in front of an audience explains the issues about energy consumption following a script that, typically, evolves in four phases: in the beginning (phase 1), after setting up the system, the map of the campus is explored, reading summary energy consumption values for some campus buildings, until one building is selected for detailed analysis. Then (phase 2) summary and detailed data for the selected building is shown and commented in several representations, tabular and graphic, and

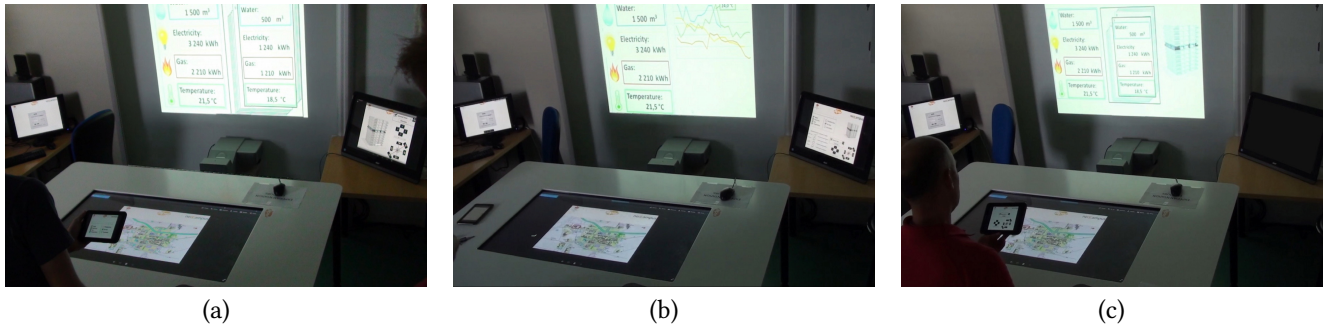


Figure 1: The multi-device setup used in the experiment

related to different time spans: instant consumption, cumulated consumption over a period, historical series. In the third phase a 3D representation of the building is visualized and explored, selecting a floor or a specific room or lab, showing detail consumption values related to the selection. In the fourth and last phase a simulation is executed by changing the equipment working parameters (e.g., changing the duty cycle or the time of use, turning equipments on-off, changing the levels of air temperature and environmental parameters) and showing the effect of such changes on energy consumption. The four phases are repeated in other buildings of the campus to compare energy consumption in different areas.

Running such a scenario in an MDE context is of course dependent of the setting of the MDE in terms of available resources, topology of the devices, etc. The interactive experience is therefore not straightforwardly linked to the scenario, but may also largely be influenced by the way it is deployed. Considering an existing multi-device laboratory setting in one of the departments of the University, we envisioned three different ways of projecting this scenario, resulting into three different configurations.

### Projecting the scenario into an MDE laboratory setting

The laboratory installation is composed of several pieces of equipment that can be used in different experiments with different setups. We consider the following devices:

- a PC with a monitor, a keyboard and a mouse;
- an interactive large multitouch table with autonomous processing capabilities;
- a projector for public display of information on a laboratory wall;
- a medium-size multitouch screen running Android OS;
- a mobile device, actually a 7-inch tablet.

Three different configurations using all or some of such devices are defined in the following; the rationale for each configuration is also explained in order to allow for some generalization. Figure 1 shows the three lab configurations,

while Table 1 summarizes for each configuration what is displayed on which device and how the devices are used to execute the operations defined in the four phases of the procedure described above.

*Configuration 1.* This configuration uses all the five devices and corresponds to the setting shown in Figure 1a. The allocation of information and tasks to devices follows the rule that application and control inputs are segregated: the management of the overall system is done by a console (the PC) that controls allocation of information and tasks to the various devices, and manages the system's state. The map is rendered and controlled on a device on which it can be moved and zoomed (the table); the control of the application behavior (what information is displayed where and how) is managed by a mobile device (the tablet); tabular application data related to the energy is presented on a fourth device (the projector); a fifth device (the touch screen monitor) is devoted to the display and management of the 3D representation.

