HAL open science

Analysing Interaction Trajectories in Multi-device Applications

Emmanuel Dubois, Augusto Celentano

To cite this version:

Emmanuel Dubois, Augusto Celentano. Analysing Interaction Trajectories in Multi-device Applications. 9th Nordic Conference on Human-Computer Interaction (NordiCHI 2016), Oct 2016, Gothenburg, Sweden. pp. 1-6. hal-01912803

HAL Id: hal-01912803
https://hal.science/hal-01912803

Submitted on 5 Nov 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Open Archive Toulouse Archive Ouverte

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible

This is an author's version published in: http://oatao.univ-toulouse.fr/19096

Official URL: http://doi.org/10.1145/2971485.2996726

To cite this version:

Dubois, Emmanuel and Celentano, Augusto *Analysing Interaction Trajectories in Multi-device Applications.* (2016) In: 9th Nordic Conference on Human-Computer Interaction (NordiCHI 2016), 23 October 2016 - 27 October 2016 (Gothenburg, Sweden).

Any correspondence concerning this service should be sent to the repository administrator: tech-oatao@listes-diff.inp-toulouse.fr

Analysing Interaction Trajectories in Multi-device Applications

Emmanuel Dubois
IRIT, Université de Toulouse
Toulouse, France
emmanuel.dubois@irit.fr

Augusto Celentano
Università Ca' Foscari Venezia
Venezia, Italia
auce@unive.it

DOI: http://dx.doi.org/10.1145/2971485.2996726

Abstract
We analyse the activities related to the use of multi-device applications where the same action can be executed in different ways, on different input devices, according to several interaction paradigms. We propose the concept of *interaction trajectory* as a means to describe the interaction in such environments and metrics to analyse the *fluidity* of the interaction and compare different design solutions involving multiple devices.

Author Keywords
Fluidity; interaction design; human-computer interface; multi-device; trajectory.

Introduction
To face the increasing amount of information now available, several interaction techniques have been proposed to facilitate the exploration and use of rich information environments at different levels of details, from different perspectives, with different goals. Such interactive systems often rely on some form of multiple visualization such as, for example, overview plus detail, multiple perspectives, or variable zoom into the information, and are also taking advantage of the variety of available devices by combining them in a multi-device and multi-interaction fashion [9]. Due to the growth of mobile personal devices and to the increasing interconnection among them, the domain of multi-device applications is receiving increasing attention even for simple applications. As a counterpart, the interaction environment is becoming far more complex than the initial triple (screen, keyboard, mouse). According to the task, the variety of information and the different representation techniques, the interaction is split among several devices and information can be

distributed and/or replicated over different devices and over time. The user's interaction path is thus subject to interruptions, changes, reduction of control, homing effects, etc.

In this paper we discuss an approach to support the reasoning about interaction design in multi-device environments. The goal of our study is to support the analysis of the dynamics of interaction in such environments, that depend, in principle, on four factors: 1) the type, amount and structure of information, 2) the different representations with which information is brought to the user's attention and accessed, 3) the devices (number and type) on which interaction takes place, and 4) the user's goals and steps according which information is accessed.

Our approach is based on two concepts: *trajectory* and *fluidity*. Both concepts have been analysed with different meanings and goals in the literature. With these two words we mean, respectively, (1) the sequence of phases, steps and actions that a user performs to complete an information related task on a specific set of equipment, and (2) the smoothness of interaction in terms of actions, information presentation and device deployment and use during the development of an interaction trajectory.

The study grounds on previous work by the authors on multi-level information access [3] and addresses interactive environments and applications today popular: shared devices, collaboration, integration of personal and public devices, personalization are a few of the keywords around which this area of research on user interaction design develops.

Related work

In the literature the concepts of trajectory and fluidity have been studied in several contexts, but generally with meanings different from those assigned by us to the two words.

In [5] interface objects (widgets, windows, icons) are defined through their features (e.g., position, aspect) in a multidimensional space where they evolve in time. A trajectory is a set of positions in such a space that describe how the interface evolves, and is a means to understand the behaviour of the interface objects. Benford et al [2] approach the domain of museums and interactive exhibitions; in such contexts, a trajectory is defined as a set of steps or states of a user in a rich interactive experience in which the relations between the physical world and the digital world are complex and dynamic. As opposed to these works, the concept of transition path diagram considered in the ICS project [7] adopts a psychological point of view to describe the visualization process involved by the user interacting with a computer system. A number of transitions between groups of information building the user interface are considered to characterize the appropriateness of the interface to a user's task. The concept of trajectory thus appears here as a set of steps during the user's interaction with an application, but is limited to the perception of the interface, and does not fit with the context of a multi-device interactive environment. The interaction trajectory we propose is thus a novel concept that adapts from previous works and will extend the work initiated by the ICS project by addressing also the information type, representation, devices and user's goals.

