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The Meaning of Interactivity—Some Proposals for Definitions and Measures

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New interactive applications, artifacts, and systems are constantly being added to our environments, and there are some concerns in the human–computer interaction research community that increasing interactivity might not be just to the good. But what is it that is supposed to be increasing, and how could we determine whether it is? To approach these issues in a systematic and analytical fashion, relying less on common intuitions and more on clearly defined concepts and when possible quantifiable properties, we take a renewed look at the notion of interactivity and related concepts. The main contribution of this article is a number of definitions and terms, and the beginning of an attempt to frame the conditions of interaction and interactivity. Based on this framing, we also propose some possible approaches for how interactivity can be measured.

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1. INTERACTIVITY IN CHANGE

Interactive artifacts and systems are being introduced in almost all contexts of human activity; in our homes, at work, and in every other realm of everyday life, the number of interactive artifacts and systems is growing. Generally this development may seem both desirable and unavoidable in view of all the benefits that this new technology can bring to people and organizations. However, there are also critical voices that question the good of increasing interactivity (Brende, 2005; Carr, 2010; Jarrett, 2008; Morozov, 2013; Schenk, 1999). Assuming that these concerns should be taken seriously, we need to explore how to translate the criticism into analytical investigations and potentially into new research questions regarding interactivity.

Let it be clear that the purpose of this article is not to settle issues about increasing interactivity. Rather, we explore possible interpretations of what it might *mean* and explore suitable *conceptual tools* for discussing and (where possible) deciding on such issues, focusing our efforts on examining the most basic concepts of interaction. The result is a number of basic terms and definitions. They are not specially tailored for the issue of increasing interactivity but on the contrary meant to be a generally applicable conceptual framework in discussing, analyzing, and designing interaction.

There are two reasons why we are doing this investigation into the basic concepts of our field with reference to the questions of increasing interactivity. One is that interactivity is a somewhat controversial issue that engages the research community at this time, and some clearing up of the basic assumptions and clarifying of the basic concepts should be welcome for all parties involved. The second reason is that we have found the issue productive for our own creativity and thinking about the basics of interaction; it is a domain of application we have found conducive to

producing and honing various basic interaction concepts. Regarding the question of what is good and what is bad with respect to interactivity in a larger, societal, and cultural context, we are not trying to make a contribution here, but we hope that clearer and more finely tuned concepts can facilitate the articulation of more transparent and clearly argued standpoints.

With that said, let us get back to the worries about increasing interactivity. In current human–computer interaction (HCI) research there are today proponents for reducing or at least questioning the level of interactivity in our everyday environments (Dourish & Bell, 2011; Hallnäs & Redström, 2001; Odom et al., 2014; Pierce, 2012; Sengers, 2011). Some of these are not only critiquing present development but trying to explore and develop artifacts and systems that provide intended support for human activities while carefully avoiding increasing interactivity. This is particularly common within areas such as ambient technology and ubiquitous technology, where there is an explicit ambition to lessen or remove the need for direct HCI, usually by removing or changing the traditional interactive interface. Others argue for decreasing or at least being wary of the overall level of interactive technology (Carr, 2010; Morozov, 2013; Schenk, 1999), and yet others critique the dominating contemporary understanding of technology from a philosophical perspective (Borgmann, 1984; Feenberg, 1999; Ihde, 1990).

At the same time, the flood of new interactive applications, artifacts, and systems emanating from contemporary HCI research shows that many researchers do not see increasing interactivity as a problem in itself, or at least do not see it as a hindrance to their ongoing efforts in designing new systems, even for activities in areas where we traditionally have not seen interactive technology as providing suitable and desired solutions, such as close relationships, emotional monitoring, health and exercise, experiences of nature, and culture.

We take the existence of these different and in many ways conflicting attitudes as indicating a common belief that *interactivity* is something that exists in our everyday environments, that there is something that we might call *level of interactivity*, and that this level is possible to affect and change by design. From our point of view, however, the basic phenomenon of interactivity does not appear to be clearly delineated, and the notion of level or intensity of interactivity is in need of a fuller explanation (Bucy, 2004). If we can do something about this vagueness and ambiguity, we should among other things be better equipped to address the issues of increasing interactivity: Is it actually happening? Is it good or bad? Are there conclusions to make for designers? It is of course possible that less vagueness and ambiguity of core concepts will not make it easier to handle the worries we have mentioned or answer the questions we just listed, but we do see the overall anxiety around interactivity as a call for a closer investigation of the basic terms and concepts. We hope that our work will provide some form of conceptual foundation that could be useful for anyone who wants to engage with the more practical and societal issues concerning interactivity.

Our approach is mainly analytical or, with another term, philosophical. We have engaged in a detailed examination of how interactivity can be defined and what such

definitions would entail. As a starting point we have chosen an everyday intuitive understanding of interactivity, as our purpose is to develop concepts that make good sense from a practical point of view. We have worked through many examples, and we have refined and iterated on alternative definitions. In the process we have developed some new concepts that we have found necessary to capture the richness and complexity of interactivity.

We take a design perspective in our studies, which means that we try to develop knowledge that is meaningful to designers. We do this by examining properties and qualities of designed artifacts. The aspects of artifacts that we primarily examine are those that are *open for manipulation to designers*, that is, properties that designers can and do intentionally affect by their design decisions. Rather than taking users and their experiences of the artifacts as a primary target for examination, unfashionable as it may be, we favor an approach that is objective in the sense of artifact centered.

This does not mean that we regard users as unimportant, of course: They are the obvious sine qua non of HCI. But we think that the efforts already directed toward ferreting out experiences need to be complemented by equally serious studies of the artifacts that make HCI possible. In fact, artifact studies can be quite revealing as to mistaken or misdirected assumptions about users. One may recall how Bill Buxton scolded contemporary design in *Human-Centered System Design* (Norman & Draper, 1986):

> Imagine a time far into the future, when all knowledge about our civilization has been lost. Imagine further, that in the course of planting a garden, a fully stocked computer store from the 1980s was unearthed, and that all of the equipment and software was in working order. Now, based on this find, consider what a physical anthropologist might conclude about the physiology of the humans of our era? My best guess is that we would be pictured as having a well-developed eye, a long right arm, a small left arm, uniform-length fingers and a "low-fi" ear. But the dominating characteristics would be the prevalence of our visual system over our poorly developed manual dexterity. (p. 319)

Being able to analyze and discuss design-relevant properties; qualities; and, where applicable, quantities of interactive artifacts and systems puts us in a better position to assess in which respects they match or do not match particular user needs, use situations, and social contexts.

Set in a broader perspective, our approach is neither unique nor new if we compare it with the practice in other areas of design with a much longer history, such as architecture. Architecture has been engaged throughout its history with close examinations of buildings. Architectural education has always included the analysis of historical and influential buildings and building styles. This approach has led to insightful and intricate conceptual ways to frame qualities of buildings that have complemented the contextual and situational use and user-oriented aspects always guiding architectural design.

Our attention to the concrete objects of design is not to be understood as competing or in conflict with established approaches but as complementing what

others have already achieved. There is a history of HCI research dealing with interaction and interactivity, some more influential than others, for instance, in the collections of texts in the seminal books *User Centered System Design* (Norman & Draper, 1986) and *HCI Models, Theories, and Frameworks* (Carroll, 2003). We read some of these texts as pointing in the direction we have taken, such as theoretical exploration and the endeavor to develop foundational models and frameworks that describe the workings of interactive systems—a particularly good example is "Direct Manipulation Interfaces" (Hutchins, Hollan, & Norman, 1986). They have inspired us.

We are also aware of the contributions in our field during the last couple of decades from what might be seen as an opposing or even conflicting approach, focusing on the contextual and situated aspects of interaction, as exemplified with the works of Suchman's (1987) "situated action," Barad's (2007) "intra-action," or Orlikowski's (2007) "entanglement." Another stream of research that also has taken a conscious and strong user-oriented approach has led to substantial contributions to the notion of "user experience" (Forlizzi & Battarbee, 2004; Hassenzahl, 2004; McCarthy & Wright, 2004). We acknowledge that contextual and situational approaches to interaction and interactivity have led to insights, but our work is inspired by the thought of what a more objective and analytical approach can reveal and lead to, as a complement to these existing approaches.

We have also been inspired by other attempts in HCI to engage with more formal methods in the analysis of interactive systems, such as Harrison and Thimbleby (1990) and Dix (1991, 2003). Even though we have distinctly different purposes, there are aspects of what we are trying to do that resonate with their work. Harrison and Thimbley argued, for instance, that there is a need for formal approaches with the purpose to "produce precise frameworks" regarding interactive systems, which is something we agree with. They continued, "Formal methods first specify *what* we are talking about and lay down precise rules about *how* one is allowed to reason about those things" (p.2-3). We see our own work as following at least the first part of this principle. One important difference, however, between our work and this strand of research is that we are not aiming for the development of formal design methods directed at supporting the specification of new systems—what they label as "principled design." In contrast, our ambition is to develop some definitional precision of terms suited to better *understand* interactivity. They continued to note that such an approach brings inevitably brings some issues, for instance, that with a focus on formal aspects, "many important features that *may* affect the user are lost" (p. 4). We are also fully aware of this but like Harrison and Thimbleby we believe that a more formal or objective approach can lead to insights that otherwise would be missed.

