Loki

↳technology & knowledge for interaction

a research team in Human-Computer Interaction
at Inria Lille - Nord Europe
in partnership with CRIStAL (UMR 9189, CNRS | Centrale Lille | Université de Lille)

Loki is a follow-up of Mjolnir

Summary: Human-Computer Interaction (HCI) research is not only about tomorrow's interfaces or applications but also about the original ideas, fundamental knowledge and practical tools that will inspire, inform and support the design of interactive systems in the next decades. We favor the vision of computers as tools and would ultimately like them to empower people. We are especially focusing on how such tools can be designed and engineered, and propose to specify and create new technology dedicated to interaction: the *Interaction Machine*. By better understanding phenomena that occur at each levels of interaction and their relationships, we will acquire the necessary knowledge and technological bricks to reconcile the way interactive systems are engineered with human abilities.

Contents:

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Loki is an Inria research team created in January 2018 –officially promoted as an "Inria project-team" on July 1st, 2019– in partnership with the Joint Research Unit UMR 9189 CNRS-Centrale Lille-Université de Lille, CRIStAL. **Loki** is a follow-up of Mjolnir.

Research scientists and faculty members


Stéphane HUOT (Inria, *Directeur de recherche*) – scientific head

Stéphane HUOT received is PhD from Université de Nantes in 2005 and his *Habilitation à diriger des recherches* from Université Paris-Sud in 2013. He was a postdoctoral fellow at Télécom ParisTech) and CNRS (LRI) in 2006 and 2007. He was associate professor at Université Paris-Sud (IUT Orsay & in | situ |) from September 2007 to September 2014 and has been a senior researcher at Inria Lille since then.
His curriculum vitæ is available online.


Géry CASIEZ (Université de Lille, *Professeur* & IUF) – deputy head

Géry CASIEZ received his PhD and *Habilitation à diriger des recherches* from Université Lille 1 in 2004 and 2012. He was a postdoctoral fellow at the University of Toronto (DGP) in 2005 and associate professor at Université Lille 1 between September 2005 and September 2013, when he was promoted to full professor. In 2018, he has been appointed junior member of the Institut Universitaire de France for 5 years.


Sylvain MALACRIA (Inria, *Chargé de recherche*)

Sylvain MALACRIA received his PhD from Télécom ParisTech in 2011. He was a post-doctoral fellow at the University of Canterbury (HCI Lab) and the University College London (London Media Technology Campus) between October 2011 and September 2014 and has been a researcher at Inria Lille since then.
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Mathieu NANCEL (Inria, *Chargé de recherche*)

Mathieu NANCEL received his PhD from Université Paris-Sud in 2012. He was a post-doctoral fellow at the University of Canterbury (HCI Lab), the University of Waterloo (HCI Lab) and Aalto University (User Interfaces Lab) between January 2013 and November 2016 and he has been a researcher at Inria Lille since then.


Thomas PIETRZAK (Université de Lille, *Maître de conférences*)

Thomas PIETRZAK received his PhD from Université Paul Verlaine, in Metz, in 2008. He was a postdoctoral fellow at Telecom ParisTech (VIA) and the University of Toronto (DGP) in 2010 and 2011. He has been an assistant professor at Université Lille 1 since September 2011.
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Associated external collaborators


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Inria International Chair for 2016-2020.


Edward LANK (University of Waterloo, *Professor*)
Inria International Chair for 2019-2023.

Administrative assistant

Julie JONAS (Inria)

At the time of its creation in 2018, the team was also composed of the following non-permanent members.

Post-doctoral fellows

Raiza HANADA (Inria, since December 2018)

PhD students

In Lille

- Thibault RAFFAILLAC (Inria, since November 2015)
  Languages and system infrastructure for interaction
  Advised by Stéphane HUOT
- Nicole KECHEN PONG (Inria, since October 2016)
  Understanding and improving users' interaction vocabulary
  Advised by Sylvain MALACRIA, Nicolas ROUSSEL & Stéphane HUOT
- Axel ANTOINE (Université de Lille, since October 2017)
  Understanding and improving the relation between interaction simplicity and expressivity for producing illustrations
  Advised by Géry CASIEZ & Sylvain MALACRIA
- Marc BALOUP (Inria – IPL AVATAR, since October 2018)
  Interaction with avatars in immersive virtual environments
  Advised by Thomas PIETRZAK, Géry CASIEZ & Martin HACHET (Inria Bordeaux)

In Rennes

- Hakim SI MOHAMMED (Inria, since October 2016)
  Improving Interaction based on a Brain-Computer Interface
  Advised by Anatole LECUYER & Géry CASIEZ

In Montréal

- Jeronimo BARBOSA (McGill University, since January 2016)
  Low Threshold, High Ceilings: Designing Effective Creativity Support Tools for Music
  Advised by Marcelo M. WANDERLEY & Stéphane HUOT

Scientific foundations & Vision

Our research lies within the field of Human-Computer Interaction (HCI), a discipline concerned with "*the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them*" [1]. HCI is a constantly moving field [2]. Changes in computing technologies extend their possible uses and modify the conditions of existing ones. People also adapt to new technologies and adapt them to their own needs [3]. Different problems and opportunities thus regularly appear that require to be addressed from both the user and the machine perspective, in order to understand and account for the tight coupling between human factors and interactive technologies. In what follows, we summarize the essential elements of our vision –***Knowledge & Technology for Interaction***– before to develop the associated goals in the next section.

Knowledge for Interaction

In the early 1960s, at a time where computers were scarce, expensive, bulky and formal-scheduled machines used for automatic computations, ENGELBART saw their potential as personal interactive resources. He saw them as *tools* we would purposefully use to carry out particular tasks [4] and that would empower people by supporting intelligent use. He believed in the coevolution of humans and their tools and he was not just interested in designing a personal computer but also in changing people, to radically improve the way we manage complexity. Others at the same time were seeing computers differently, as *partners*, intelligent entities to whom we would delegate tasks. These two visions constitute the roots of today's predominant human-computer interaction paradigms, *use* and *delegation*.

In the delegation approach, partners must be instructed what to do. While early intelligent systems only supported communication at their initiative (*human in the loop*), modern ones operate in a reactive mode by constantly monitoring their environment. They respond to explicit demands or observe people with unobtrusive sensors to guess their intentions and respond implicitly. A lot of effort has been made to support oral, written and non-verbal forms of human-computer communication, and to analyze and predict human behavior. But the inconsistency and ambiguity of human beings make these tasks very difficult. The difficulty is not caused by the lack of models, but by their limited applicability when confronted to the complexity of real-world situations. In the delegation approach, the limiting factor is what the machine understands, and the machine is thus the center of interest.

Computers as tools

Our focus is on computer users and our work should ultimately benefit them. Our interest is not in what machines can understand, but in what people can do with them. Instead of intelligent systems, we aim for systems supporting intelligent use. We do not reject the delegation paradigm but clearly favor the one of tool use. And as the frontier between the two is getting thinner, ***one of our goals will be to better understand what it takes for an interactive system to be perceived as a tool or a partner, and how the two paradigms can be combined for the best benefit of the user so as to create true* Man-Computer Symbiosis *[5].***

Empowering tools

As their performances increased, computers turned from calculators to generic and complex information processors. A lot of what could be has actually been automated and we are now "*doomed to become inventive, to become intelligent*" [6]. This, again, illustrates our interest in what people can do with machines, not in what machines can do by themselves. The ability provided by interactive tools to create and control complex transformations in real-time can support intellectual and creative processes in unnatural but powerful ways. The digital world can be made different from the real one, and we want to take advantage of this to give people the power to do things impossible otherwise[1]. But mastering powerful tools is not simple and immediate, it requires learning and practice. ***Research should not just focus on novice or highly proficient users but should also care about intermediate ones willing to devote time and effort to develop new skills, whether for work or leisure.***

Transparent tools

Technology is most empowering when it is transparent. But the transparent tool is not the one you cannot see, it is the one invisible in effect, that does not get into your way but lets you focus on the task. HEIDEGGER characterized this unobtruded relation to things with the term *zuhanden* (*ready-to-hand*). MERLEAU-PONTY emphasized the primacy of perception and of the body in this practical understanding of the world that he described as an active and constructive process. Expanding on this, phenomenologists and situated, embodied and enactive cognitivists have developed converging approaches that place the tight and inextricable perception-action coupling at the root of cognition, even for high-level tasks such as reasoning and problem-solving [10]. Like many other HCI researchers, e.g. [11, 12, 13, 14, 15], we want to draw upon these philosophical and cognitive approaches.