Bederson explores the concept of "being in the flow", which is underlying most of the works related to fluidity. Being in the flow in a context of HCI relies on the presence of feedback, user's control over the system, challenges or skills, and a limited number of interruptions [1]. Fluidity is studied by Elmqvist et al [4] as a set of design guidelines for helping to choose the most appropriate interaction technique for a given visualization in terms of smoothness, responsiveness, etc., to give a comprehensive user experience. Morris et al [8] analyse the collaboration among users in a multi-display environment, defining fluidity in terms of seamless coordination of users with multiple devices. The paper defines three heuristic to measure the degree of fluidity as absence of interruption points and distractions. Guimbretière et al [6] define fluid interaction as a type of interaction not interrupted by events related to the interface (output), e.g., pop-ups, dialog boxes, etc. They analyse a case study around a wall display where operations are executed by free-hand pen interaction with the screen, including handwriting recognition. It thus appears that fluidity has mainly been addressed to characterize interruption caused by the system on the user's interaction. Furthermore, there is still no study relating the concept of fluidity to a measure of the changes of behaviour that a user meets in a multi-device environment.

Building an Interaction trajectory

Definition

An *interaction trajectory* is the set of interactive steps a user has to go through in order to complete an activity, i.e., reach a goal. We call each step an *operation*; it requires information

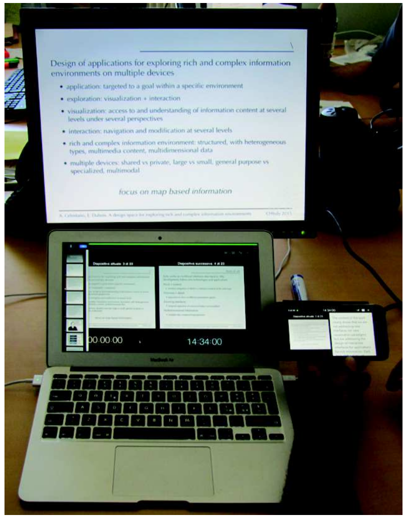


Figure 1. A multi-device configuration for a Keynote presentation.

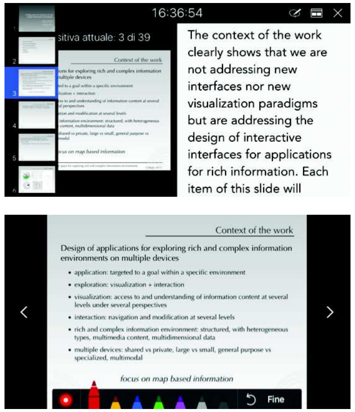


Figure 2. Two representations on the smartphone for different operations.

represented on some device, some input device to operate, and produces a result in form of output information on some device impacting the information space and the system state.

At a basic level an operation is thus a function of a device, an information representation and an interaction technique. More precisely, we define it as a triple (*Init*, *Tech*, *Final*) composed of:

• the *initial state of the interactive system* (*Init*) before the execution of the operation. It includes the description of all the information representations relevant to the operation and the device on which it is provided;

• the *interaction technique* (*Tech*) used to access or operate the initial state. Describing an interaction technique in an interaction trajectory is limited to the identification of the user's action performed (e.g., touch, press, move, etc.) and the device on which the user's action is performed;

• the *final state of the interactive system* (*Final*) after the execution of the operation. As for the initial state, it includes the information representation relevant to the operation (required by or affected by the operation) and the device on which it is presented.

Generally speaking, an operation can be executed in different ways that refer to the same initial state, but may use different devices and user's actions and can produce at the end the same or a different final state. Being a sequence of operations, an interaction trajectory therefore combines the subsequent uses of different information representations, devices and user's actions that create the complex user's interaction path through his/her activity.

Rules for coherency

Operations can be described individually but cannot be freely sequenced to create a valid interaction trajectory. We have identified a set of additional rules in order to guarantee coherence of the information state along the trajectory.

First, a concatenation [O1, O2] of two operations is valid if the elements required in the initial state of O2 are already present in the final state of O1. In other words, to act on an information representation it must already be in the user's interaction space.

Second, an operation may rely on an empty initial state, i.e., its purpose is just to make some information accessible. This is typically required to bring into the user's interaction space new information. In terms of interaction, it describes the need to use a device currently not in use. Such operation can be inserted at any place in an interaction trajectory and enriches the information space with one or more new elements.