We are aware of the many difficulties with our approach. We should, for instance, not naively assume that what constitutes relevant artifact properties is unproblematic, static, and absolute. On the contrary, our investigation shows that the notion of interactivity is elusive; a number of concepts are needed to frame and capture its various facets. Still, because interactivity is one of the most commonly

mentioned and prominent characteristics of digital artifacts, we believe it deserves our full attention and serious effort at explication and definition.

From our perspective it is highly desirable to combine these conceptual investigations with others that are more empirical. We see the work reported here as creating a foundational understanding of interactivity, a basic, somewhat provisional, setting for empirical work in the form of studies "in the wild," as well as for experimental studies.

2. SOME CURRENT INTERACTIVITY CONCERNS

We believe, thus, there is a need for a closer examination of the meaning of interactivity and how it can be defined. There are numerous reasons for such an investigation—general concerns about life in an interactivity-busy society, as well as open questions of special relevance to our field of research. Here we mention some of the issues that are commonly raised when interactivity and increasing interactivity is discussed, and we pose some questions that such discussions may lead to, questions that have inspired our investigation of basic concepts of interaction and interactivity.

2.1. The War of Attention

A common assumption seems to be that a user over time will become increasingly engaged in interactions as a result of increased exposure to a growing number of interactive artifacts and systems. The sheer number of interaction possibilities would allow us to interact more than with earlier, less interactive technology, and perhaps not just allow us but compel us. As everyday users of interactive technology, we may sometimes feel that we are the unfortunate battleground for an increasing number of artifacts and systems competing for a share of our attention (which we assume is a limited resource). Some work has been done in HCI regarding the idea of competition for attention or how to handle interruptions (e.g., McFarlane, 2002; Oulasvirta, Tamminen, Roto, & Kuorelahti, 2005). This concern has been addressed in some recent writings in relation to the concepts of *distraction* (Crawford, 2015) and *focus* (Goleman, 2013) and in a slightly different context to the notion of *attention economy* (Davenport & Beck, 2001; Goldhaber, 1997).

Even if the number of interactive artifacts and systems did not increase further, and the range of interaction possibilities offered by the different artifacts and systems did not, on average, expand further, isn't it quite possible that interactive artifacts and systems might still increase interactivity by becoming more and more efficient and successful in engaging people in interactions? Is there no end in sight for this "war of attention"? Or could it be that interaction possibilities and demands on our attention may start cancelling each other out when they come together in greater numbers?

2.2. Disinteracting

When overall interactivity increases, people may develop resistance and counter-strategies to uninvited interaction attempts. If interacting is acting to satisfy different "goals" or "requests," striving toward some temporary or final closure or satisfaction (which is very much in line with the old dialogue model of interaction), what should we call the act of refusing engagement, avoiding to take part, mutely resisting attempts at being interacted with? Let us call it *disinteracting*. The existence and conditions of, as well as strategies for, disinteracting with people in social life are well known and investigated (Goffman, 1963; Simmel, 1903). There are some reports of individuals' attempts to escape interactivity in different ways (Brende, 2005; Sengers, 2011).

You could argue that disinteracting is still a form of interacting (albeit disobliging) and that it still costs some effort. Also, could it be that disinteracting in one situation leads to increased interaction in other settings? Could it be that the interaction needed to achieve certain outcomes remains constant, and disinteracting only means that interaction is moved or shifted in time or place?

2.3. Time Expenditure

Do we in fact spend more time interacting with our artifacts and environments? Are we more often engaged in interactive behavior than before?

Perhaps a parallel can be drawn with traveling. Do modern people spend more time traveling than people in earlier and technically less developed societies? It is a debated issue, but a number of researchers (Schafer & Victor, 1997; Szalai, 1972; Zahavi, 1979) have propounded the idea that the time expenditure for travel is fairly constant regardless of the available means of transportation, be it by foot, canoe, commuter train, jet plane, or whatever. The more money and technical resources you have, the faster and wider you tend to travel, but the average time spent on traveling seems to remain about 1.1 hr per day. The empirical evidence for a constant "time budget" may be inconclusive, but we can transfer the idea to the area of interaction and ask similar questions as transportation research has: If it is constant, why is it constant? And if it increases, why does it increase?

So, suppose there is a fixed time budget for "interaction," meaning that regardless of the technological level of our environment we tend to spend roughly the same amount of time per day interacting. To make a technology-independent claim like that, we must first of all extend the notion of interaction from being restricted to "digital things" and "human–computer interaction" (whatever that is thought to cover) to include any kind of artifact interaction, and indeed interactions with any kind of environment, whether natural or artificial, including people and animals. Assuming such a broadened definition of interaction, suppose that the average interaction time budget *is* fairly constant. What kind of theory could explain that? As in transportation research we might look for biological, cultural, and economical explanations.

For example, there could be biological reasons for humans to have a certain daily, natural need of or limited capacity for interaction, so that when that quota is satisfied or exhausted, humans go into "noninteractive mode" (it remains unclear what that means, but people do sleep on a regular basis). If this were true, then technology would have nothing to do with it and we could simply reject the suggestion that interactivity is increasing. Still, if you think that there is an important difference between interacting with digital artifacts and systems and interacting with people, you might be more concerned about the proportion of artifact interaction to people interaction, and so still not be reassured.

Such a broadened, but in a sense more natural, notion of interactivity inevitably raises the question, What do we do when we are not interacting? Or, are we perhaps always interacting and it is more a matter of what *kind* of interaction?

2.4. How Many Balls in the Air?

There is a biologically and physically determined upper limit to how many balls a juggler can keep in the air: The more balls, the higher you have to throw them. These are hard constraints that cannot be overcome, and we might have a similar situation with more abstract and general interactions. Of course, juggling is not quite like keeping threads of interaction going. No matter how carelessly you "throw" an interaction, a response is likely to sooner or later come back to you, without crashing on the ground—or if it doesn't, does it really matter? You do not feel the need to have any attention to it while it is "in the air." At least, we take this to be a common attitude that has developed in the wake of the massive introduction of computer-mediated asynchronous human–human communication.

What happens then, however, is that actions tend to be reduced to reactions, and we run in danger of becoming the pawns of interaction games going on above our heads—processors in large webs of interactions rather than individual agents of our own design. The thicker the web of interaction threads is weaved, the less we are truly interacting.

Our environments are in constant change and evolution, so from that point of view there is no stable state that we can use as ground truth or benchmark when it comes to measuring the level of interactivity. But if, indeed, there is an upper limit to what is possible for humans to deal with before all we do (at best) is reacting, then could that give us a fixed reference point against which interactivity could be related and measured?

These issues seem to relate rather closely to multitasking, fragmentation, and the notion that we are living in the age of interruption (Friedman, 2006; Rose, 2010). Of course, it makes a difference if the number of interaction threads is a choice of the user or required by the environment. The inconvenience that multiple threads may cause is also a matter of good or bad timing and the predictability or unpredictability of the interruptions. Although a whiff of chaos may be stimulating and perhaps raise the level

of creativity, isn't there a considerable risk that the costs of frequent task switching in terms of slower performance and more errors (Monsell, 2003) will become prohibitive?

Questions like those just raised are complicated, diverse, and highly difficult to answer, and we do not attempt to do that. We believe that any attempt to answer them will require a more precise understanding of what we mean by interactivity. We do not claim that precise definitions are enough to resolve these issues, but we believe that more developed definitions would make it possible to operationalize questions such as these, making them amenable to proper examinations. With that, we start our investigation of basic interaction concepts and our attempt to capture the meaning of interactivity.

3. EXAMINING INTERACTIVITY

Even though HCI research is all about interactivity, there are surprisingly few serious attempts at defining what it is. It seems as if there exists a commonsense understanding of interactivity as something quite straightforward, along the line of "interactivity is the back and forth of control and action between a human and an artifact or system." We simply take this everyday notion as our point of departure, exploring, examining, and amending the concept along the way.

3.1. Interactivity, Interactability, and Interactiveness

First we need to examine the relationship between the concepts *interactive, interactivity, interaction*, and *interacting*.