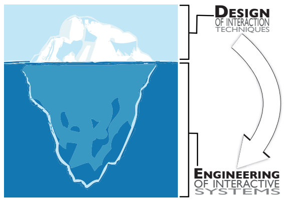
Transparency of interaction is not best achieved with tools mimicking human capabilities, but with those taking full advantage of them given the context and task. For instance, the transparency of driving a car "*is not achieved by having a car communicate like a person, but by providing the right coupling between the driver and action in the relevant domain (motion down the road)*" [11, p. 164]. Our actions towards the digital world need to be digitized and we must receive proper feedback in return. Input and output technologies pose somewhat inevitable constraints while the number, diversity and dynamicity of digital objects call for more and more sophisticated perception-action couplings for increasingly complex tasks. ***We want to study the means currently available for perception and action in the digital world: Are they suited to modern contexts of use and tasks? Do they leverage our perceptual and control skills? Do they support the right level of coupling for transparent use? Can we improve them or design more suitable ones? We also want to study the effects of their use, as even the most basic tools can modify our capabilities in complex ways.***[2]

[1] The impact of the conceptual model of the spreadsheet illustrates this well. Programmable calculators sped up financial calculation but left users with "*furious button punching and number scribbling*" [7]. The combination of formula-based values with interactive modifications and macros revolutionized financial work and changed the face of computing with applications in many other domains [8, 9].

[2] A stick we use to poke an object out of arms reach becomes incorporated into our body representation for action (*body schema*) and alters our representation of space [16]. Simply observing someone using the stick might even alter this representation [17]. Similar modification of the peripersonal space representation and of the body schema has been observed when using a computer mouse for basic pointing tasks [18, 19].

Technology for Interaction

Studying the *interactive phenomena* described above is one of the pillars of HCI research, in order to understand, model and ultimately improve them. Yet, we have to make those phenomena happen, to make them possible and reproducible, whether it be for further research or for their diffusion [20, 21]. However, because of the high viscosity [22] and the lack of openness of actual systems to non-standard interaction, this requires considerable efforts in designing, engineering, implementing and hacking hardware and software interactive artifacts. And when successful, results of these efforts are generally invisible and likely to be ignored as significant and useful contributions [21].



This is what we call "*The Iceberg of HCI Research*", of which the hidden part supports the design and study of new artifacts, but also informs their creation process [THS.1]. ***But how can we capitalize on this "hidden" knowledge? How to rationalize, extend and reuse it for future designs, studies, and to explore further? How to make it accessible to other researchers or practitioners?***

Computers vs Interactive Systems

In fact, today's interactive systems –e. g., desktop computers, mobile devices, or distributed platforms– were not designed to be (or to produce) empowering interactive tools. They share very similar layered architectures inherited from the first personal computers of the 1970s. Each layer encapsulate and provide access to the resources of the layer below (Figure 2.1). This abstraction of the resources provides developers with standard components (UI widgets) and high-level input events (mouse and keyboard) that obviously ease the development of common applications based on the WIMP[3] paradigm. Although beneficial for predictable and well-defined tasks and users' behaviors (e. g., office work), this approach does not favor the design and integration of non standard interaction techniques that could be better adapted to more particular contexts, to expressive and creative uses, that would lead to make computers becoming "empowering tools". It often requires to go deeper into the system layers and to hack them until getting access to the required functionalities and/or data, switching between programming paradigms and/or languages.

Overall, the underlying concepts, architectures and environments of actual systems are mostly optimized for computation, not interaction [23]. They are focused on data and computation, but as stated by CONVERSY, Computer Science can also be considered as the "Science of controlled transformations" [24] where the user-in-control and interaction are paramount concerns. Instead, interaction mechanisms and capabilities are appended on top of those "computational" architectures and are similar for all kinds of contexts or applications. This is a suboptimal design in terms of interaction since:

(i) it *does not consider interaction – and thus the user and the context of use – as a priority*, yet every system have at least a user interacting with them at a point;
(ii) it *restricts interaction* to standardized user interfaces with no or very little distinction between different users, application contexts and their specificities;
(iii) it *limits the exploration, the study and the improvement* of alternative interaction methods because of little flexibility and poor room for extension or revision.

[3] "Windows, Icons, Menus, Pointers", the most common style of GUI introduced in the 1970s at Xerox Parc.

Input and events management in actual systems illustrates well these limitations. Data from input devices is transformed and propagated through the layers of the system (see figure 2.1). At the last level, the application development framework, there is mostly only high-level interaction events remaining, encapsulated in UI widgets (e. g., action on a button, scrolling on a view) that has to be handled with callbacks. The first problem is that it is often impossible at this level to identify which device triggered an event since they are often labeled as to be "Mouse" or "Pointer" events, whatever the physical device that have been used. Secondly, most of the original data that has gone through the layers has been lost. Thirdly, the events/callbacks approach promoted at all the levels has proven not to be the most appropriate for implementing and maintaining highly interactive applications [25, 26, 27, 28]. As a result, some more productive or better adapted but non-standard interaction styles are still cumbersome to prototype and implement today, such as for instance leveraging the specific data channels of advanced input devices (e. g., pressure applied on a stylus device, shape of touches on a touchpad), managing several pointing devices or enabling precise subpixel interaction [29]. They require patching and accessing data at several levels through multiple system or constructor libraries that are not always well documented and most of the time implemented in different languages, using different abstractions, to implement specific drivers or custom system feedback [26].

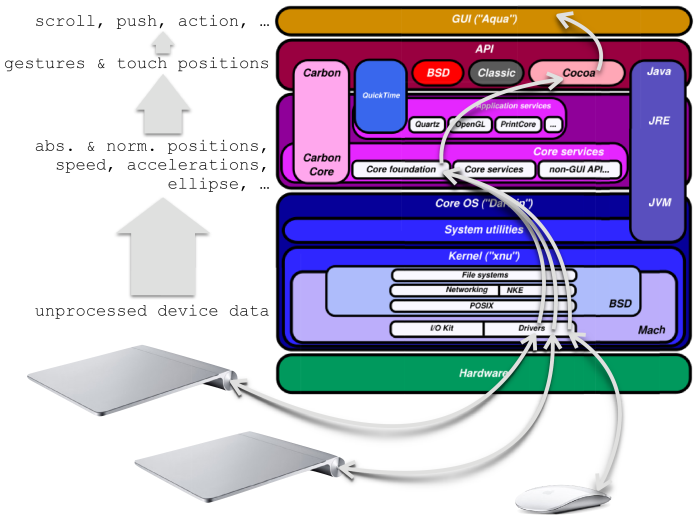


Figure 2.1: The standard layered architecture of a common Operating System is not tailored for prototyping, programming and adapting interaction. For instance, data from input devices is 'lost in transformation' between the multiple layers and requires many tricks and hacks to be accessed.

Another example is the shortcomings of mainstream programming languages and UI frameworks for programming advanced interaction. Their syntaxes and structures are again well-adapted to data manipulation and to symbolic or numerical computation. But they do not ease the expression of concepts specific to interaction programming [30] such as states/transitions [28], transformations [24], active processes and dynamic bindings [31], animations [CNF.18]. Despite many relevant contributions from both the HCI and Software Engineering communities, actual interactive systems are still based on relatively inappropriate architectures, languages and frameworks when considering interaction.

Interactive Systems are no longer Computers
And these limitations are even more pervading as interactive systems have changed deeply in the last 20 years. They are not anymore limited to a simple desktop or laptop computer with a display, a keyboard and a mouse. They are becoming more and more distributed and pervasive (e. g., mobile devices, Internet of Things). They are changing dynamically with recombinations of hardware and software (e. g., transition between multiple devices, modular interactive platforms for collaborative use [32]). Systems are moving "out of the box" with Augmented Reality, and users are going " inside of the box" with Virtual Reality. This is obviously raising new challenges in terms of human factors, usability and design. But it also deeply questions actual architectures, inherited from personal computers, and have opened the way to promising new concepts in HCI, with important contributions in the engineering of interactive systems such as: the "plasticity" of interfaces [33]; information "substrates" [34]; "proxemic" interaction [35]; Mixed Reality systems [36]. However, there is still the need for more practical solutions that go beyond this concepts, and to rethink from the root "what is an interactive system and how it should be designed".