*Configuration 2.* In this configuration (Figure 1b) the mobile device is not used; all interaction (except system control and map management which are the same as in Configuration 1) is done on the touch screen monitor; due to its size, all the required visualizations and controls can be displayed at the same time (when applicable) juxtaposed on the screen. The rationale for this configuration is to provide input capabilities to the video projection, so that the input interaction with the projection does not interfere with the map control.

*Configuration 3.* This configuration (Figure 1c) uses the mobile device in place of the touch screen monitor and is therefore quite traditional: the mobile device is used as a remote controller to interact at a distance with another display. All interaction (except system control and map management) is done on the mobile device. Due to its small size the display of information and control panels and widgets requires some form of 'multiplexing', e.g., through exclusive tabbed panels.

	Configuration 1	Configuration 2	Configuration 3
Console	Initialization controls	Initialization controls	Initialization controls
Table	Map Region of interest	Map Region of interest	Map Region of interest
Mobile	Data type selection controls Historical data controls 3D interaction controls Equipment parameter controls		Data type selection controls Historical data controls 3D interaction controls Equipment parameter controls
Projector	Selected energy instant value All energy instant values Historical data Energy instant values of a floor	Selected energy instant value All energy instant values Historical data Energy instant values of a floor	Selected energy instant value All energy instant values Historical data Energy instant values of a floor 3D view
Touchscreen	3D view	Data type selection controls Historical data controls 3D interaction controls Equipment parameter controls	

**Table 1: The MDE configurations in the neOCampus scenario.**

Beyond the devices, the information and the distribution of the information over the displays, the dynamics of the interaction over the different devices and along the scenario can be rather complex in MDE: for each configuration, such dynamics correspond to a different *trajectory in the large*. Furthermore, each device involves a specific way of interacting, generating a series of *trajectories in the small*. If existing notations such as the ASUR model [12] could cover the ItS, there is no support for describing the ItL in an MDE. Therefore, we introduce in the next section a notation to describe a trajectory in the large in an MDE.

#### 4 A NOTATION TO DESCRIBE A TRAJECTORY IN THE LARGE

A trajectory in the large is a sequence of phases (activities, tasks) described by three environmental components (who is doing what, where, using which device):

- the user’s physical location, possibly changing in time;
- the device(s) used in each phase;
- the user’s activity, i.e., the task executed during each phase by an application program or function;

and three relational components (how the user relates to space and devices):

- spatial access: access a device, i.e., go to the device location or grab it (for mobiles);
- logical access: use a device, i.e., issue commands through its interface; refinement of its use would be done at the level of interaction in the small;
- visual access: look at a local or distant device; we assume that using a device implies also to look at it.

At each phase of a trajectory in the large the user experience (application, task, function) is declared together with the user relations with the environment (i.e., location), device used and access type. Thus, each step corresponds to the statement: *the user is doing this task in this location (or is accessing this location), is accessing or using or looking to this device for executing the task*. A synthesis of such statement can be described by a 4-tuple  $\langle \text{task}, \text{location}, \text{device}, \text{type of use} \rangle$ . In the following section we shall illustrate how this notation can support a theoretical analysis and comparisons of the three configurations, focusing on the interactive experience during the execution of the phases of the scenario.

#### Using the notation to compare the three configurations

Table 2 summarizes the phases of the scenario projected on the three configurations, making explicit the trajectories in the large. The task, being the same for the three configurations, is factorized on the left of the table. Each trajectory is described by three columns corresponding to the other components of the tuple, where interruptions in the continuity of work due to changes in location, device and activity in the three trajectories are visible. As noted above, for simplicity we have made explicit the visual access wrt use only when the visual access is the only way to use the device, e.g., with the projector. We note that some activities represented in different rows in the table, e.g., the sequence *change view* and *change data* in phase 2, could as well be executed in parallel or in a repeated loop, generating local variants in the trajectories. We do not enter into such details since they do not change the meaning and goal of trajectory analysis.