There are several different general dictionary definitions of *interactive*. In the *Merriam-Webster Dictionary* two definitions are mentioned ("Interactive," n.d.):

1. mutually or reciprocally active
2. involving the actions or input of a user; *especially*: of, relating to, or being a two-way electronic communication system (as a telephone, cable television, or a computer) that involves a user's orders (as for information or merchandise) or responses (as to a poll)

These two definitions resonate well with a layman's everyday intuitive understanding of interactivity. The first definition points to the general aspect of interactivity as being something that "happens" or takes place between two parts and to the fact that both parts have to be active. The second definition is more developed and detailed and refers to the fact that interactivity has to do with a user of some kind of system that engages and interacts with that system through "orders" and "responses."

A note on our use of *user* as the term for the person who is interacting with an artifact, system, or environment: This is the term traditionally used in HCI, and we

stick with it in this article to make it easier for the reader to focus on the following series of new terms and definitions. As many others in the field, however, we are aware of its flaws as a general term and prefer a generic term less biased toward a special type of purpose and circumstance of interaction (e.g., *interactor*).

Dag Svanæs (2000) proposed an analogy between being *interactive* and being radioactive: "The relation between interactivity and interactive consequently becomes the same as between radioactivity and radioactive: Uranium is radioactive; Madame Curie studied radioactivity. Modern computers are interactive" (p. 5). However, whereas the property of being radioactive entails an ongoing process—if a piece of radioactive material ceases to emit ionizing radiation, then by definition it has ceased to be radioactive—the property of being interactive can also be interpreted as a potential or a disposition: It does not require unceasing interactions, and a modern computer is considered to be interactive even during the periods it rests unused on a desktop or in a briefcase. A similar ambiguity is inherent in the term *interactivity*, which can be interpreted in two different senses: (a) as a general term for the phenomenon of interaction, and (b) as a term for ongoing interaction. We occasionally use the term in the first, broader sense, as in the title of this article, for example, but we primarily use it in the second, more specific sense—the context should make it clear which sense is intended.

When discussing interactivity as *activity*, as an ongoing *process*, different measures, such as the *instantaneous* level of interactivity, which may fluctuate from moment to moment, as well as the *average*, the *minimum* and the *maximum* interactivity over an interval, may all be of interest. But they depend on how the artifact or environment is being used; they do not capture interactivity as an intrinsic quality of the artifact or environment.

In view of this, it appears we need another and different term for the intrinsic quality, the ability of things and systems, their potential, to engage in interaction. We have chosen the term *interactability* for that purpose. It is a term already in limited use: Wiktionary explains interactable as "(of an object) able to be interacted with" ("Interactable," n.d.), which suits our purpose here.

Having such a term makes it possible to discuss our subject with greater clarity, using the term *interactivity* to refer to the process, the activity (with different further qualifications such as momentary, average, maximum, minimum, etc.), while using *interactability* to stand for that intrinsic quality of an artifact or system that allows for interactions with a user. It also enables us to refer to level of interactability as the dispositional counterpart of level of interactivity, which henceforth is reserved to refer to the level of activity.

A possible drawback of interactability as the particular word choice is that it may sound as if the artifact is assumed to play a passive role—you can interact with it; it can, almost reluctantly, interact with you—whereas we certainly want to include the cases where the artifact urges or even forces a user into interaction. In fact, we take a special interest in those cases, as we suspect that it may be that specific aspect of interactability that makes some researchers wary and wanting to put restrictions on interactions.

Bear with us, but at this point we see a need to introduce yet another notion: the propensity of an artifact or system to give rise to and maintain interaction. There may be a high level of interactability and yet not that much interaction is actually taking place; that is, the potential for interaction is high, but users in fact do not get involved in much interaction. This appears to be a more subjective notion than interactability. Some may find an artifact engaging in a positive sense, and others may think it bland; some may find it irritating and annoying, and others may hardly notice it is there. Still, beyond idiosyncrasy and habituation, there is a basic, common sense in which an artifact or system is powerful or weak, insistent or meek, in making a user interact.

The means by which we are drawn into interaction range from interaction by lure to potentially more annoying interaction by insistence (silent or obstreperous), and interaction by sheer necessity, that is, we see no other or better way to get done what we believe must be done. Let us use the term *interactiveness* for an artifact's or system's propensity to engage users in interactions.

Regarding the terms *interaction* and *interacting*, they can both be seen as related to the activities that go on between a human and an artifact. We see these terms as less problematic in our investigation, especially because the introduction of interactability makes it possible to view interaction, interacting, and interactivity all as concepts related to an activity that takes place between a user and an artifact or system.

Interactivity is a concept that is used in many disciplines and fields and is sometimes more formally developed, whereas in other areas it is used as an everyday word. For instance, interactivity is a concept that to some extent is dealt with in Human Factors research (Nemeth, 2004; Sanders & McCormick, 1987). However, in this type of research the focus is on the combined human–machine system, where the human becomes one element among others. This more systems-oriented view on interactivity is less relevant to our more artifact-focused approach. Another area that has quite extensively explored and defined interactivity is media studies (Bucy & Tao, 2007; Downes & McMillan, 2000; Jensen, 1998, 2008; Kiousis, 2002; McMillan, 2000, 2010; Rafaeli, 1988; Retzinger, 2009; Stromer-Galley, 2004). Some of these attempts have reached recognition and are commonly referenced definitions within that discipline. However, these definitions have different purposes and are built on assumptions that do not align with the purpose of this article. For instance, because they are grounded in media studies, they commonly understand interaction and interactivity primarily as communication between humans. Within this tradition, technology is usually seen as a medium through which human–human communication flows, which leads to less attention to the artifacts or systems themselves. Similar definitions are also quite common in HCI research, but it is not a direction that our exploration will take.

Our focus in this article is on interactability as an intrinsic quality of an artifact, system, or environment that allows for interactivity between it and a human. One reason for this choice is that it is closely aligned with what we see as an intuitive understanding of interactivity in HCI and with what can be seen as an everyday understanding among nonexperts. It seems quite unproblematic to assume that most people are comfortable with the notion that they "interact" with

their laptop, iPad, car, toaster, or smartphone; that such activities could be described as a form of interaction; that interactivity is made possible by a property of these artifacts, namely, their interactability; and that interactivity is to different degrees "pushed" by the artifacts' interactiveness.

Many everyday objects are possible to interact with and fit our definitions, so what is not an interactive artifact? How about a piece of wood, or a piece of paper? It is obvious that we can act on the wood or the paper—we can shape it, manipulate and control it—and it is clear that it "responds" by giving in to our actions, for instance, by changing its location, shape, and appearance. However, we do not usually see this as a consequence of wood or paper being interactive. One reason is that the common understanding of interactivity seems to include some form of agency.

3.2. Agency

The notion of *agency* in relation to interactivity has to do with the idea that the actions of both parties (human and artifact/system) are guided by some internal design to achieve certain goals. This explains why people probably are more ready to accept that a toaster is interactive than that a piece of wood is. We tend to assume that the actions of the toaster are based on some internal mechanism designed to achieve certain ends in a purposeful way. Even though a piece of wood may "yield" to a knife or a drill by changing shape, and a piece of paper "respond" to a pen by showing visible traces on its surface, we do not see that as a designed response, the result of a plan residing within it.

It is of course still possible to view the "actions" of the wood or paper as expressing some kind of agency or plan. You could argue that the designer of the paper has designed the paper to behave in a particular way in response to the user's penmanship: to show exactly the curve along which the tip of the pen has traveled over the paper. "Wrongly" designed paper might, for instance, spread the ink too widely or erratically, making it hard to see what was written or drawn.

The problem with the pen and paper example is not that it cannot be brought into the format of designed behavior; it is rather that the paper so perfectly traces and mirrors our own behavior, that it is so compliant with our own actions as to not recognizably have a "will of its own"—all we can see is our own actions and our own purposes.

In fact, an artifact that is "acting up" may give a stronger impression of agency than a properly working, obedient, and yielding artifact, because we then take notice and may view its "misbehavior" as an expression of a "will" distinct from our own. So it would seem that one requirement for proper interaction is that the actions of one party are not completely subjugated to the actions of the other party.

Not wanting to undertake a fuller exploration of agency (a complicated notion with diverse interpretations), we are content with noting that some form of agency is part of people's intuitive understanding of interactivity and that there needs to be a certain moderation of compliance of the artifact or system with the

user's actions in order for agency to emerge. It may be that agency, for our purposes, rather than being an absolute notion is better viewed as being strong or weak, as perceived by the user.