Third, an initial/final state and an interaction technique can be composed of multiple elements, meaning that a set of configurations, composed of different devices and/or different information content and representations, can be equivalent from the point of view of the operations executed.

A case study

Let's consider the execution of an interactive presentation with the application program *Keynote* by Apple. We chose such apparently trivial program because it is a multi-device application offering multiple views on the same set of information elements (the presentation slides). The Apple operating environment natively supports the control of a presentation with a variety of devices, ranging from the personal computer keyboard and touchpad to tablets (iPad, iPhone) and to Apple Watch. It is therefore suitable to illustrate the concept of interaction trajectory.

The equipment we consider in our example is centred on a laptop executing the presentation (Figure 1): an external screen shows the slides, while the laptop's screen contains information useful for the presenter (such as current and next slides, the presenter's notes, a slide browser, a timer etc.). The presentation can be controlled in several ways and, with more or less options, through several input devices: we choose the laptop's keyboard, a mouse, the laptop's touchpad and an iPhone running Keynote in remote command mode. Figure 2 shows two different configurations of the iPhone screen, with a slide browser (top) and with the annotation tools (bottom). Other possible devices are a Bluetooth remote command and an Apple Watch, but for brevity we shall limit our discussion to the three cases above.

With a keyboard the direction arrows are used to advance/back the presentation; with a mouse, left and right click serve the same purpose. With a touchpad (besides the mouse emulation) left and right swipe gestures supply the same commands as the keyboard arrows. An iPhone (or an iPad) can also be used to issue commands, with the additional benefit that its display replicates the presenter's screen on the laptop possibly with a different configuration), and its tactile input capability offers additional functions for pointing and annotating the projected slide. In this simple case the output concerning the presentation control is replicated on the desktop screen and on the smartphone screen in compatible ways (the differences are not relevant for the goals of this example). Even in its simplicity, this example contains a quite ample set of configurations supporting several different interaction trajectories.

Let's analyse a typical sequence of operations, assuming that the presentation is already open and the first slide is displayed:

O1. go to next slide (repeated *n* times);

O2. activate (O2a) and read (O2b) the presenter's notes;

O3. activate (O3a) the slide browser and browse (O3b) the slides;

O4. activate (O4a) the annotation mode and add a graphical annotation to the slide (O4b);

O5. go to previous slide.

Operation O1 can be executed in several ways: on the laptop with the arrow keys, with the attached mouse, tapping the touchpad, and swiping on the touchpad. It can also be executed on the smartphone by touching or swiping the slide on the touchscreen.

Operation O2 depends on the actual visibility status of the notes: whether they are already on the screen, and on which device. If not visible, they can be activated on the laptop and on the smartphone independently with a setup command through a dedicated icon (operation O2a). Then the notes can be scrolled and read (operation O2b).

Operation O3 requires the slide browser which can be activated independently on the laptop and the smartphone (operation O3a). On the laptop the keyboard can control the slide browser or the current slide, depending on the selected context of use: if on the slide browser, the arrow keys scan the slides without changing the current one (operation O3b). The touchpad can be used to point to the slide browser button and to browse the slides. On the smartphone the slide browser can be activated with a swipe gesture from the left screen's edge (O3a), and the slides scrolled as usual (O3b).

Operation O4 can be executed only on the smartphone, since there is no annotation tool in the desktop version of the program. An icon activates and deactivates an annotation toolbar (operation O4a) where tools can be selected for drawing (operation O4b).

Operation O5 can be executed like operation O1, but the use of the touchpad (or of the touchscreen) to emulate a mouse requires a different gesture: a tap with two fingers, or a tap in a special area of the touchpad, depending on the system settings.

The sequence of five operations can thus be executed using several input devices with different gestures. The user in some cases must change the type of gesture and the device, while in other cases his/her operations are executed in a more fluid way, i.e., with a constant gesturing technique and with the same device.

Consider the operations O1 and O5, going to the next/previous slide, and the devices used to execute them. The arrow keys on the laptop keyboard are a common choice, fast and with a robust tactile feedback. The touchpad emulating a mouse is another common choice, except that different setups exist for the right click, which may require two different gestures for going forward/backward. The swipe gesture on a smartphone is also very common, and has the advantage of being symmetric.