Software libraries, toolkits or frameworks are currently the most common solution to circumvent the limitations of actual systems, and the HCI community has a long history in producing and distributing toolkits for many purposes (e. g., UI development [37], zoomable UIs [38], advanced graphics and input management [27], programming models for interaction [28], touch interaction [39]). They embed, make reusable and spread the knowledge we gathered in both "parts of the iceberg": they support the exploration and the design of new interactive systems and provide a way to make it possible [21]. But even if specific toolkits ease parts of the process and appreciably reduce the need for hacking systems, this is still a partial solution since they are by nature limited to their scope and they are *in fine* shifting the problem. In facts, toolkits are unlikely to share the same concepts, at the same levels of abstraction, or to be written in the same languages or programming paradigms, and they still raise the issue of their combination and interoperability when one need to take advantage of several of them [THS.1], similarly to layers in actual systems.

|summary| Technology & Knowledge for Interaction

Promoting computers (and digital devices in general) to ***empowering tools*** requires to ***augment our fundamental knowledge about interaction phenomena*** AND to ***revisit the architecture and design of interactive systems*** in order to support this knowledge and make these empowering tools possible. The study of human factors and the design of new interaction techniques can reveal many of the technical limitations of actual systems and lead the way to their improvement ("Designeering Interaction").

Following such a comprehensive systems approach –encompassing human factors, hardware elements and all the software layers above– we want to define the founding principles of an *Interaction Machine*, new hardware and software technology dedicated to interaction. This revisitation of interactive systems raises many challenges, at several levels, that we describe in the following section with our associated mid- and short-term goals.

Scientific objectives

According to our vision and the scientific foundations described before, the main objective of the team is dual: promoting "computers" (at large) to empowering tools, and informing on how such technology should be designed and implemented. Back to our metaphor of the iceberg, this requires to reunite its two parts. For that, our long term objective is to specify and design a new generation of interactive systems, the *Interaction Machine*.

Long-term objective: The Interaction Machine(s)

Our concept of the "*Interaction Machine*" is a way to support and promote our vision of computers as empowering tools, as well as our holistic and integrative vision of HCI, bringing together the design and study of interactive phenomena with engineering of interactive systems. For that, its design will be informed by our studies on the human abilities that we will leverage to reach this empowerment of users. Ultimately, we want the Interaction Machine to be a new technology that ***reconciles how interactive systems are engineered with human abilities*** by:

- considering ***interaction and the user as a priority***;
- ***not being tied to one particular interaction style or model***;
- ***supporting exploration, improvement and adaptability*** by embedding knowledge about human factors within technology.

The concept is inspired by the Lisp Machines of the 70s, dedicated computers which hardware and operating system were optimized for Lisp, the reference language of the time for research in Artificial Intelligence. The goal was to satisfy the huge processing requirements that more conventional computers were not able to deliver at that time. Similarly, we have seen that actual systems are merely not designed for interaction, or at least were designed to support only a very particular and stereotyped interaction paradigm, which is restrictive from both the user and the designer/developer perspectives. Hence, we are far from the seminal idea of computers as empowering tools. Our long-term objective (~8 to 12 years) is thus to revisit interactive systems as a whole in order to better support the specificities and requirements for designing, studying, implementing and using interactive systems. This Interaction Machine would result from our efforts on both parts of the iceberg and should also lower its hidden part by easing the design and study of new forms of interaction, the engineering of interactive systems and their adaptability. Ultimately, it should also support the empowering of the end-user and their "evolution" (skills acquisition, system tuning and adaptation). This is an ambitious challenge that will require to specify "what such a system should conceptually be" at several levels: hardware, system architecture and libraries, languages and APIs for application development.

Computing technology that relies on interaction

The Interaction Machine has to rely on interaction as a first order object and on mechanisms adapted to make it happen and manipulate it. It implies to rethink the different layers that make an interactive system in order to get rid of abstractions, transformations and mechanisms that were primarily designed for data manipulation and computation. For instance, it would require to redefine input management and event propagation, to rethink the way it is linked to graphical architectures, and even to propose new concepts at the programming language and framework levels in order to better handle interaction. Yet, one challenge is also to not sacrifice computation capabilities in order to preserve the primary function of computers that is to accomplish various tasks, but also to ensure seamless and high-quality interaction (e. g., performance and optimization).

Technology that helps producing knowledge
We envision interactive technology as a facilitator for producing fundamental knowledge on interaction by easing the design, implementation and study of new interactive artifacts, not to make it more difficult if not impossible. The Interaction Machine should thus not only be tailored to interaction (design and use), but when reaching its limits, it should provide all the necessary concepts / properties / mechanics to be extended to do so. One major challenge we will address is to improve technology so that it can help identify *a priori* what can be done with it, how it can be done or why it cannot be done, and how it supports extension of its "adjacent possible" [THS.1]. Consequently, we are not tied to a particular technology (e. g., input, output, OSs & software). Having the freedom to look for the best technology for a particular context, to extend existing or to fabricate new one, is important to us as we believe this is a good way to produce radical new knowledge in our field.

Knowledge that augments technology
On the other hand, technology has to be augmented with knowledge – i. e., models, theories, results from HCI research. Many "real" tools hold some of the knowledge we have from the world and the context of use [40], revealing their basic and even sometimes alternative uses. In contrast, computer tools rarely embed such affordances. We want the Interaction Machine to support and embed fundamental knowledge from our field such as e. g., models of pointing, bimanual interaction, human behavior in general. By analogy with actual systems, we want to make the atomic building blocks of actual interfaces that encapsulate an action, the *widgets*, evolve to "***knowdgets***": interoperable and combinable building blocks that encapsulate knowledge about interaction. Widgets are visible and atomic user interface components that embed all the mechanisms required by the user to trigger an action (e. g., a UI button). They do not embed knowledge, or very little, about human factors, interaction capabilities of the system or the user, context of interaction or the task. This sometimes leads to misuse them or to simply not have the right one available. We want the knowdgets to fill this gap by embedding methods, data and algorithms that make visible and reusable some knowledge about interaction.

Early Interaction Machines
Some of our recent works illustrate these guiding principles and can be considered as early instances of the Interaction Machine concept:

- *Libpointing* [41] is a low-level multi-platform library, a "patch" to actual systems for managing multiple input devices and their mapping to actions. Resulting from our research on transfer functions, it is a technology that helps to produce knowledge by easing new studies based on our previous results. It also augments existing systems with knowledge by embedding several mechanisms for applying specific transfer functions in given contexts (i. e., knowdgets).

- *Probatio* [JNL.8] is a new hardware and software toolkit, designed “from scratch” for quickly prototyping original Digital Musical Instruments (DMIs). It enables rapid prototyping of new instruments for studying their properties (e. g., playfulness, expressiveness, learnability), and also embeds some advanced design principles to inform their design (e. g., physical properties and arrangement of actuators, default mappings of sensors to synthesizers).

Short- to medium-term objectives: the Dynamics of Interaction

Interaction is by nature a dynamic phenomenon that takes place between interactive systems and their users. Redesigning interactive systems to better account for interaction requires fine understanding of these dynamics from the user side so as to better handle them from the system side (i. e., knowledge that augments technology). In fact, layers of actual interactive systems that we mentioned before were introduced to abstract hardware and system resources from a system and programing point of view. Following our Interaction Machine perspective, we will instead reconsider this architecture from the user perspective, through different ***levels of dynamics of interaction***.

In the next two to five years, we will study these dynamics along three levels depending on interaction time scale and related user’s perception and behavior: *Micro-dynamics*, *Meso-dynamics*, and *Macro-dynamics* (see figure 3.1). Considering phenomena that occur at each of these levels as well as their relationships will help us to acquire the necessary knowledge (Empowering Tools) and technological bricks (Interaction Machine) to reconcile the way interactive systems are designed and engineered with human abilities. Although our strategy is to investigate issues and address challenges for all of the three levels of dynamics, our immediate priority will be to focus on micro-dynamics since it concerns very fundamental knowledge about interaction and relates to very low-level parts of interactive systems, which is likely to influence our future research and developments at other levels.