At a higher level, writing or painting on a piece of paper may yet be understood as a form of interaction. There is a sense in which a writer in the process of writing reacts to the words already written, her very own words, in ways she didn't care to, want to, or was unable to predict prior to writing them down; similarly, an artist painting a watercolor sometimes or often cannot predict the exact effect of a stroke with the brush—every action on the artist's part is a little experiment—and even less can the artist know in advance how the effect it has on the painting will affect the next stroke, and the next, and so on. There is a sense in which *trying something out*, whether it is in writing a text, arranging flowers or furniture, setting a table, or in any number of other everyday situations, has the trappings of interaction. Because of our limited power of imagination and limited power of prediction—limited by random elements, incompletely known conditions, incompletely known causal relations, computationally hard relations—we need, or find it more expedient, to *try it* and see the result: Only then can we properly judge and proceed. This is the phenomenon that makes sketching and prototyping useful for designers. Some people have greater power of imagination: Evidently, Beethoven was able to write his last string quartets without "trying out" any sounds, deaf as he was by then. Most people sometimes need to experience their ideas outside of themselves as externalized objects. They need interactivity.

However, in cases such as the ones just mentioned, it would seem that only in a metaphorical or contrived sense is there agency in the opposite party. The piece of paper is not an agent, and neither is the partially completed painting; there is no plan, no designed purpose toward which it is actively striving. If there is, it is only in our imagination. Of course, one way of explaining what is going on is to see it as externalized, extended, or distributed thinking, an interchange of ideas and impressions made partly visible and tangible, an idea that has been introduced and developed by many in different fields (Bateson, 1979; Clark & Chalmers, 1998; Hutchins, 1995; Suchman, 1987). This point is rather interesting because digital technology has made it so much more easy and convenient to "try out" things rather than do lengthy and careful planning before getting into real action. In terms of the distinction between *epistemic* and *pragmatic* actions introduced by Paul Maglio and David Kirsh (Kirsh & Maglio, 1994), actions of "trying out" are epistemic actions—doubling as pragmatic in retrospect when the outcome happens to be approved and accepted. The famous *undo* facility is emblematic of a new, blooming mentality of "trying out." It is, though, we believe, of a different and generally less problematic variety of "interaction" than the kind of interaction we are focusing.

Even as we choose not to include that kind of "imaginary" interaction into the concept of interaction that we now are trying to capture, an element of the same "trying out" may be present in many cases of proper interactions. You do not know exactly what you are doing, in the sense of having full insight into the consequences, before the external response helps you to appreciate what you did. There is

sometimes a fine line between what you do and the consequences of what you do, but that doesn't mean you need to invoke some external agency.

With our understanding of agency, many mechanical artifacts will be seen as being interactive. For instance, a car is designed with purposes and plans enabling a user to interact with it to accomplish certain results, such as moving and steering to get somewhere. It is designed so that if the user lets go of the gas pedal, the car will slow down and come to a stop. Of course, modern cars come with considerable computational power, which means that their interactability can be higher.

Higher interactability does not necessarily imply stronger agency, however, because the degree of compliance with the user's actions may remain unchanged or even increase.

3.3. Receptivity and Predictability

If agency, *recognizable* agency, then requires some measure of independence of the user's actions and purposes, it is equally important that independence does not go too far. If our actions have no perceivable or recognizable effect on an artifact or system, then we have no interactivity: The artifact or system has to show some *receptivity* to user actions; there has to be some discernible connection between what the user does and what it does. To be recognizable as reactions, there has to be some degree of *predictability* of the behavior of the artifact or system partly in terms of user actions. If a system's behavior remains a complete mystery to the user over an extended period of "use" (whatever that might mean under those circumstances), we do in effect not have interaction. If an artifact is highly active but apparently acts in completely random ways, the artifact or system will not be seen as interactive.

Predictability might in some cases be very weak; we may be able to conclude that the system does react to our actions but not be able to make a useful prediction of what the reaction will be. One simple indication of receptivity is synchronicity or continuity of user action and system response. But if we cannot go further than that in understanding the system's behavior it will be a very weak case of interactivity, although it may be that we simply are unable to figure out the regularity, the design, and the plan that may be hiding within the system. We might even have been played, without realizing; yet it would not qualify as interaction (we think) if the user does not understand at all what is going on.

Leaving such bleak possibilities aside, a fair amount of predictability by the user would seem to be a condition for interactivity. On one hand, if system reactions are too predictable, too easily predicted, there will be a corresponding loss of sense of agency (see previous section). On the other hand, when a system's (re-)actions are becoming too hard, too tedious, to predict even in very general and vague terms, the interactability and the interactivity will drop toward zero. We cannot interact with what appears as randomly behaving systems, whether it is because they are truly random or because their behavior is too complex to deal with.

It may of course be possible to develop an alternate or complementary understanding of interactivity that would bypass the issues of design and agency. There are complex relationships between properties such as agency, compliance, receptivity, independence, and predictability that taken as a whole determine the interactability of an artifact or system. Yet we believe it is safe to say that it doesn't make sense to see everything as interactive: Paper is too pliant, and many natural phenomena are too unpredictable. Such artifacts and systems deny us the possibility to develop a properly interactive relationship to them.

3.4. Pace

An interesting aspect of interactivity that has not quite gotten the attention we think it deserves is the *pace* of interaction, ranging from very fast to very slow. Fast interaction could be illustrated with sports like football and boxing, and game hunting; slow interaction could be illustrated with debates in traditional scientific journals and books, traditional education, and farming. We believe that fast interaction is commonly seen as a characteristic of the new digital artifacts. The popularity of fast computer games may be partly responsible, but also the long-standing emphasis on efficiency in HCI, exemplified by the stress on short response times: *Slow* interaction has become hard to see as anything but a deficiency, and *designing* for slow interaction almost a contradiction in terms even though it has recent proponents (Hallnäs & Redström, 2001; Odom et al., 2014; Pierce, 2012; Sengers, 2011; Siegel & Beck, 2014). This could, hypothetically, have made our impression of generally increasing interactivity biased: Even if more time is spent on relatively *fast* interactions, we might be spending correspondingly less time on *slow* interactions without being aware.

With regard to the pace of interaction, we still have a dimension of interaction with a bounded interval within which interaction must be located to remain feasible. At some point things begin to happen too fast for us to perceive and act on, and before that point we may be able to perceive what is happening without being able to act quickly enough to do anything about it. For instance, sometimes it seems as if the buying and selling on the stock market when supported by extremely fast software ceases to be an interaction between a human and a system. At the other edge of the interval, changes eventually become too slow for us to perceive and thus able to act on. Well before we reach the edge of perceptibility we begin to run into problems of keeping our attention and interest in the interaction. Slowness in itself threatens to cause us to lose interest in or make it hard to maintain attention to what is going on.

Within this interval, interaction will differ in quality: fast interaction depending more on reflexes and trained behavior, slow interaction more likely to invite and require thoughtful reflection and planning.

The human disadvantage in dealing with very fast and very slow processes may be partly overcome by technological means. For example, we can slow down time with ultrafast cameras and speed up time by speeding up a slow development (such as

weather system developments or even climate changes) at a much higher speed. In the latter case, obviously there can still be ample amounts of time to act if we regularly keep an eye on the long-term developments, and thus to truly engage in interaction (of course, for processes with an observable rate of change on the order of the human life span or more, it would not be individuals that interacted). In the case of very fast processes we are worse off, but we may in some cases be able to resort to interaction by proxy. As an example, modern fighter planes are built to be inherently unstable to allow faster, more extreme maneuvers; to keep them in stable flight, flight control surfaces must be constantly adjusted at a very fast rate, much too fast for any human pilot. The problem is solved by inserting a computer to do these fast, low-level adjustments, leaving it to the pilot to make the high-level decisions about which direction to go.

The main focus in analyzing and defining interactivity no doubt rests on less extreme cases, the more "ordinary interaction" will be in the midrange of various dimensions of interaction, where we may expect to find the conditions more suitable for human interaction.

4. THE SPACES OF POSSIBLE ACTIONS AND POSSIBLE OPERATIONS

New interactive environments are responsive, active, sensitive, and in a constant dialogue with people in the environment. The environments themselves are in some sense becoming more *agential* and *goal driven*. Because interactivity is understood here as requiring agency of some sort, interactivity is not only about being reactive and responsive but also about *pushing reality* in a certain direction.

Every interactive artifact and system behaves in accordance with its design, pushes toward its designed goals, which in turn encourages or forces the user to move in certain directions. Each interactive situation creates a *space of possible actions* for the user.

The space of possible actions is the totality of the actions or reactions that are available or possible for a user in relation to the artifact or system: as a response to the system or proactively so as to get it to do something. With regard to a microwave, for instance, when the user has placed something in the microwave there are a finite number of things the user can do, like setting the mode and setting the cooking time. These actions are limited by the design of the microwave and its intended context of use, and they make up a space of possible actions. Of course, there are a number of other things that the user can do, such as hitting the microwave, turning it upside down, using the glass door as a mirror, and so on. These actions, however, are in all likelihood not among the actions intended and designed for by the designer of the microwave.