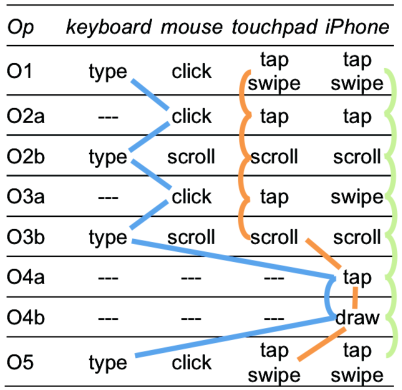
When moving to operation O2, even assuming that the presenter's notes are already on the screen, the three devices above behave differently. The keyboard cannot be used alone: in case of a long note, scrolling it requires to redirect the user input to the notes' area, which cannot be done with the keyboard alone. The touchpad (or the smartphone touchscreen) can be used for both the operations O1 and O2 seamlessly.

The same constraints exist for operation O3. As it must access several elements on the screen, direct pointing is required to move between the slides and the browser; the keyboard can be used to scroll through the slides, but cannot be used alone to execute the whole operation.

Operation 4 requires the use of the smartphone, the unique device able to write graphical annotations; it is necessarily a point

Op	*keyboard*	*mouse*	*touchpad*	*iPhone*
O1	type	click	tap swipe	tap swipe
O2a	---	click	tap	tap
O2b	type	scroll	scroll	scroll
O3a	---	click	tap	swipe
O3b	type	scroll	scroll	scroll
O4a	---	---	---	tap
O4b	---	---	---	draw
O5	type	click	tap swipe	tap swipe

Table 1. Sample combinations of operation, device and interaction technique.



Op	*keyboard*	*mouse*	*touchpad*	*iPhone*
O1	type	click	tap swipe	tap swipe
O2a	---	click	tap	tap
O2b	type	scroll	scroll	scroll
O3a	---	click	tap	swipe
O3b	type	scroll	scroll	scroll
O4a	---	---	---	tap
O4b	---	---	---	draw
O5	type	click	tap swipe	tap swipe

Figure 3. Three trajectories on different devices.

of discontinuity in the interaction if the smartphone is not currently in use, while it gives to the user a continuous experience if used in all the operations.

Table 1 shows the available combinations of devices and gestures to accomplish the operations. As described above, we have split operations O2, O3 and O4 in two phases, the first to activate the proper tools, the second to execute the operation itself. For space reasons the table does not contain references to the information displayed, hence it is not a complete replacement for the triples that have been introduced in previous sections.

Analysing an interaction trajectory

We have identified a set of indicators towards the assessment of the cost of the variability inside an interaction trajectory. The goal of such indicators is to provide a set of metrics for comparing two (or more) interaction trajectories.

An interaction trajectory is basically grounded on four elements: information representation, interaction technique input devices and output devices. The first major metric is the *number of different elements* (i.e., different representations, different interaction techniques and different devices) involved in the trajectory.

The second major metric is the *number of times* a device is used and released along the trajectory: we only retain the value corresponding to the device used in the trajectory that maximizes this metric. These two indicators depict the changeability of the interaction trajectory from two complementary views: the *diversity* and the *stability*. For example, an interaction trajectory that requires only two different devices has a limited diversity. If it uses the first device several times and then requires switching to the second device until the end of the activity, the stability is high. But if the user has to continuously switch between the two devices all along the trajectory, then the stability is rather low.

The third indicator is the *scope* of the devices involved, which corresponds to the number of different operations of the trajectory that can be performed with the device. This depicts the *flexibility* of the devices used.

The fourth indicator is intrinsic to the specific interaction trajectory: it is the *length* of the trajectory, i.e., the number of operations done in it.

Of the four metrics above, the one giving more evidence in terms of fluidity is the second one, the maximum number of device changes along the trajectory.

With reference to the Keynote example, we analyse three trajectories: the first, using the keyboard and the mouse; the second, using the laptop's touchpad; the third, using the smartphone touchscreen for all the operations. Since operation O4 requires the use of the smartphone, it will clearly be the key element in evaluating the trajectory diversity and stability.

Figure 3 enriches Table 1 with the three trajectories drawn in different colours. As foreseen, the major difference is caused by operation O4; even without considering this operation, trajectory 1 (in blue) presents high values for diversity and stability, due to the frequent switches between the keyboard and the mouse. Trajectories 2 (in orange) and 3 (in green) present high ranks for stability, but the operation O4 gives to trajectory 2 a higher diversity score due to the need to change the device.

Tables 2 and 3 on next page summarize the metrics for the three trajectories. In Table 2 the output devices are not listed because they do not change; in Table 3 the last column lists the scopes of the devices in the order in which they appear in the trajectory according to Figure 3. In trajectory 1, the keyboard is used four times after switching to a different device (including task beginning). In trajectory 3 the iPhone supports all the operations of the trajectory.