Micro-dynamics: Empowering users by leveraging human control skills

Micro-dynamics concern low-level phenomena and human abilities which are related to short time/instantness and to perception-action coupling in interaction, when the user has almost no control or consciousness of the action once it has been started. From the system perspective, it has implications mostly on input and output management (I/O).

Transfer functions design and latency management

Our group has developed a unique and recognized expertise in *transfer functions*, i. e., the algorithmic transformations of raw user input for system use. We notably worked on the precise characterization of the indirect pointing (Figure 3.2) and scrolling transfer functions used when interacting with Microsoft Windows, Apple OS X and Xorg [41, 42] and explained how interactive graphics systems could be redesigned to support much higher precision pointing tasks [29]. We showed these functions are mainly non-linear and have

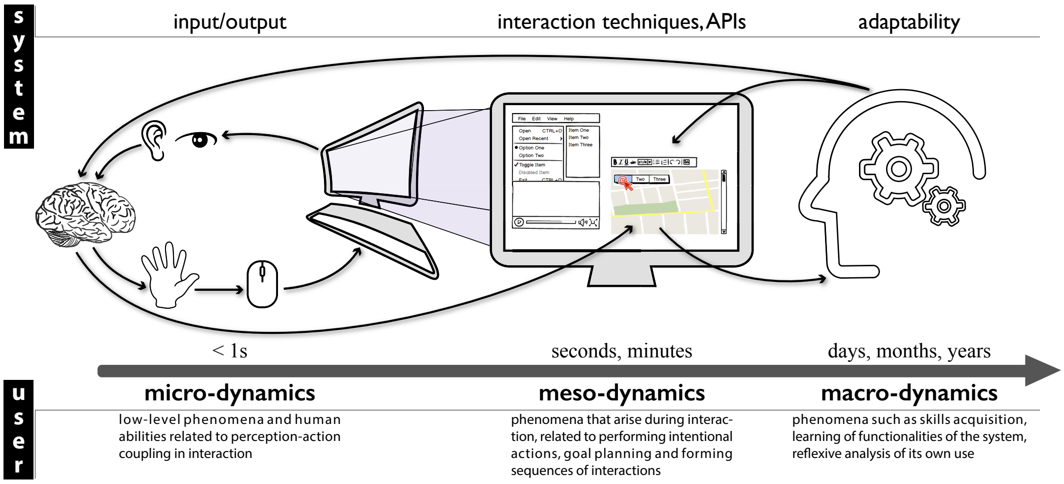


Figure 3.1: Levels of dynamics of interaction.

an impact on performance. We also showed that the rationale behind them is mostly unknown and when it is known, reduces to ad hoc choices. We also developed the foremost expertise in how to design efficient transfer functions for interactive setup for which no standard already exists and designed the most efficient ones in the literature today [JNL.4], in ways that can be easily tuned to any device and task.

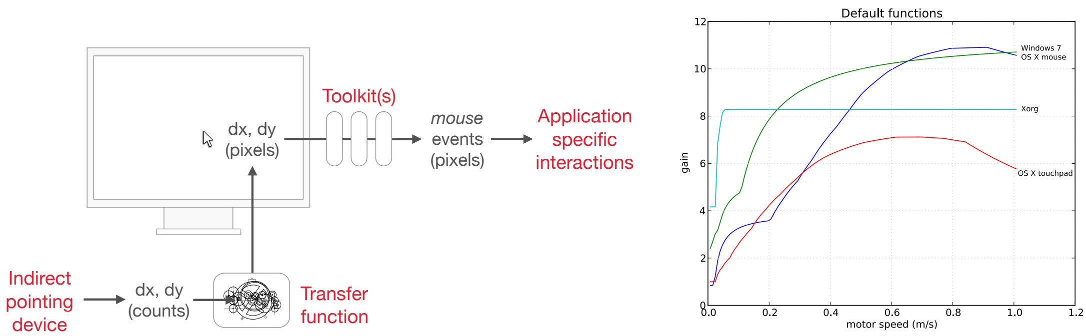


Figure 3.2: The left diagram illustrates the general principle of indirect pointing transfer functions. The right plot shows the default functions used by Windows, Xorg and OS X in 2011 [41]. It illustrates the differences between systems for the mouse, and between mice and touchpads for OS X.

Transfer functions define how user actions are taken into account by the system. They can make a task easier or impossible and thus largely condition user performance, no matter the criteria (speed, accuracy, comfort, fatigue, etc). Ideally, the transfer function should be chosen or tuned to match the interaction context. Yet the question of how to design a function to maximize one or more criteria in a given context remains an open one, and on-demand adaptation is difficult because functions are usually implemented at the lowest possible level to avoid latency. Latency has indeed long been known as a determinant of human performance in interactive systems [43] and recently regained attention with touch interactions [44]. The latency and transfer function of an interactive system also contribute to the senses of *initiation* and *control*, two crucial component of the sense of *agency* [45].

Latency management and transfer function design are two problems that require cross examination to improve human performance with interactive systems. Latency is less noticeable in indirect systems (e.g. mouse-based) than in direct (e.g. touch) ones, where it results in a spatial gap between fingers and on-screen feedback. But it deserves careful attention in both cases as it can be a confounding factor when evaluating the effectiveness of transfer functions. Transfer functions also deserve attention when attempting to tackle the latency problem as they could take it into account and try to compensate for it.

We have recently proposed new methods for the measurement of end-to-end latency [TOP.19, TOP.30] and are currently working on compensation methods [TOP.38] and the evaluation of their perceived side effects [TOP.24]. Our ultimate goal on these topics is to automatically adapt the transfer function to individual users and uses [PDW.10] while reducing latency in order to support stable and appropriate control. To achieve this, we will investigate combinations of low-level (embedded) and high-level (application) ways to take user capabilities and task characteristics into account and reduce or compensate for latency in different contexts, e.g. using a mouse or a touchpad, a touch-screen, an optical finger navigation device or a brain-computer interface.

Tactile feedback & haptic perception

We are also concerned with the physicality of human-computer interaction, with a focus on haptic perception and related technologies. For instance, when interacting with virtual objects such as software buttons on a touch surface, the user cannot feel the click sensation like with physical buttons. The tight coupling between how we perceive and how we manipulate objects is then essentially broken although this immediate and continuous feedback is instrumental for efficient direct manipulation. We have addressed this issue in multiple contexts by designing, implementing and evaluating novel applications of tactile feedback (tactile displays for direct manipulation [TOP.22], tactile feedback for mid-air interaction [CNF.20], tactile buttons and sliders with printed actuators [PDW.15]).

Perception and action are closely related through the sensory-motor loop. Perception is interpreted by the cognitive system and influences action, and our actions in turn influence our perception of the environment [46]. Therefore, understanding and improving perception helps improving interaction with interactive systems. When working with an actuation technology, we have to investigate the perception of the haptic effects it creates.

We typically experiment:

- *Absolute detection thresholds*: minimum value for a parameter for which the presence of a stimulation is perceived;
- *Just noticeable differences (JND)*: parameter threshold for which two different stimulations can be distinguished;
- *Identifiable values*: parameter values that one can identify without a reference value.

In comparison with many other modalities, the difficulty with tactile feedback is its diversity. It groups sensations of forces, vibrations, friction or deformation. Although a richness, this diversity also raises usability and technological challenges since each kind of haptic stimulation requires different kinds of actuators with their own parameters and thresholds. And results from one are hardly applicable to others. On a "knowledge" point of view, we want to better understand and classify haptic variables and the kind of information they can represent (continuous, ordinal, nominal), their resolution, and their applicability to various contexts. For instance, in the Avatar project, we will investigate how several forms of haptic feedback based on this classification could enhance embodiment and improve interaction in a Virtual Reality environment. From the technological perspective, we want to develop tools to inform and facilitate the design of future haptic interactions taking best advantage of the different technologies in a consistent and transparent way.