Phase	Activity	Configuration 1			Configuration 2			Configuration 3		
		location	device	relation	location	device	relation	location	device	relation
1	setup	console	console	use	console	console	use	console	console	use
	explore map	table table	table table	go use	table table	table table	go use	table table	table table	go use
	consult data	table table table	mobile mobile projector	grab use look	touchscreen touchscreen touchscreen	touchscreen touchscreen projector	go use look	table table table	mobile mobile projector	grab use look
2	select a building	table	table	use	table table	table table	go use	table	table	use
	change view	table	mobile	use	touchscreen touchscreen	touchscreen touchscreen	go use	table	mobile	use
	change data	table	mobile	use	touchscreen	touchscreen	use	table	mobile	use
	consult data	table	projector	look	touchscreen	projector	look	table	projector	look
3	visualize 3D	table touchscreen	mobile touchscreen	use go	touchscreen	touchscreen	use	table table	mobile projector	use look
	explore 3D	touchscreen	touchscreen	use	touchscreen	touchscreen	use	table table	mobile projector	use look
	select floor	touchscreen	touchscreen	use	touchscreen	touchscreen	use	table table	mobile projector	use look
	consult data	touchscreen	projector	look	touchscreen	projector	look	table	projector	look
4	start simulation	touchscreen touchscreen	mobile mobile	grab use	touchscreen	touchscreen	use	table table	mobile mobile	grab use
	exec simulation	touchscreen	mobile	use	touchscreen	touchscreen	use	table	mobile	use
	consult data	touchscreen	projector	look	touchscreen	projector	look	table	projector	look

**Table 2: The trajectories in the large defined for the three configurations of the scenario.**

### Towards a theoretical analysis to compare the configurations

From the ItL point of view, Configuration 1 appears as the most articulated and complex. This is expected because there are more devices involved, the devices are located in different areas and some of them are non moveable. Each device has a specific role and the tasks to be done require interleaving of such roles, hence switching devices. On the other side, Configuration 3 is the simplest if we consider the user displacement an important part of ItL complexity; this also is expected, since the mobile device can be carried with the user, lessening the need to displace to reach it. Moreover, being the only device to be operated (except for map control), there's no need to take/drop it several times as in Configuration 1.

The analysis of ItL trajectories shows globally a limited variance since the access to the touch table for map control is needed only at the beginning of the operations. There is a wide loop in the scenario as the four phases are repeated by inspecting other parts of the campus, but there are no back-and-forth operations between the phases. Considering not only the input commands but also the user attention to output, Configuration 3 seems the best at the ItL layer

because the user can stand where he/she wants, due to the fact that almost every interaction (except at the beginning) happens on the mobile device.

From the ItS point of view, in Configuration 1 the roles of the devices are well defined and not multiplexed. If task interleaving is limited, this situation is the least complex in ItS terms. On the contrary, Configuration 3 gives the user a higher cognitive load, given the overload caused by function multiplexing on the mobile device. Configuration 1 is more effective, Configuration 2 is ranked in-between, due to less need to switch the device interface to access all the functions.

The theoretical analysis may be useful to help reasoning about the MDE design. It could help to anticipate interaction problems such as the number of location changes, device switching, data distribution, etc., all constituting parameters that potentially alter the fluidity of the interaction. But of course, which metric has a real influence on the MDE must be established. To confirm that this notation and the subsequent theoretical analysis constitute useful supports for reasoning about the design of interactive experience in the different multi-device configurations, we have designed an experiment to examine and compare different multi-device



configurations during the execution of the activities related to energy management, based on the three configurations introduced. It aims at identifying the pros and cons of each configuration with respect to the ease of use, the continuity of work, the fluidity of interaction, etc. It also aims at identifying the events or elements of the interactive experience that seem to be more prone to disrupt the interaction. Finally, a subjective ranking of the different configuration is also analyzed. Of course, pros, cons and influencing events are expected to be some or all of the elements introduced in the notation. Therefore, this experiment will also serve as a first assessment of their impact on the user's experience.