Consider, however, taking an everyday nondigital example—that there actually is an infinite number of ways a cup of coffee can be moved from the tabletop to the mouth of the coffee drinker. Even disregarding outlandish movement paths like

putting it on a train to Paris and back again, disruptive maneuvers like turning the cup upside down or knocking over the coffeepot along the way, or subjecting the cup to excessive acceleration, an infinity of manners and stylistic variations in taking a sip of coffee still remains. Some would look silly or irrational; most could be interpreted as expressing something—a mood, a character, an illustration maybe of an argument or an outward sign of what is going on in the drinker's mind. In contradistinction to this cornucopia of actions and infinity of meanings, in human–computer interaction it is usually only the end result that counts.

Such examples show that we need a way to separate from the rich variety of humanly possible actions those that are directly involved in the interaction, and the specific aspects of them that are effective.

4.1. Actions and Operations

Let us distinguish the *operations* that are effective in interacting with an artifact from the *actions* of the human operator. The operations are what the artifact is designed to "perceive" of the user's actions. The operations constitute a strict regime of input channels through which human actions are sampled, filtered, reduced ("distorted," if you will), and allowed to affect the artifact in a way intended and authorized by the designer.

As a consequence of this distinction we also make a clear distinction between the *space of possible actions*, alternatively called *action space*, and the *space of possible operations*, alternatively called *control space*.

The coffee cup example may make us reflect on the fact that many modern artifacts, and digital artifacts in particular, have a quite small and coarse-grained control space compared to the user's natural action space, which is finely structured, rich, and huge—perhaps even open-ended. A light switch may have only two operations (switch on, switch off); a user still has available an infinitude of actions and manners of *performing* the operation of switching it on: fast or slow, hard or gently, with the index finger, the thumb or the elbow, by throwing a ball at it, and so on—distinctions none of which the switch will notice or care about.

What should we do with this observation? It can be interpreted in different ways. It could be taken as a starting point for a general criticism of the extremely coarse and obtuse view of the user that digital artifacts presently take, that is, that our present designs expect every user to be content with interacting only via a narrow and strictly circumscribed space of operations. Such criticism could then become a call for more sensitive artifacts, more responsive to human expressiveness and sensibilities.

The same observation could also lead to the reflection that sometimes or maybe even often it is a very good thing that certain details, subtle variations and manners, uncertainties, shaky hands, bad feelings, and so forth, in fact do not matter. It is possible to achieve robustness, reliability, tolerance, and so on, if you keep operation possibilities limited, thoughtfully "digitizing" human actions in a suitable manner. Carefully designed "obtuseness" can actually serve to preserve or increase user control.

Such thoughts about potential qualities in existing interactive artifacts aside, with regard to our examination of interactivity, the notions of *action space* and *control space* as defined here are useful in our later attempts to find ways of measuring interactivity.

4.2. Affordance and Possibilities Space

The notions of "action possibility" and "operation possibility" evoke the concept of *affordance* in its original Gibsonian form (Gibson, 1977, 1979)—which differs from how the term has come to be used in HCI as *perceived* possibility as introduced by Norman (1988, 1999, 2004) and recently critiqued and discussed in Kaptelinin (2014) and Kaptelinin and Nardi (2012). Gibson's notion is probably closer to our notion of *operation* possibility than to our notion of *action* possibility, as Gibson may be interpreted as highlighting the net effect while abstracting from the finer details of performance; for example, a horizontal, flat, extended, rigid surface affords walking, according to Gibson—but obviously there are many different *manners* of walking encompassed by that single affordance (Gibson, 1977).

Although our notions of action possibility and operation possibility are relatively close to Gibson's notion—with the important proviso that we exclude action possibilities that fail to translate into operations and thus fall outside the scope of the designer's purpose with the artifact—our focus is now not on the particular possibilities but rather on the size, shape, and structure of the abstract spaces spanned by the totality of the action possibilities and the totality of the operation possibilities.

In designing the control space of an artifact or system, designers have great freedom of choice in how much they persuade or compel users to engage in certain points and regions of the space, sometimes by selectively blocking parts of the action space depending on the present situation. Alternatively, designers may try to make it as neutral and open as possible, leaving it to the users to find and make their own patterns of operation. The issue of how much freedom of action the user has is relevant for interactivity and has been considered by several researchers (e.g., Laurel, 1986, 1991; Steuer, 1995). If the user's actions are enforced at every step, it is obvious that the user actually is in the reverse situation of being too compliant with the agency of the artifact or system. No matter how much agency we may feel that we have inside us, if we are compelled at every step of the interaction it will not find external expression in a way that impacts the artifact or system. We are simply pushed along. In some circumstances this may certainly be a good thing: The examples that Norman gives of enforcing designs are typically about critical situations where people run into danger of making serious mistakes (Norman, 1988, pp. 132–140).

A narrowing down of the possible actions may be intentionally brought about by users themselves; a user might, for instance, choose to lock a file or a setting in order not to destroy it accidently. This means that the space of possible actions is a dynamic space that may be influenced by actions of the user (a point emphasized by Gibson): by actions designed for in the artifact or system but also by actions not recognized by the artifact or system (like disconnecting the microwave from the power outlet or

blocking the oven door). The space of possible actions can also change as a result of external events and causes (e.g., a power outage).

There may be situations where a user *has* to take action, and other situations where a user *can* take action but may choose not to without immediate disaster, perhaps because it is not so urgent or important or perhaps because the system will handle the situation itself by some kind of default procedure. Modern cars seem to be moving in this direction: They are designed in such a way that the driver can take action in almost every instance but can also let the car take action on its own. For instance, the driver may decide to park the car without any support from the car or let the car do the parking. With a collision awareness system, however, the car will at some critical point unconditionally take the control from the driver (Janlert & Stolterman, 2010).

4.3. Implicit Interaction

We have not so far commented on the notion of *implicit interaction*. The concept has lately been explored and defined as a new form of interaction (Fujinami, 2009; Ju, 2015; Schmidt, 2000). Albrecht Schmidt (2000) defined it as "an action performed by the user that is not primarily aimed to interact with a computerized system but which such a system understands as input" (p. 192). Our interpretation and reformulation is that implicit interaction is "interaction" that does not *require* user attention. But if a user does not attend to the "interaction," arguably the proper sense of agency will be missing and so cannot really be a case of genuine interaction, according to our analysis. Implicit interaction may rather be seen as a kind of automation.

There is a fine distinction between un*in*tended and un*at*tended consequences that may play a role here. In performing an action with a specific purpose in mind, you may be aware that the action has certain other effects, thus in a weak sense intending those, too, but without paying much attention to them. (Some of them may actually be undesired, but not strongly enough to stop you from acting.) For example, you walk toward the sliding glass doors of the hotel entrance with the intention of getting to the reception desk behind the doors; your focus of attention is already on the persons behind the reception desk, but you are not completely unaware that the doors will sense your approach and react by opening. The primary aim with walking up to the doors is *not* to make them open, although you are implicitly expecting them to do so and probably also have some anticipation of the eventuality that they fail to open. In this case, the implicit interaction with the doors is clearly instrumental in achieving the main goal of getting to the reception.

For an everyday example of implicit interaction that is not instrumental with regard to the primary purpose, consider the use of the brake pedal in a car: Your intention is to slow down the car, but you are also remotely aware that your brake lights will turn on, in effect interacting with drivers behind your car. In another situation a driver might lightly touch the brake pedal, not to actually brake but rather with the intention of warning a driver close behind. The latter case also

illustrates that (in discussions of interaction and interactivity) it is appropriate to define *intention* to be *part* of the action so that the same overt behavior may correspond to several distinct actions. Thus, walking toward the sliding doors in order to get to the reception is considered to be a different action from doing the very same walk to test if the doors work correctly (in which case, clearly, the interaction would not be implicit).

Contrast these examples to cases where the user has no awareness that some "implicit interaction" is or might be going on, or what forms this "implicit interaction" might take: This would be even harder to interpret as proper interaction.

Implicit interaction is thus not proper interaction in the sense that it engages us in addition (be it cognitively, only) to what we otherwise are doing. Yet, although it may appear not to take extra time and effort and attention, possibly it might still take a small toll on the user's cognitive resources, as indicated by a certain readiness for breakdowns. The presence or absence of such a readiness, however, may say more about the reliability in the automation and the trust it has managed to instill in the user.

We do expect the use of implicit interaction to generally be on the rise—and increased implicitness should mean or at least could mean decreased interactivity. Whether it will be enough to compensate for the new interaction possibilities and potential new sources of interactivity that seem to be added to our lives on a regular basis is more doubtful.