Conclusion

In this paper we have defined the new concept of interaction trajectory, as a support to describe the dynamics of the user's interaction in a multi-device environment. This definition is built upon previous work exploring the concept of trajectory in interactive situations but is here dedicated to the description of the user's interaction path through a complex and interactive information system.

In addition to this definition, we have provided a set of rules to ensures that the trajectory is correctly built from a syntactic point of view. The interaction trajectory definition we provided together with these building rules constitute a support to explore and generate all the possible and coherent trajectories that can be considered at design level through the multiplicity of in-

Traj.	Trajectory components		
	Information representation	Interaction techniques	Input devices
1	4	4	3
2	4	5	2
3	4	4	1

Table 2. Metrics related to trajectory components.

Traj.	Use/Release	Scope
1	4	4 / 2 / 2
2	2	6 / 2
3	1	8

Table 3. Metrics related to device use and scope.

put/output devices, information representation and required interaction techniques.

Finally, through the proposition of metrics and indicators, we have provided the concept of interaction trajectory with an ability to analyse the user's interaction path through a complex system. More precisely, it supports the characterization of a trajectory in terms of its variability and intrinsic properties.

These different aspects of the contribution have been progressively illustrated through a concrete case study. This example, albeit simple, successfully highlights the ability of our approach to describe an interaction trajectory involving multiple devices to browse an information space. Defining the concept of interaction trajectory and developing the associated rules and assessment indicators is thus an original contribution useful for extending the property of fluidity in complex interactive environment. Although the characterization of the fluidity of an interaction trajectory cannot yet be directly linked to the quality or the usability of the resulting interactive activity, such characteristics are useful to compare different alternatives.

Perspective

In addition to the promising interest of this approach to help reasoning about the design of interactive multi-device systems for rich information environments, we identified several perspectives.

If the concept is well framed in this introductory work, attributes, properties and rules must be better defined and expressed. Formalizing this approach is therefore required to allow its use. This formalization may rely on a graphical notation or a mathematical notation. In both cases, the main challenge is the complexity of the notation resulting from this process.

A second perspective is to avoid reinventing the wheel. We mean that models and notation already exists to very accurately describe an interaction technique or part of it. Being able to provide a link between these existing notations and our current approach, would be very useful to allow a multi-level use of the concept of interaction trajectory: at a very abstract level our current definition might be sufficient, while at a finer grain using formal models or other existing HCI models might provide the designer with a very expressive tool.

Finally, a report about a concrete use of this concept and its impact on a real case study is on-going work and could not be presented here for sake of space. But such concrete illustration is definitely required and is already being explored.

REFERENCES

1. Bederson, B.B. 2004. Interfaces for staying in the flow. Ubiquity 2004, 1–1.
2. Benford, S., Giannachi, G., Koleva, B. and Rodden, T. 2009. From interaction to trajectories: designing coherent journeys through user experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (*CHI* '09). ACM, New York, NY, USA, 709–718.
3. Celentano, A. and Dubois, E. 2016. A layered structure for a design space dedicated to rich interactive multimedia content, *Multimedia Tools and Applications*, First online, DOI 10.1007/s11042-016-3714-6, 1–30.
4. Elmqvist, N., Vande Moere, A., Jetter, H.-C., Cernea, D., Reiterer, H. and Jankun-Kelly, T.J. 2011. Fluid Interaction for Information Visualization, *Information Visualization*, 10, 327–340.
5. Gorgan, D. and Duce, D. A. 1997. The Notion of Trajectory in Graphical User Interfaces. In *Design, Specification and Verification of Interactive Systems '97: Proceedings of the Eurographics Workshop*. Springer Vienna, 257–272.
6. Guimbretière, F., Stone, M. and Winograd, T. 2001. Fluid interaction with high-resolution wall-size displays. In *Proc. of the 14th annual ACM symposium on User interface software and technology* (*UIST* '01). ACM, 21–30.
7. May, J., Scott, S. and Barnard, P. 1995. Structuring displays: a psychological guide (Chapter 4). *Eurographics Tutorials Notes Series*.
8. Morris, R., Marshall, P. and Rogers, Y. 2008. Analysing fluid interaction across multiple displays. In *Workshop on designing multi-touch interaction techniques for coupled public and private displays at AVI 2008*, Naples, Italy.
9. Roberts, J.C. 2007. State of the art: Coordinated & multiple views in exploratory visualization. In *Proc. of the Fifth Int. Conf. on Coordinated and Multiple Views in Exploratory Visualization*, *CMV '07*, IEEE Computer Society, 61–71.