## 5 THE EXPERIMENT

### Experimental protocol

The experiment follows the scenario introduced above: it consists of identification, exploration and simulated variation of energy related parameters in selected buildings, floors and rooms of the campus. 2D and 3D representations of the campus area and buildings are visualized, together with data tables and graphics of energy values across different temporal intervals. Controllers of different natures (menu, checkbox, button, slider, tactile manipulation, etc.) are provided to allow the control of the interface of the application. The experiment also reproduces the three configurations identified and is therefore composed of three sessions in which the same scenario is run. In each session part of the equipment is used differently: different information and user input are allocated to different devices to conform to the configurations. The experiment is executed in form of a Wizard of Oz experience where the information processed and displayed according to different presentations on several devices is fictitiously generated by human intervention rather than by real applications.

*The apparatus.* Figure 1 shows an overview of the MDE lab setting in the three configurations. A large interactive table hosting a 46-inch screen combined with an infrared frame able to detect multi-touch interaction is placed in the middle of the lab. The mobile device is a 7-inch Samsung Galaxy Tab 2. The projector is a Sanyo ultra-short focus projector displaying a 73-inch image on a vertical wall. The touchscreen is a 24-inch Android powered tablet, placed near one corner of the interactive table. The PC is connected to a 22-inch screen and is positioned near the other corner of the interactive table. The distance between the interactive table and the PC, the projection and the touchscreen allows the participants to freely walk around the table.

*Participants and tasks.* Six participants, members of the Department of Computer science of the University, took part in this study (two females, average age 30). They were used

to advanced forms of interaction, but none of them had previously been working in multi-device environments. During the experiment the experimenter is leading the participant through the different phases of the scenario. The experimenter drives the participant to the appropriate location in the MDE, describes the task that is taking place, and acts on the devices to control the interactive process. At each step, the experimenter asks the participant questions about data displayed on different devices to keep the participant in the loop of the interactive experience. For example, after activating the visualization of the energy consumption data of the four energy flows (water, electricity, gas and temperature) the participant is requested to tell the value displayed for the electricity consumption. The scenario is reproduced three times with each participant in order to cover the three configurations. The experiment took 50 minutes on average for each participant, including the compilation of the questionnaires as explained in next section.

*Procedure and data collected.* We counterbalanced the sequence of the configurations presented to the participants. After each configuration, a questionnaire was filled by the participants, requesting to express three positive and three negative comments related to the interactive experiment they just had attended. Participants also had to tell which phases they had been through and what aspects or events of the interactive experience contributed to the identification of these phases. At the end of the experiment, a final questionnaire was given to the participant asking for a ranking of the three configurations in terms of preference. The questionnaire also contained a list of six events occurring during the experiment and related to the device (change of interface and change of device), activity (change of task and change of action) and to the location (change of physical location and change of visual focus). The participants had to rank them from 1 to 6, 1 being the event that, according to them, would systematically materialize a change of layer in the interaction, i.e. moving from an interaction part focusing on a specific aspect of the experience (ItS) to a more global aspect (ItL) or conversely.

### Results

We first synthesize the positive and negative points mentioned by the participants, then we report the ranking of the configurations and events that are perceived as fostering a change of interaction level.

*Subjective comments of the participants.* The six participants were requested to provide up to three positive and three negative comments for each configuration. We ultimately collected a total of 50 positive comments and 50 negative comments. The clustering of the comments relies on a synthesis performed by two HCI specialists. This process

results into the identification of 4 classes of negative considerations and 4 classes of positive comments.

From the negative point of view, the four classes of comments are related to physical arrangement of the MDE (36%), device manipulation (28%), information dispatch (10%), and generic HCI considerations (26%). Half of the 18 comments related to the physical arrangement noted that it is annoying to physically change location during the interactive experience. And yet only two configurations required location changes during the experiment performed by 6 participants: it means that this negative consideration was expressed in 75% of the cases. This is a very surprising and interesting comment: indeed, it means that efficient interaction supports should be provided in MDE to allow users interact with distant displays. Another quarter of the comments related to the physical arrangement focused on the difficulty to deal with multiple devices (5 comments): device switching and identifying the appropriate device to interact with appears problematic. Finally four comments concerned the console which is seldom used and shouldn't be on a separate device.