4.4. Environment Interaction

"Environment" is not a very precise term: It may be used as a broad reference to the general kind of setting that users of interactive artifacts and systems are in; it can refer to a specific place furnished with a specific set of interactive artifacts and systems, or it can be interpreted as referring rather to the *situation* that a user is in, with focus on the various interactive artifacts and systems present to the user at that moment in that location. We are mostly using "environment" in the situational sense, emphasizing the dynamic character, the changeability, and the possibility of transitory environments, the more or less chance crossings of the trajectories of a number of artifacts and systems and persons. This is not to deny that environments in the second sense, stably recurring situations, play and will continue to play a central role in society. Much effort is spent in designing homes, workplaces, and public facilities so that the situations they create and re-create will be familiar to us, thus saving us much cognitive effort and probably adding to our sense of comfort and confidence. Stably recurring situations are just a special case, of course, and we suspect that part of what makes increasing interactivity appear threatening is the increased mobility and fluidity of interactive situations that seems to go with it. Some recent work in HCI has recognized this challenge and introduced notions such as "artifact ecology" (Bødker & Klokmose, 2011) and "device landscape" (Stolterman, Jung, Ryan, & Siegel, 2013).

A user may be said to interact with a certain environment, but note that this has a different meaning from interacting with an artifact or a system, except in the unlikely event that the environment behaves as a single unified agent. An environment will normally not be viewed by users as having a single agency. In effect, what it means to interact with the environment is to interact with one or a number of its constituent elements.

4.5. User Control of Interactivity

Even though we primarily take an analytical and objective perspective toward interactivity, it is at this point relevant to ask, To what extent can a user exercise control over the level of interactivity with an artifact or system?

In Section 4.2, we touched briefly on the possibility of user control of the space of possible actions, thus regulating the interactability of the artifact or system. Many interactive artifacts and systems are designed to give the user opportunity to decide and control what parts of the control space should be accessible. The purpose may be to prevent inadvertent operations (like locking the settings of a digital artifact kept in a pocket or handbag, or locking a graphical component in a drawing under construction), to hide certain currently irrelevant features in order to focus attention, to simplify and speed up interaction, to ensure that certain operations can be performed only by a properly authorized user, and so on. Although changed interactability does not straightforwardly translate into changes in the level of interactivity, it certainly remains a relevant factor. We return to this subject.

Similarly, it may be possible for the user to influence interactiveness by setting the means by or level to which the artifact will demand attention. For instance, if the user turns down the ringtone of a smartphone, or puts it into silent mode, or turns off all notification functionality, its interactiveness will be reduced. Reducing or increasing the level of interactiveness of an artifact does not necessarily influence the interactability of the artifact, but by definition it should have the effect of changing the average level of interactivity. It may be relevant to think about the level of interactability and interactiveness as determined by user control as situational while the intrinsic levels of the artifact could be seen as the potential.

Obviously, users may also affect interactivity by how proactive they are. If a user takes initiative and engages proactively with an artefact, it leads to more interaction. Similarly, a user can completely ignore an artifact regardless of its interactability and how demanding it is. How proactive users are is not just a consequence of their mood, personality, and use situation but is also influenced by the interactiveness and the interactability of the artifact or system.

Any attempt to measure interactivity, interactability or interactiveness must take into account such possibilities of user control.

5. MEASURING INTERACTIVITY

It seems clear that a precise definition of interactivity is not to be accomplished in a sentence or two. The phenomenon of interactivity is complex and rich; defining it becomes a process of a step-by-step conceptual framing. We have so far introduced many, if not all, of the necessary concepts for a successful framing of the phenomenon. We have introduced the notions of interactability, interactiveness, space of possible operations, and space of possible actions; we have discussed the role of agency, time, independence, receptivity, predictability, and enforcement.

Let us now turn to the question of whether it is possible to measure interactivity and what that could mean.

In considering how *measures of interactivity* and interactability might be formed and credibly introduced, several methods are conceivable. For each method, we have to consider the different *purposes* that interactivity and interactability measures (and, in particular, measures that would be practicable) might serve, as well as desired *formal properties* of such measures.

One method would be to ask people whether they find certain artifacts and situations to be more or less interactive, more or less interactable than certain others, and see how able people are to take on the task and how consistent and reliable their answers are. This kind of empirical investigation to find out the degree to which people's intuitive assessments are concordant, coherent, and stable will be useful, first to see whether there already exists a more or less strong and shared pretheoretical notion that any more formal and precise measures would have to be able to either account for or provide explanations why they sometimes differ, and second to build a first testing ground for developing the new measures. In this particular research we do not present any substantial empirical studies; however, over the years we have been heavily involved in analytical, experimental, and empirical studies of interactivity. These previous studies have played a fundamental role in the work that we present here.

Another approach is to seek a theoretical grounding, which will require at least the rudiments of a theory of what interaction is or involves. A theoretical framing of interactivity makes it possible to engage in careful analysis of existing artifacts and systems as a way to both explore the usefulness of the theory and examine properties of the artifacts in question.

Preferably all available approaches should be used in combination. This is more or less the road we have taken so far. We have in our analysis of examples compared our conceptual framing and definitions with what could be considered an everyday intuitive understanding of interactivity.

Theoretical development and refinement, ultimately, is the goal, because it is what might make it possible to explain our experiences of interactivity, predict interactivity outcomes, and potentially turn the measures into workable tools for design. But there is always a risk in introducing specific methods of measuring that the measure will be interpreted as operationalizing the theoretically framed property it is meant to measure. For instance, there is a risk that a simple and efficient way of

measuring will change the meaning of the original concept to align and be identified with that measure, dumbing down and distorting the original idea. Although in the long run measures and theory should converge to match each other well, it would be unfortunate if specific measures quickly became so popular as to inadvertently and prematurely kill the possibly much richer nuances and deeper meanings they are supposed to serve. By pointing out a number of possible measuring approaches we hope to convey the idea of supporting, strengthening, developing, and sharpening the original ideas rather than heavy-handedly redefining and oversimplifying them: No single measure, we think, should be trusted to determine our interpretations of the concepts, but rather a number of different measures should be exploited to support, make practicable, and where possible carve out their meanings in greater detail.

In the following list of suggested methods of measuring, we first focus on the human actor and interactability, then move the focus to the environment and interactiveness.

5.1. Measuring Size of Control Space and Engaged Space

Our aforementioned work toward a more articulated understanding of interactivity gives some clues to how interactivity and interactability might be measured. The size (or amount, degree, or level—it is not yet clear which is the most appropriate attribute) of interactability could be considered as dependent on the size of the space of operation possibilities, the control space. The control space of a light switch is intuitively very small compared to the control space of the software Microsoft Word, so for that reason we would expect their interactability to be small and large, respectively.

In the case of Microsoft Word the control space is in an intuitive sense large, yet it seems likely that most users engage only in a tiny portion of the control space, leaving the rest untouched (if not necessarily unknown). The size of what we might call the *engaged space* may possibly tell us as much or more as the size of the whole control space, and the *relationship* between the engaged space and the total control space could be an interesting measure in itself. In some cases the relation could be 1.0, when the two spaces fully coincide, as with the light switch, whereas for an application such as Microsoft Word the relationship may be 0.01, if only a hundredth part of the application is actually used, engaged with. Of course, any measurement of engaged spaces has to consider individual variations and situational aspects. It may be that any such measure has to be carefully crafted by the use of conventional scientific principles regarding sample size and selection, bias reduction, and so on.

Then what is the "size" of such a space? If the space contains a finite number of points, like the light switch, they could be counted, but then continuous operations present a problem, for instance, with control spaces typically governed by sliders, knobs, or some gestures. A coarse but rather common way of characterizing control spaces with continuous operators is their dimensionality, or how many degrees of freedom they have. That makes it hard to compare spaces with the same

dimensionality or a continuous space with a discrete space. Of course, in many cases there will be a combination of continuous and discrete dimensions. Continuous dimensions could be handled by considering digitization based on the relevant practical limits of resolution for that dimension, its "grain size," essentially bringing us back to counting points. Perhaps a combination of dimensionality count and counting discretized points would be workable; possibly, we may want to put more weight on dimensionality than on how fine-grained, above a certain limit, each dimension is.

An artifact or system with a small space of possible operations but that demands many actions (even if it is a single action that needs to be repeated often) may be seen as highly interactive because of its high degree of interactiveness, whereas an artifact or system with a large space of possible operations but with a low degree of interactiveness, placing low demands on user intervention, may be perceived as not very interactive. Quite possibly its *perceived interactiveness* may affect its perceived interactability somewhat, but except for having an upper limit determined by the objective interactability, the objective interactiveness should be largely independent of the objective interactability.

So it seems as if the approach of comparing different spaces (control, action, engaged, and total) is one way of getting interesting information about interactivity, but it is not obvious how to compare and what the results may mean. For instance, the relation between the control space and the action space could give an idea of how sensitive and rich the interaction with an artifact is, and that could certainly be one important aspect of its interactability.