Meso-dynamics: Empowering users by leveraging human expressiveness

Meso-dynamics relate to phenomena that arise during interaction, on a longer but still short time-scale. From the user perspective, it is related to performing intentional actions, to goal planning and tools selection, and to forming sequences of interactions based on a known set of rules or instructions. From the system perspective, it relates to how possible actions are exposed to the user and how they have to be executed, namely *interaction techniques*. It also has implication on the tools for designing and implementing those techniques (programming languages and APIs).

Interaction bandwidth and vocabulary

Interactive systems and their applications have an always increasing number of available features and commands due to e. g., the large amount of data to manipulate, increasing power and number of functionalities, multiple contexts of use.

On the input side, we want to augment the *interaction bandwidth* between the user and the system in order to cope with this increasing complexity. In fact, most input devices capture only a few of the movements and actions the human body is capable of. Our arms and hands for instance have many degrees of freedom that we use together when manipulating physical tools, and that are not fully exploited in common computer interfaces. We have recently explored new methods to improve expressibility such as the *FlexStylus*, a bendable digitizer pen [TOP.29], or reliable technology for studying the benefits of finger identification on multi-touch interfaces [TOP.31, JNL.9].

On the output side, we want to expand users' *interaction vocabulary*. All of the features and commands of a system can not be displayed on screen at the same time and lots of *advanced* features are by default hidden to the users (e. g., hotkeys) or buried in deep hierarchies of command-triggering systems (e. g., menus). As a result, users tend to use only a subset of all the different tools the system actually offers [47]. We will study how to help user to broaden their knowledge of the range of functions available in an interactive system. Among others, we will study how the graphical design of control widgets can be refined so it better conveys their interaction, as well as how applying game design knowledge to the design of applications can encourage users to extend their interaction vocabulary.

We will continue this "opportunistic" exploration of such alternative and more expressive input methods and interaction techniques. We will particularly focus on the necessary technological requirements to integrate them into interactive systems, in relation with our redesign of the I/O stack at the micro-dynamics level.

Spatial and temporal continuity in interaction
At a higher-level, we have investigated how such more expressive techniques affect users' strategies when performing sequences of elementary actions and tasks [CNF.9]. More generally, we will explore the "*continuity*" in interaction. As mentioned in section 2.2.2, interactive systems have moved from one computer to multiple connected interactive devices (computer, tablets, phones, watches, etc.) that could also be augmented through a Mixed-Reality paradigm. This distribution of interaction raises new challenges from both the usability and engineering perspectives that we obviously have to consider in our main objective of revisiting interactive systems. It involves the simultaneous usage of multiple devices and also the changes in the role of devices according to the location, the time, the task, contexts of use: A tablet device can be used as the main device while traveling, and it becomes an input device or a secondary monitor for continuing the same task once in the office; A smart-watch can be used as a standalone device to send messages, but also as a remote controller for a wall-sized display. One challenge is then to design interaction techniques that support seamless and smooth transitions during these spatial and temporal changes of the system in order to maintain the continuity of uses and tasks. Some research work already explored these notions [35], and some commercial systems even support this paradigm (e. g., Apple's Handoff). We want to better integrate these principles in future interactive systems. In particular, we are interested in better understanding the tasks and contexts for which multiple devices interaction is suitable, and to better support users' learning and mastering of such complex systems by making the interfaces "reappearing".

Expressive tools for prototyping, studying and programming interaction
As we already discussed, actual systems suffers from issues that keep constraining and influencing how interaction is thought, designed, and implemented. Addressing the challenges we presented in this section and making the solutions possible require extended expressiveness, and researchers and designers must either wait for the proper toolkits to appear, or "hack" existing interaction frameworks, often bypassing existing mechanisms. A central theme of our Interaction Machine vision is to promote interaction as a first-class object of the system [48], and to provide designers, researchers, developers and even end-users with the appropriate tools for manipulating it (e. g., programming languages, frameworks and APIs, prototyping and programming environment). Along this line, we have recently proposed a new syntax for easing the programing of animations [CNF.18] and a new environment for the design and programming of interactive spaces [CNF.23]. In the coming years, we will continue to identify such areas for improvement.

For instance, numerous usability problems in existing interfaces are stemming from a common cause: the lack, or untimely discarding, of relevant information about how events are propagated and changes come to occur in interactive environments (see section 2.2.1). On top of our redesign of the I/O loop of interactive systems, we will investigate how to facilitate access to that information and also promote a more grounded and expressive way to describe and exploit input-to-output chains of events at every system level. We want to provide finer granularity and better-described connections between the *causes* of changes (e.g. input events and system triggers), their *context* (e.g. system and application states), their *consequences* (e.g. interface and data updates), and their *timing*. In doing so, we want to solve two ubiquitous issues and avoidable limitations in modern GUIs:

- *Task-disruptive interruptions* are unpredictable interface updates occurring during or right before the completion of a user action, such as clicking or pressing a key, too quickly for the user to interrupt. They result in user inputs being interpreted wrongly, or sent to the wrong application, causing unwanted and sometimes non-undoable loss of time and information. They are seldom considered in interaction design and research, possibly because they cannot be modeled within today's programming paradigms in which the precise timing of user actions and visual updates are unknown, and users are expected to react instantaneously to system outputs. The ability to distinguish the timings of raw input events and perceivable interface updates will facilitate the detection, avoidance, and mitigation of such issues. We will also develop new models of human perception, agency, and interruptibility to be tested systematically before triggering a system response.
- *Command history mechanisms* (i. e.,undo-redo) have stayed virtually unchanged for the last 30 years, allowing only to navigate chronologically in the states of the document. Yet, in that same period, HCI researchers have explored a number of improvements to this model, such as branching chronologies to explore alternative designs, undoing operations on specific regions of the document, undoing non-last operations, and so on [TOP.12]. However this consists only of point designs without any attempt to be compatible with previous approaches, and even sometimes with the basic undo-redo functions—a possible reason why they are seldom implemented in real-world applications. In [TOP.12], we proposed a conceptual model of command history that enables all of these past improvements at once, based on an information architecture that links causes, context, and consequences of document changes. It also illustrated how this model enables novel editing and error correction opportunities. We will push further in this direction, by implementing this model in real applications and exploring its opportunities and challenges in terms of interaction and system design.

We will first define and document the best ways to enable access to this lost information by "patching" existing systems, through methods such as accessibility APIs, software probes, template matching estimation, extended history logging, etc. In doing so, we intend to demonstrate how access to more information about I/O processes can significantly contribute to improving both interaction design and theoretical psychomotor knowledge on multiple issues. Ultimately, the technical solutions to each usability problem will be merged into a proposition for a unified model of software scaffolding for interaction that will contribute to the design of our Interaction Machine.

Macro-dynamics: Empowering users by leveraging human learning skills

Macro-dynamics concern longer-term phenomena such as skills acquisition, learning of functionalities of the system, reflexive analysis of its own use (e. g., when the user has to face novel or unexpected situations which require high-level of knowledge of the system and its functioning). From the system perspective, it implies to better support cross-application and cross-platform mechanisms so as to favor skill-transfer. It also requires to improve the instrumentation and high-level logging capabilities to favor reflexive use, as well as flexibility and adaptability for users to be able to finely tune and shape their tools.

We want to move away from the usual binary distinction between "novices" and "experts" [JNL.2] and explore means to promote and assist digital skill acquisition in a more progressive fashion. Indeed, users have a permanent need to adapt to the constant and rapid evolution of the tasks and activities they carry on a computer system, but also the changes in the software tools they use [49]. The way users acquire new digital skills goes from *appropriation* of a tool, when using it for the first time, to *discovering* more of its features and making sure to use the best tool to achieve a goal, to *improving* one's skills with a given tool and forming strategies to coordinate of a set of functions to achieve a task, to finally *re-appropriation* of a tool due to changes in the tool itself, the task or the environment. And software strikingly lacks powerful means of acquiring and developing these skills [JNL.2], forcing users to mostly relying on outside support, for example being guided by a knowledgeable person, or following online tutorials of varying quality. As a result, users tend to rely on a surprisingly limited interaction vocabulary [47], employ inefficient methods for completing tasks [50] or *make-do* with sub-optimal routines and tools [51]. Ultimately, the user should be able to easily master the interactive system to form durable and stabilized practices that would eventually become *automatic* and reduce the mental and physical efforts expended on this task [52], making their interaction *transparent*.