Six comments out of the 14 negative comments related to device manipulation highlight the underuse of the capabilities of some devices. It includes for example a very limited use of the interactive touch table despite its large screen, multi-touch input and computing capabilities. Four other comments stress the isolating effect of having to interact with a fixed vertical touchscreen: it enforces to be very close to this device and to face it, thus blocking the user from visualizing the remainder of the MDE. Finally, four comments emphasize that manipulating multiple modes on a single device (the mobile device) is cumbersome. Regarding information dispatch, the five comments were oriented toward a lack of homogeneity, i.e. a mix of information nature and role, and a too high information density. Finally generic HCI considerations were mentioned, such as suggestion for better icons representation, request for direct manipulation of 3D rather than manipulation through widget buttons, position of information on a given screen, etc. Although these considerations affect the user's interactive experience, we do not further refine them as they are not straightforwardly related to the MDE.

From the positive point of view, the four classes of comments are related to spatial considerations about the user and the devices (28%), output device arrangement (30%), input device arrangement (12%), and generic design options (32%). One third of the 15 comments addressing the physical arrangement (5 comments) are related to the fact that no location change is required (like in Configuration 3). Given the negative comments made about the need to move during the interactive experience, this is a coherent result. Another third highlights that the use of a mobile display allows its use everywhere. Further comments consolidate this statement

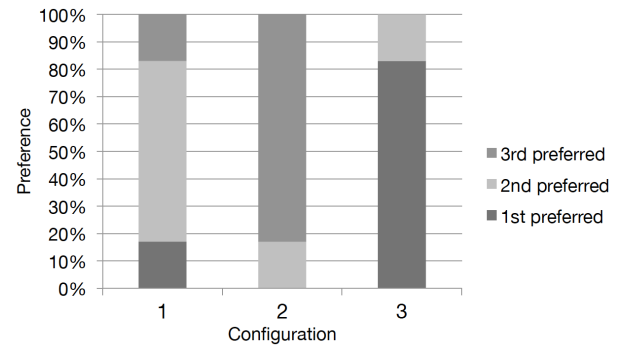


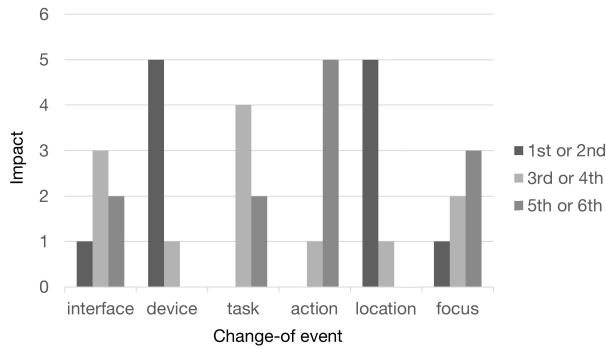
Figure 2: The ranking of the configurations.

by underlining that mobile devices establish a glue over the MDE and facilitate multiple user interaction as the device can be passed over to someone else.

From the perspective of the output device arrangement, two thirds of the responses (11 comments) emphasize the relevance of allocating different sets of commands and information to different device. Various comments reinforce this positive aspect by explaining that it adds clarity, avoids high density of information and allows for a clear overall view of the whole information at one time. Positive comments related to the input device arrangement are less focused because this part of the interaction was not detailed in the scenario. However, it seems to be particularly appreciated to group all the controllers on a single device (half of the comments). Finally, generic design consideration particularly emphasize the use of the focus and context paradigm, the presence of different types of data and interactive features. These comments were however not directly related to MDE interaction.