5.2. Measuring Interaction Time Expenditure

Measuring interactability means measuring the *potential* for interactivity. A more direct approach to measuring interactivity is in terms of *time spent interacting*. We note that increased interactability might well *reduce* time expenditure: With a richer set of control possibilities you may be able to perform tasks more quickly. (Less remarkably, it might also *increase* time expenditure if the expanded control space has a significantly higher complexity, making the appropriate operations slower to locate.) It is far from obvious, however, that time saved on certain interactivities will be spent on rest or contemplation, that is, on noninteraction, and not on extended or additional interactivities.

As a consequence of our discussion just presented about the *pace* or *frequency* of interactions, to measure time expenditure is not always straightforward. Slow interactions might be difficult to measure. For instance, when are the individual activities in a slow interaction better understood as separate interactive sessions and not part of an ongoing interaction? However, even with these difficulties we believe that a serious attempt in measuring time expenditure would reveal interesting aspects that may not otherwise be recognized.

5.3. Measuring Number of Ongoing Interactions

As long as we stick with the idea that interaction requires recognized agency, we also seem to sustain the notion that there are, so to speak, *threads* of interactions, quite similar to the idea of discourse and turn-taking in conversational models of interaction. That implies that it could make sense to distinguish different threads (with different agents, at least; to tell different, concurrent threads with the *same* agent apart may be more difficult), but it is far from obvious how to do it. For instance, when working with a desktop computer with a big screen we may have several activities or threads open and ongoing at the same time. Should we view the computer as a single agent (the "artifact"), or is each program or application rather to be seen as individual agents involved in separate threads? In any case, the number of concurrent threads a person is engaged in at a specific time and place is a conceivable measure of interactivity. It is conceivable that you could trace a person's travel through different environments and measure how the number of threads changes, resulting in some form of interactivity maps.

5.4. Measuring Interaction Pressure

Perhaps the most obvious approach to measuring interactivity is by counting the number of user actions or operations per time unit; let us call it *interaction pressure*. We might alternatively choose to count system or artifact actions, but by measuring the activity on the user's part, the intensity of the interaction is more clearly in focus. The less urgent and demanding, the more independent, automatic, and reliably doing what the user considers to be the right thing the artifact or system, the less active the user can be expected to be, ceteris paribus. The more autonomous and well behaved the artifact or system, the more the role of the user becomes one of monitoring, only occasionally intervening to correct or change direction even if the artifact or system remains very active. The interaction pressure is directly related to the pace and response times of the interaction; importantly, it will reflect the strength of the demands of the artifact or system for user action (which a count of artifact or system actions would not).

It is probably methodologically less problematic to count operations rather than actions, and questions about what should count as an operation can probably be resolved in ways similar to what was suggested regarding measuring control space in Section 5.1.

5.5. Measuring Environment Interactivity

Finally, we pose the question of how we could measure the *overall interactivity* of an environment as a whole, rather than individual artifacts or systems. A straightforward, practical approach would be to consider the totality of artifacts and systems in an environment as a composite system, as if it were one big system having the combined functionality and the combined action and control spaces of all its elements taken together. Any of the proposed methods of measuring should be possible to apply as before, but as we noted in Section 4.4, we normally cannot view this synthesized, composite system as something with which the user actually interacts.

Considering that most environments are not designed as a unit but are the result of combining several different and more or less unrelated design efforts, and that in many cases the environment will constantly change from moment to moment as individual artifacts are brought in or taken away, the interactivity characteristics of the whole setting may be importantly and interestingly different in character from that of the individual artifacts and systems. The concepts and tools for analyzing and investigating the interactivity conditions may well be the same, but the problem, especially from a design point of view, is how to relate the properties of the totality to the properties of its parts.

Let us be clear that we are not simply referring to context effects in general here. Any artifact or system is designed with certain assumptions—explicit or implicit, precise or vague—about its context of use, the intended use context. Designing a certain artifact for office use, for instance, might involve designer assumptions such as there will be light, the noise level will be moderate, the artifact will be operated in room temperature, it will not be used while walking around, and so on. If we take the artifact out of its intended use context, we expect some loss of interaction possibilities and interactivity. There is nothing remarkable in that.

The issue here is different: It is about what could be called the *digital context*. What happens when a number of separate, independently designed, interactivity-hungry digital artifacts and systems come together in the same setting? One major concern is cluttering (Janlert & Stolterman, 2015): *perceptual cluttering*—the inflow of information from a number of unrelated, uncoordinated sources, which may cause chaos, occlusions (information from one source hides or masks other sources), and distractions; and *behavioral cluttering*—actions intended for one artifact or system interfere with "normal" everyday actions and/or with operations of other artifacts or systems. Another general concern is that of artifacts and systems acting at cross-purposes, calling for extra interaction to bring order to the situation and enable productive outcomes.

So, measuring the overall level of interactivity in a particular context raises new methodological questions. It may be that the measures we have discussed in this article, primarily aimed at individual artifacts, are still useful, but there also seems to be a need for some new measurements or ways to capture the overall combined interactivity. It is obvious that people today have an intuitive sense of what environment is more interactive than another, but to translate that intuitive sense into more objective ways of measuring is still a challenge.

6. SOME CONCLUSIONS AND IMPLICATIONS

It is time to summarize what our investigation of interactivity has led to so far.

6.1. Framing the Window of Interaction

Our investigation has led us to see interactivity as a complex phenomenon that requires a set of developed concepts and definitions to capture and describe.

Interactivity depends on a number of parameters such as agency, pace or time, independence, receptivity, predictability, and enforcement. For an overview of our main concepts, terms, and definitions, see the list in the appendix.

Several of the dimensions of interaction considered here have turned out to have the character of an, in principle (but it remains to choose suitable measures), quantifiable parameter with a discernible bounded interval within which interaction is feasible (and outside of which it is unfeasible). For example, there has to be a certain measure of *agency*: If an interaction entity is too dependent, too compliant, interactivity will be missing; if the entity is not receptive enough—if it is too independent, too stubborn—it will also be missing. Also, there has to be a certain measure of *predictability*: If there is too little, if the entity appears to behave randomly, there can be no interaction; if it is too easily and routinely predicted, the entity will be experienced as either too submissive or too unyielding for a sense of agency to develop, hence no proper interaction. A third example is given by the time or *pace* dimension of interaction: If the pace is too high, our perception and action capabilities cannot keep up; if the pace is too slow it becomes very hard to attend to, and we may also be distracted from or lose interest for what is going on.

These observations have made us think of our investigation as involved in a quest for the general conditions under which humans are able to interact, properly speaking—to develop an interactive relationship to some entity—and the beginning of an effort to frame these conditions, outlining what we want to call the *window of interaction*. Within this window interaction is possible. Near to the edges the conditions for interaction become more and more severe, less and less favorable, to finally rendering interaction impossible at the very edge and beyond.

The exact dimensions of interaction that this window identifies can be discussed. The dimensions we have suggested and investigated here seem reasonable, quantifiable, and to match rather well to current praxis and theories—taken one by one—but the relations between them are less clear and probably in part an empirical matter to determine. We do not imagine that they are a completely orthogonal set of dimensions, nor are we confident that such an orthogonalization exists that would make practical sense.

6.2. Observations Regarding Interactivity Relations

During our investigation we found that a single concept is not enough to capture and define the everyday meaning of interactivity with any precision. After first pinpointing "interactivity" to refer to the *activity* of interacting, the core new concepts that we have developed are interactability and interactiveness. Having defined these concepts as precisely as we can and learning how to apply them through a broad variety of examples, we have sought to understand their relationships to each other, also with respect to the relation between artifacts and systems considered singly and whole environments of artifacts and systems. These relationships turned out to be both more intricate and weaker than we anticipated, and

although we are not claiming to have a complete grasp of all the connections, we here summarize some findings that we think deserve consideration.

First, consider artifacts and systems singly or in isolation, that is, without digital context.

Increased interactability does not necessarily imply increased interactiveness or interactivity. Interactability can be raised by expanding the action space (a wider range of actions can serve to interact), by expanding the control space (a larger repertoire of operations), or by both at the same time. We believe there are also other means of increasing interactability, such as various design moves to center the artifact within the window of interaction. Independent of these changes in interactability, interactiveness and interactivity may stay the same or even decrease. One example of this is when the addition of more powerful, more nuanced, and more adequate operations to the control space enables the user to perform key tasks with less interaction. Similarly, an expanded action space may give the user improved control, again enabling the user to perform key tasks with less interaction. One very simple example would be in the use of a smallish virtual keyboard (such as on a smartphone): By accepting not only a clean hit on a key as valid input but also a hit somewhat off center and touching neighboring keys as well, the number of typing errors is reduced, each of which would need extra interaction to correct.

In contrast to increased interactability, *increased interactiveness should generally raise interactivity*. This is not an observation, of course, but a consequence of how interactiveness has been defined.

In symmetry with the aforementioned, *lower interactability may (but need not) lead to higher interactivity*: Key tasks that need to be done may require a greater number of interactions when the control space or action space is smaller.