In our previous work, we identified the fundamental factors influencing expertise development in graphical user interfaces and created a conceptual framework that characterize users' performance improvement with UIs [TOP.10, JNL.2]. We designed and evaluated new interaction mechanisms to leverages user's digital skill development with user interfaces, such as command selection and learning methods that minimize the cost of selecting commands using shortcuts on both desktop [TOP.8] and touch-based computers [CNF.2, TOP.6, TOP.11]. We showed that historical accounts of interactions and real-time activity monitors support personalized critical reflection on tool use and skills development, encouraging users to switch earlier to more efficient interaction methods [TOP.10].

We are now interested in broader means to support the analytic use of computing tools. We want to help people to become aware of the particular ways they use their tools and then to increase their interaction vocabulary, that is, to discover the other ways that exist for the things they do, and the other things they might do. We want to help them to increase their performance when interacting with computing systems either by adjusting their current ways of doing through better interaction strategies, or by providing new and more efficient interaction techniques and by facilitating transitions from one technique to another. Finally, we are also interested in means to foster reflection among users and facilitate the dissemination of best practices. In that perspective, our main research objectives are:

- *to foster understanding of interactive systems.* A critical obstacle to the development of digital skills is the understanding of how interactive systems work. As the digital world makes the shift to more and more complex systems driven by machine learning algorithms, we increasingly loose our comprehension of how a system 'reason', i. e., what processes yielded the system to respond in one way rather than another. We will study how novel interactive visualizations can help reveal and expose the "intelligence" behind, in ways that people become capable of understanding concepts behind computer processes in order to better master their complexity.
- *to foster reflexion on interaction.* As users tend to use sub-optimal tools, commands and strategies, even when performing productive tasks [TOP.10], we will study how we can foster users' reflexion on their own interaction in order to encourage them to

acquire novel digital skills. We will build real-time and off-line software for monitoring how user's ongoing activity is conducted at an application and system level. We will develop augmented feedbacks and interactive history visualization tools that will offer contextual visualizations to help users to better understand their activity, compare their actions to that of others, and discover opportunities for improvement.

- *to optimize skill-transfer and tool re-appropriation.* The rapid evolution of new technologies has drastically increased the frequency at which systems are updated, often requiring to relearn everything from scratch. In that purpose, we will explore how we can minimize the cost of having to appropriate an interactive tool by helping users to capitalize on their existing skills when appropriating a new interactive system.

We plan to further explore these research directions as well as the use of such aids in other contexts such as web-based, mobile or BCI-based applications. Although, a core aspect of this work will be to design systems and interaction techniques that will be the less platform specifics as possible, in order to better support skill-transfer. At a larger extent, as part of Marcelo WANDERLEY's International Chair in our group, we will also investigate these notions of appropriation, reflexive use, skill development and re-appropriation in the context of musical performance with Digital Musical Instruments (DMIs). We will build on our previous experiences in the instrumentation of interactive systems for logging purposes [53, CNF.19] and analysis of usages [PDW.7]. Following our Interaction Machine vision, this will lead to rethink how interactive systems have to be engineered so that they can offer better instrumentation, higher adaptability, and fewer separation between applications and tasks in order to support reuse and skills transfer.

Links between the 3 levels and with the Interaction Machine

These 3 levels of dynamics are obviously not isolated and many of our projects and of the research questions that we are addressing overlaps between them. Thus the interactions between these levels will also be fundamental in our progress towards a better understanding of interactive phenomena and redesigning interactive technology. For instance, our objectives at the macro-dynamics level, aiming at improving skills acquisition with interactive technologies, are highly related to issues at the meso-dynamics level such as designing and studying appropriate short-term interaction techniques to reveal the possibilities of a system. Our work on adaptable transfer functions at the micro-dynamics level will certainly have implications on the continuity of interaction that we want to study and improve at the meso-dynamics level. And as explained and summarized at the end of each section, our work at each of these levels of dynamics and their interactions will help us to better understand and describe interactive phenomena but also to consider implications and operationalization of this knowledge in terms of engineering of interactive systems. Overall, this will contribute to define and implement our first prototypes of Interaction Machine(s). However, the 3 levels of dynamics are not necessarily destined to replace the layers of actual systems, but we believe they are instrumental in the specification of the new concepts and mechanisms we will propose to improve interactive technology. For instance, and as mentioned earlier, our low-level studies of human-factors at the micro-dynamics level and of the use of time in interaction at the meso-dynamics level are both essential to rethink input and interaction events management in interactive systems as a whole, with a more user-centered perspective than the actual system-centered perspective. More generally, the work we did recently on exploring the use of the Entity-Component-System model for implementing interactive systems [DOC.9] could be used as an unique paradigm to represent both low-level (input / output), application-level (data), and interaction-level (interaction techniques) objects. This is an example of a way for unifying the layers of existing systems into a consistent framework, better adapted to "describe" and implement interaction at the 3 levels of dynamics in our Interaction Machine.

Methodology: "Designeering Interaction"

In the methodology we adopt in human-Computer Interaction, we can observe a loop going back and forth between designing and evaluating new interaction techniques, and defining and implementing new software architectures or toolkits. And both are strongly influencing each other: The design of interaction techniques informs on the capabilities and limitations of the platform and the software being used, giving insights into what could be done to improve them. On the other hand, new architectures and software tools open the way to new designs and possibilities, by giving the necessary bricks to build with [THS.1].

JOHNSON observed this situation about innovation in general, drawing on KAUFFMAN's theory of the "Adjacent Possible": "*The trick to having good ideas is not to sit around in glorious isolation and try to think big thoughts. The trick is to get more parts on the table.*" [54, p. 42]. These parts define the adjacent possible, the set of what could be designed by assembling the parts in new ways. In HCI, technology –hardware and software– and knowledge –experience and theories– are the spare parts of the adjacent possible, i. e., the new techniques or systems that could be designed. For example, the *Nintendo Wii Remote* is a "first-order" combination of infrared LED, accelerometers, buttons and bluetooth wireless technology, which was obviously in the adjacent possible when it was designed. Nevertheless, this cheap motion sensing device extended the adjacent possible, leading to a radical change in the gaming industry [55], and was in turn used as a part for new combinations [56]. But an idea or an invention that lies outside of the adjacent possible cannot be designed by simply "climbing the mountain via the steep cliff". The necessary technological evolutions that will make it possible should be addressed first. This is a slow and gradual but uncertain process, where things cannot be built until the required technology is available and where the most innovative ideas will push the technology further, which helps to explore and fill a number of gaps in our research field but can also lead to wrong ways and deadlocks. Throughout our work towards building an Interaction Machine, ***We want to better understand, frame and master this process –i. e., analyzing the adjacent possible of HCI technology and methods– and introduce methods and tools to support and extend it. This could help to make technology better suited to the exploration of fundamentals of interaction and to their integration into real systems, uncovering new possibilities for interaction design and improvement of interactive systems to be empowering tools.***

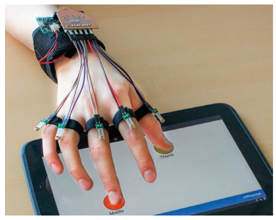
Recent software and technologies

The following list describes our most recent and significant software and technologies, with names of all team members emphasized. For each contribution, a self-assessment is given according to Inria's Evaluation committee's criteria.

WhichFingers (since 2017)

A-2 SO-4 SM-2 EM-1 SDL-2↑

WhichFingers is a low-cost prototype for finger identification using piezo-based vibration sensors attached to each finger. By combining the events from an input device with the information from the vibration sensors we demonstrate how to achieve low-latency and robust finger identification [TOP.31]. WhichFingers consists in hardware and software components that are publicly available under the GPLv2 license from http://ns.inria.fr/mjolnir/whichfingers/.



Contributors: G. Casiez, A. Goguey, S. Huot, S. Malacria, D. Masson

Lagmeters (since 2015)

A-2 SO-4 SM-1 EM-2 SDL-4

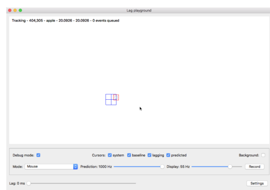
As part of the work reported in [TOP.19, TOP.30], we implemented our original methods for measuring end-to-end latency on mouse and touch-based platforms using Java/Swing, C++/GLUT, C++/Qt and JavaScript/HTML5. We also wrote Python scripts to parse and compare the logs generated by these implementations. Materials and source code for replicating both the hardware and the software (about 4,000 lines of code) are publicly available under the GPLv2 license from http://ns.inria.fr/mjolnir/lagmeter/.