A further remark stemming from the comparison of the theoretical analysis of the three configurations and the participants' comments faces an issue out of the scope of the experiment but deserving attention at a different level of analysis: in terms of spatial location the layout of the laboratory is not optimal. Placing the table with the touch screen monitor towards the audience would improve the overall ergonomics because the displacement between the table and the touch screen monitor would be limited (a gain for interleaved map/data interaction) and looking at the projector would be more comfortable.

*Rankings.* At the end of the experiment, each participant had to rank the three configuration they had been through in terms of preference, 1 being the preferred configuration and 3 the least preferred. As illustrated in Figure 2, over the six participants the configuration involving the projector and the mobile device is largely the preferred configuration: it was ranked first in 83% of the cases and was never ranked



**Figure 3: The ranking of the events.**

third. Conversely, the least preferred configuration is the one involving the projector and the touchscreen: it is ranked third in 83% of the cases and was never ranked first. Giving the negative aspects expressed, this is most probably due to the need for the user to change location to reach the touchscreen and because of the density of the information displayed on it. The configuration including all the five devices was ranked second by 67% of the participants and 17% of them ranked it first or third. This result is another very interesting and surprising outcome. Indeed, although allocating different information to different displays is the most often cited positive consideration (20% of the cases), the configuration using the maximum number of devices is not the preferred one.

As mentioned in Section *Procedure and data collected*, participants also had to identify which events were more prone to materialize a change of interaction level. The most impacting event is ranked 1 and the least one is ranked 6. As illustrated in Figure 3, it clearly appears that the change of device and the change of location are the most influential events for expressing a change of interaction level. The result also reveals that a change of visual focus and a change on interaction activity (e.g. button click, slider, etc.) are not really affecting the interaction level felt by the user. Although it creates a discontinuity in the interaction flow, focus change and interaction change are usual events when interacting with a system and hence are no longer considered as really disturbing. Finally, on overall, events related to the use of the application (change of task and change of action) are the least impacting events on the perception of interaction level change. Results highlight that changes in terms of devices and locations are the most influencing events in terms of segmentation of the user’s interactive experience.

This final observation is confirmed by the last part of the questionnaire provided to the users after each configuration. They were asked to mention the phases they had felt in the interactive experience and what elements were triggering the identification of these phases. Out of 18 answers (3

configurations  $\times$  6 participants), 9 (50%) answered that the identification of the phases was linked to a change of device and 5 (27%) mentioned the change of location. The remaining answers were distributed over three different reasons.

## 6 CONCLUSION

In this paper we first introduced the notions of interaction in the large and in the small to denote two layers at which an MDE can be designed and exercised; the distinction between local interactive tasks at one side, and interactions spanning several devices, locations and activities distributed in time at the other side, defines two layers where specific interaction trajectories can be defined and analyzed. We then focused on the notion of trajectory at the interaction in the large layer. We have defined the core elements of a notation describing such trajectory, and have illustrated its use on a concrete scenario, deployed into three different MDE settings, relying on the trajectory notation to analyze in a theoretical perspective these configurations. Differences in terms of location change, visual focus and interaction mode were highlighted.

We then performed a user study in a lab setting reproducing the three configurations of the scenario. The results confirmed the impact on user’s interactive experience of location changes, information distribution over the devices and of the way a device involves the user (isolating versus gluing): these three class of comments were the most often considered elements during the experiment (approx. 15% of the comments for each class). These experimental results establish a clear link with the analysis performed via the theoretical analysis based on the trajectory notation introduced and therefore consolidate the relevance and validity of the approach proposed as a support to the design of MDE. Concrete results also establish that location changes should be considered with much care as it is clearly the most disrupting event felt by the participants.

This preliminary experiment will be deepened in order to better assess the effect of the interaction in the large components. Concretely, a larger user experiment is needed to collect quantitative data (e.g., time, errors), allow the users to manipulate the devices and data themselves and run a live application. Future work will also focus on the trajectory notation. Additional resources and metrics need to be considered in order to help in comparing different trajectories. An extension of the use of the trajectory concept is also required in order to establish links with a description of the interaction in the small layer, potentially based on already existing design notation.

## 7 ACKNOWLEDGMENTS

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