Contributors: G. Casiez, S. Conversy, M. Falce, S. Huot, D. Marchal, T. Pietrzak, S. Poulmane, N. Roussel

Liblag (since 2014)

A-1 SO-4 SM-1 EM-2 SDL-1

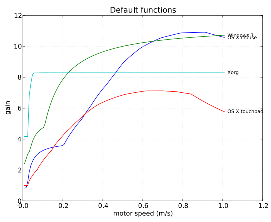
Liblag is a software toolkit designed to support the comparison of latency compensation techniques. The toolkit notably includes a playground application that allows to compare different trajectory prediction algorithms on desktop (OS X and Ubuntu) and mobile (iOS and Android) systems. The source code for this toolkit (about 9,000 lines of code) is only available to Turbotouch partners for now.



Contributors: G. Casiez, S. Poulmane, N. Roussel

Libpointing (since 2011)

A-3 SO-4 SM-3 EM-3 SDL-5

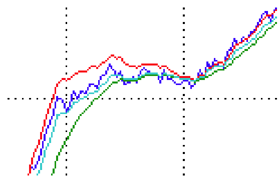


Libpointing is a software toolkit that provides direct access to pointing devices and supports the design and evaluation of pointing transfer functions [41]. It bypasses system's transfer functions to receive raw events from pointing devices. It replicates as faithfully as possible the transfer functions used by MS Windows, Apple OS X and Xorg, enabling comparison of the replicated functions to the genuine ones as well as custom ones. It is written in C++ with many bindings available (about 49,000 lines of code in total). Binaries are distributed through common package managers (Homebrew, apt, npm) and source code is publicly available under the GPLv2 license from https://github.com/INRIA/libpointing.

Contributors: G. Casiez, M. Cranness, S. Huot, D. Marchal, I. Mukhanov, P. Olivo, N. Roussel

1€ filter (since 2011)

A-4 SO-4 SM-2 EM-2 SDL-4



The 1€ filter is a simple algorithm to filter noisy input signals for high precision and responsiveness [57]. It uses a first order low-pass filter with an adaptive cutoff frequency: at low speeds, a low cutoff stabilizes the signal by reducing jitter, but as speed increases, the cutoff is increased to reduce lag. The algorithm is easy to implement, uses very few resources, and with two easily understood parameters, it is easy to tune. When compared with other filters, the 1€ filter shows less lag for a reference amount of jitter reduction. Reference implementations in Python and C++ (<150 lines of code each) are freely available from http://cristal.univ-lille.fr/~casiez/1euro/ as well as a dozen other implementations mostly contributed by external researchers (e.g. IN-SITU, the Media Computing Group at RWTH Aachen University, ENAC-LII) and practitioners (e.g. Sensorit, "I'm in VR"). It is also included in the Tracker software from Vicon.

Contributors: G. Casiez, N. Roussel, D. Vogel

Publications

Unlike in many academic fields, select conferences in HCI are premier publication venues intended for archival. ACM SIGCHI conferences such as *CHI (Conference on Human Factors and Computing Systems)* and *UIST (Symposium on User Interface Software and Technology)* have at least 5 independent reviews, a rebuttal process, a program committee meeting and an acceptance rate between 20 and 25%. They exceed most journals in their selectivity, visibility and impact. Since 2013, we have published 38 papers in these top-tier conferences (29 CHI, 9 UIST).

The following list shows the publications of the five research scientists and faculty members of the proposed team (G. Casiez, S. Huot, S. Malacria, M. Nancel and T. Pietrzak) between 2013 and 2018 (creation of the team), with names of all team members emphasized. Ten notable publications have been singled out. Acceptance rates are shown when available as AR: accepted/submitted (rate%).

Top-tier conference papers

2018 TOP.38 M. Nancel, S. Aranovskiy, R. Ushirobira, D. Efimov, S. Poulmane, N. Roussel & G. Casiez. "Next-Point Prediction for Direct Touch Using Finite-Time Derivative Estimation". In *Proceedings of UIST'18*, October 2018. ACM. UIST

TOP.37 A. Goguey, G. Casiez, A. Cockburn & C. Gutwin. "Storyboard-Based Empirical Modelling of Touch Interface Performance". In *Proceedings of CHI'18*, April 2018. ACM. ***Honorable mention (top 5% of all submissions)*** AR: 667/2590 (25%) CHI ★

TOP.36 A. Goguey, S. Malacria & C. Gutwin. "Improving Discoverability and Expert Performance in Force-Sensitive Text Selection for Touch Devices with Mode Gauges". In *Proceedings of CHI'18*, April 2018. ACM. AR: 667/2590 (25%) CHI

TOP.35 S. Siddhpuria, S. Malacria, M. Nancel & E. Lank. "Pointing at a Distance with Everyday Smart Devices". In *Proceedings of CHI'18*, April 2018. ACM. AR: 667/2590 (25%) CHI

TOP.34 A. Antoine, S. Malacria & G. Casiez. "Using High Frequency Accelerometer and Mouse to Compensate for End-to-end Latency in Indirect Interaction". In *Proceedings of CHI'18*, p. 1-11, April 2018. ACM. AR: 667/2590 (25%) CHI

TOP.33 J. Avery, S. Malacria, M. Nancel, G. Casiez & E. Lank. "Introducing Transient Gestures to Improve Pan and Zoom on Touch Surfaces". In *Proceedings of CHI'18*, April 2018. ACM. AR: 667/2590 (25%) CHI

TOP.32 A. Goguey, G. Casiez, D. Vogel & C. Gutwin. "Characterizing Finger Pitch and Roll Orientation During Atomic Touch Actions". In *Proceedings of CHI'18*, p. 1-12, April 2018. ACM. AR: 667/2590 (25%) CHI

2017 TOP.31 D. Masson, A. Goguey, S. Malacria & G. Casiez. "WhichFingers: Identifying Fingers on Touch Surfaces and Keyboards using Vibration Sensors". In *Proceedings of UIST'17*, p. 41-48, October 2017. ACM. AR: 73/324 (22.5%) UIST

TOP.30 G. Casiez, T. Pietrzak, D. Marchal, S. Poulmane, M. Falce & N. Roussel. "Characterizing Latency in Touch and Button-Equipped Interactive Systems". In *Proceedings of UIST'17*, p. 29-39, October 2017. ACM. AR: 73/324 (22.5%) UIST

TOP.29 N. Fellion, T. Pietrzak & A. Girouard. "FlexStylus: leveraging flexion input for pen interaction". In *Proceedings of UIST'17*, p. 375-385, October 2017. ACM. AR: 73/324 (22.5%) UIST

TOP.28 M. Nancel & E. Lank. "Modeling User Performance on Curved Constrained Paths". In *Proceedings of CHI'17*, p. 244-254, May 2017. ACM. AR: 600/2400 (25%) CHI

TOP.27 A. Antoine, S. Malacria & G. Casiez. "ForceEdge: controlling autoscroll on both desktop and mobile computers using the force". In *Proceedings of CHI'17*, p. 3281-3292, May 2017. ACM. AR: 600/2400 (25%) CHI

TOP.26 E. Giannisakis, G. Bailly, S. Malacria & F. Chevalier. "IconHK: using toolbar button icons to communicate keyboard shortcuts". In *Proceedings of CHI'17*, p. 4715-4726, May 2017. ACM. AR: 600/2400 (25%) CHI

TOP.25 A. Evain, F. Argelaguet, N. Roussel, G. Casiez & A. Lécuyer. "Can I think of something else when using a BCI? Cognitive demand of an SSVEP-based BCI". In *Proceedings of CHI'17*, p. 5120-5125, May 2017. ACM. AR: 600/2400 (25%) CHI

2016 TOP.24 M. Nancel, D. Vogel, B. De Araùjo, R. Jota & G. Casiez. "Next-point prediction metrics for perceived spatial errors". In *Proceedings of UIST'16*, p. 271-285, October 2016. ACM. AR: 79/384 (20.57%) UIST

TOP.23 A. Goguey, M. Nancel, G. Casiez & D. Vogel. "The performance and preference of different fingers and chords for pointing, dragging, and object transformation". In *Proceedings of CHI'16*, p. 4250-4261, May 2016. ACM. AR: 565/2435 (23.2%) CHI

TOP.22 A. Gupta, T. Pietrzak, N. Roussel & R. Balakrishnan. "Direct manipulation in tactile displays". In *Proceedings of CHI'16*, p. 3683-3693, May 2016. ACM. ***Honorable mention (top 5% of all submissions)*** AR: 565/2435 (23.2%) CHI ★

TOP.21 J. Cauchard, J. Cheng, T. Pietrzak & J. Landay. "Activibe: design and evaluation of vibrations for progress monitoring". In *Proceedings of CHI'16*, p. 3261-3271, May 2016. ACM. AR: 565/2435 (23.2%) CHI

TOP.20 G. Bailly, S. Sahdev, S. Malacria & T. Pietrzak. "LivingDesktop: augmenting desktop workstation with actuated devices". In *Proceedings of CHI'16*, p. 5298-5310, May 2016. ACM. AR: 565/2435 (23.2%) CHI

2015 TOP.19 G. Casiez, S. Conversy, M. Falce, S. Huot & N. Roussel. "Looking through the eye of the mouse: a simple method for measuring end-to-end latency using an optical mouse". In *Proceedings of UIST'15*, p. 629-636, November 2015. ACM. AR: 70/297 (23.56%) UIST

TOP.18 M. Liu, M. Nancel & D. Vogel. "Gunslinger: subtle arms-down mid-air interaction". In *Proceedings of UIST'15*, p. 63-71, November 2015. ACM. AR: 70/297 (23.56%) UIST

TOP.17 M. Nancel, D. Vogel & E. Lank. "Clutching is not (necessarily) the enemy". In *Proceedings of CHI'15*, p. 4199-4202, April 2015. ACM. AR: 495/2150 (23.02%) CHI

TOP.16 F. Haque, M. Nancel & D. Vogel. "Myopoint: pointing and clicking using forearm mounted electromyography and inertial motion sensors". In *Proceedings of CHI'15*, p. 3653-3656, April 2015. ACM. AR: 495/2150 (23.02%) CHI

TOP.15 M. Achibet, G. Casiez, A. Lécuyer & M. Marchal. "THING: Introducing a tablet-based interaction technique for controlling 3D hand models". In *Proceedings of CHI'15*, p. 317-326, April 2015. ACM. AR: 495/2150 (23.02%) CHI

	TOP.14	S. Malacria, J. Aceituno, P. Quinn, G. Casiez, A. Cockburn & N. Roussel. "Push-edge and slide-edge: scrolling by pushing against the viewport edge". In *Proceedings of CHI'15*, p. 2773-2776, April 2015. ACM. AR: 495/2150 (23.02%)	CHI
2014	TOP.13	J. Gilliot, G. Casiez & N. Roussel. "Impact of form factors and input conditions on absolute indirect-touch pointing tasks". In *Proceedings of CHI'14*, p. 723-732, April 2014. ACM. AR: 464/2034 (22.81%)	CHI
	TOP.12	M. Nancel & A. Cockburn. "Causality: a conceptual model of interaction history". In *Proceedings of CHI'14*, p. 1777-1786, April 2014. ACM. ***Honorable mention (top 5% of all submissions)*** AR: 464/2034 (22.81%)	CHI ★
	TOP.11	C. Gutwin, A. Cockburn, J. Scarr, S. Malacria & S. C. Olson. "Faster command selection on tablets with FastTap". In *Proceedings of CHI'14*, p. 2617-2626, 2014. ACM. AR: 464/2034 (22.81%)	CHI
2013	TOP.10	S. Malacria, J. Scarr, A. Cockburn, C. Gutwin & T. Grossman. "Skillometers: reflective widgets that motivate and help users to improve performance". In *Proceedings of UIST'13*, p. 321-330, October 2013. ACM. AR: 62/317 (19.55%)	UIST
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2017	CNF.22	H. Si-Mohammed, F. Argelaguet, G. Casiez, N. Roussel & A. Lécuyer. "Brain-Computer Interfaces and Augmented Reality: A State of the Art". In *Graz Brain-Computer Interface Conference*, September 2017.	GBCIC
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	JNL.8	F. Calegario, M. Wanderley, S. Huot, G. Cabral & G. Ramalho. "A method and toolkit for digital musical instruments: generating ideas and prototypes". *IEEE MultiMedia*, 24(1):63-71, January 2017.	IEEE Multimedia
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	DOC.9	T. Raffaillac & S. Huot. "Applying the Entity-Component-System Model to Interaction Programming". In *Proceedings of IHM'18*, p. 42-51, October 2018.	IHM
2016	DOC.8	L. Potier, T. Pietrzak, G. Casiez & N. Roussel. "Designing tactile patterns using programmable friction". In *Proceedings of IHM'16*, p. 1-7, October 2016. ACM.	IHM
	DOC.7	S. Malacria, A. Goguey, G. Bailly & G. Casiez. "Étude de terrain sur l'utilisation des pavés tactiles". In *Proceedings of IHM'16*, p. 19-24, October 2016. ACM.	IHM
2015	DOC.6	T. Pietrzak, N. Roussel, A. Gupta & R. Balakrishnan. "Manipulation dialogique pour affichages tactiles". In *Proceedings of IHM'15*, October 2015. ACM. 10 pages. AR: 21/42 (50%)	IHM
	DOC.5	M. Berthellemy, E. Cayez, M. Ajem, G. Bailly, S. Malacria & E. Lecolinet. "SpotPad, LociPad, ChordPad & InOutPad : exploration de l'interaction gestuelle sur pavé tactile". In *Proceedings of IHM'15*, October 2015. ACM. 6 pages. AR: 21/42 (50%)	IHM
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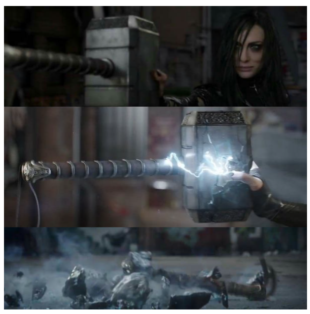
Summary

HCI research is not only about tomorrow's interfaces or applications but also about the original ideas, fundamental knowledge and practical tools that will inspire, inform and support the design of human-computer interactions in the next decades. **WE FAVOR THE VISION OF COMPUTERS AS TOOLS AND** would ultimately like these tools to empower people.

We are focusing on how such tools can be designed and engineered, and propose as a long-term goal to specify and create new technology dedicated to interaction: **THE INTERACTION MACHINE**. In the short to medium term, we will investigate this revision of interactive systems along three levels of dynamics of interaction. Research on *micro-dynamics* will focus on transfer functions, latency compensation and tactile feedback. Research on *meso-dynamics* will focus on augmenting the interaction bandwidth and vocabulary. Research on *macro-dynamics* will focus on real-time activity monitors and better system adaptability. Overall, understanding the phenomena that occur at each of these levels and their relationships **WILL HELP US TO ACQUIRE THE NECESSARY KNOWLEDGE AND TECHNOLOGICAL BRICKS TO RECONCILE THE WAY INTERACTIVE SYSTEMS ARE ENGINEERED WITH HUMAN ABILITIES**.

Considering our peer-recognized expertise and visibility, our network of collaborators, our environment and Inria's priorities, we strongly believe we are well positioned to achieve significant progress towards these objectives and goals.



Why* Loki*?

In Norse mythology, **Loki** is a god who maintains ambiguous relationships with other gods. **Loki** is also a fictional character appearing in Marvel comics as Thor's mischievous adopted brother and archenemy, although sometimes fighting on his side. **Loki** has a child, Hela, who was once able to break Thor's hammer, Mjolnir. We have first chosen this name as a last nod to our former team Mjolnir and team leader Nicolas Roussel. But **Loki**, as the one whose destiny is to provoke Ragnarök – the end of the world before its revival –, alludes to our objective of overhauling interactive systems. His ambiguous personality also evokes the dualities in our approach: interaction design vs system engineering, augmenting existing systems vs reinventing them from scratch, etc.