Increased interactiveness, finally, does obviously not always depend on an increase in interactability. There may be quite different causes of higher interactiveness, such as a more attractive and inviting interface, a more conspicuous or demanding presence, and so on.

Next, instead of focusing on individual artifacts, consider a complete environment creating a digital context in which a number of different artifacts and systems are being used.

The interactability, the interactiveness, and ensuing interactivity of the environment as a whole may be lesser or greater than the interactability and interactiveness of its different constituents might lead us to expect. Depending on the harmony or dissonance among the elements of the environment, perceptual and behavioral cluttering together will in varying degree reduce the interactability of the different elements of the environment, which may cause reduced *or* added interactivity as previously explained. Again, depending on the harmony or dissonance among the elements of the environment, purposes and behaviors at cross-purposes may call for added interactivity to check anarchy.

Finally, measuring interactivity can be done in many ways, each covering and informing us about particular aspects of an artifact's or environment's interactivity. It is important to remember that the different forms of measuring interactivity that we

have discussed do not in themselves answer what is an adequate or good level of interactivity. An appropriate level of interactivity in a particular context can be determined only in relation to the particular circumstances, who is engaged, the purpose of engagement, and so on.

6.3. Interactivity Trend Speculation

We do not have an answer to the question of whether interactivity is increasing: At the end it is an empirical question that has to be answered by empirical research. What we believe we have done is to provide a set of conceptual tools, a research kit, so to speak, that empirical research can use and develop into practical methods and measures helpful for, among other things, settling these issues.

Provisionally then, waiting for some hard(er) facts, like most researchers seem to do, let us assume that at least *interactability is indeed increasing*. There are at least three aspects to consider: whether new (and new versions of older) artifacts and systems generally are more interactable than earlier artifacts and systems, whether the number of interactive artifacts and systems is growing, and whether the proportion of artifacts and systems that offer interactive possibilities is growing. Quite possibly, interactability could be growing on all accounts. The rate and duration is hard to estimate: Possibly, we could be in the beginning of a protracted explosion of interactability, or it *might* just be a temporary and relatively short-lived boom—but we can see no indication that it would be just a passing fashion or self-defeating trend (also, that would go against the kind of development we have become used to expect in anything having to do with computer technology).

There are forces that potentially could slow or even reverse a move toward higher interactability. One such countervailing force is automation, but it is doubtful whether it will suffice to keep interactivity at bay. Another scenario might be people deciding to go off the grid in great numbers, abandoning the lifestyle of modern society and eventually making the production of interactive artifacts and systems come to a halt. Or we might experience some massive technological breakdown. But such scenarios seem at this moment quite improbable, so the hypothesis that interactive artifacts and systems will continue to grow in number and complexity in our environments and with that increasing the interactability seems plausible.

In view of such a development of increased numbers of interactive artifacts and environments, it would be almost inevitable that also *the average interactiveness of artifacts and systems will also increase*. When competition gets tougher as more artifacts and systems fill our field of perception, it would seem inevitable that the different, individual artifacts and system would need to try harder in order to stay in business. Compare how trees need to grow taller when neighboring trees grow taller in order to avoid the shade. In other words, in an evolutionary race to get our attention, the average interactiveness measured without the digital context would keep rising. Assuming a more or less fixed maximum scope and span of attention on the

human side, the net effect is of course not that on average an artifact would manage to draw more user engagement than before. (The trees become taller on average, but they do not get more sunlight on average.) An undesirable side effect, however, is that the artifacts on average would become more and more shrill and pushy, causing increased inconvenience and stress for the poor users. In the absence of strategical interventions, we expect that various methods of disinteracting would then become more common, like shutting interactive features off, relying more on automatic behavior and implicit interaction when that is an option, refusing to react, putting up a façade of indifference and insensibility, desensitizing, and so on.

7. POSSIBLE CONSEQUENCES FOR DESIGN

One of the major questions and challenges for the field of HCI and interaction design when it comes both to research and to practice is how it is possible to understand and think about new kinds of environments where interactability is all around us and interactiveness pushes us to engage. Is there need for new perspectives, theories, and approaches? What different views are around, and what do they mean?

The shaping of our everyday interactive environments seems to be a task for all of us as individuals—in organizational settings as well as in everyday settings. Each of us has the responsibility for composing our technology into a whole, a well-functioning interactive environment, with levels of interactability and interactiveness suitable for our purposes. Some will try to make all their interactive artifacts and systems to work together or side by side in an orderly fashion, and to minimize conflicting demands of interaction, that is, they try to harmonize their interactions across their artifacts. Others may purposely try to minimize the potential interactivity conflicts by reducing the connections and coordination among their artifacts. In both cases, people are engaged in this ongoing challenge using a diverse set of strategies without necessarily being supported by the design of the artifacts. Instead, the development of new digital artifacts and systems seems to be focused on the functions and appearance of each particular entity, taking very little notice of how the artifact might fit or not fit in a highly interactive landscape of other artifacts and systems.

This interactive landscape is in most cases largely unknown to the designer; it is hard or impossible for an interaction designer to foresee the exact digital contexts where their designs will end up being used. There are some attempts to deal with this problem. For instance, companies like Apple are intentionally designing their interactive artifacts to work together and to create an interactive landscape without conflicts. There are also, as we have already mentioned, some attempts in HCI research to step outside of the traditional *one user–one artifact* situation or the *many users–one artifact* situation of Computer-Supported Cooperative Work, into what can be described as *one user–many artifacts* and *many users-many artifacts* (possibly at cross-purposes) situations. Based on our investigation it seems that if we want to be able to say something about the meaning and level of interactivity, we as a field have to

pay more attention to the combined interactivity of many artifacts and systems that make up a particular environment.

It seems as if there are at least two kinds of situations in which interaction design has to deal with complex issues of interactivity. One is when we have complex but stably recurring settings, and the other is when we have emergent, ad hoc, transitory settings. Maybe the typical future situation will be a mix—a relatively stable and thought-out technological setup—the select technology that we bring ourselves and the purpose-specific technology-invested places we frequent—meets a jumble of other things that from our point of view keeps changing all the time, showing little regularity or predictability? In the end what designers still are unable to fix should the situation become too dysfunctional, too dismal, will be left to different regulatory mechanisms of society: particularly disruptive artifacts and systems being abandoned by users and discontinued; the formation of conventions and codes for use and behavior; the formation of rules and standards for artifact awareness and responsibility; and, ultimately, legislative measures. To design for these highly complex and unpredictable situations and to construct an appropriate level of interactivity, a suitable level of interactiveness and interactability will be a major challenge.

One motive for our investigation into the nature of interactivity is to develop precise conceptual tools that to some degree make it possible to analyze and understand these complex conditions, with the ambition to improve designers' ability to meet the challenge. Of course, our contribution in the form of new concepts and definitions is not in itself a solution to this major design challenge but a first step toward a more developed and grounded understanding of interactivity that includes technical as well as philosophical aspects. We have to understand the technological development, new interactive modes and styles, to imagine future interactive artifacts, systems, and environments. We have to be able to envision how these technologies will be infused in designs and manifestations and how they will be incorporated in everyday situations. At the same time we have to develop a philosophical perspective that makes it possible to critically analyze and examine the properties and consequences of these future environments with regard to interactivity. As an academic field we both have the responsibility to advance the use of new technology in the best possible way for the common good, as well as being informed critics of the technological development.

NOTES

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APPENDIX: LIST OF KEY CONCEPTS AND DEFINITIONS

action (with respect to an artifact or system): an action that a human operator can do *in its fullness*, here defined to include the intention with the action (which means that the very same physical maneuver can implement a different action if made with a different intent)

action space: same as **space of possible actions**, see below

agency (with respect to an artifact or system): the conceived presence of agency in an artifact or system

control space: same as **space of possible operations**, see below

engaged space: the part of the control space that is actually being used

implicit interaction: "interaction" that does not require human attention; a form of automation

interactability: the ability of an artifact or system to engage in interaction; that intrinsic quality of an artifact or system which allows interactions with a user

interactiveness: an artifact's or system's propensity to engage users in interactions

interactivity: the activity of interacting

operation (with respect to artifact or system): something that the artifact or system is designed to take as input as being a limited aspect or projection of an action of the human operator

pace (of interaction): the frequency of interactive exchanges between an artifact or system and a human operator

predictability: the possibility to predict (to some extent) that and how an artifact or system will react to actions of the human operator

receptivity: the ability of an artifact or system to discern and take into account (to some extent) actions of the human operator

space of possible actions, also called **action space**: the totality of possible actions with respect to a certain artifact or system

space of possible operations, also called **control space**: the totality of possible operations with respect to a certain artifact or system

trying out: when a human operator does actions with a tentative purpose affecting an artifact or system without conceiving the effects to have some agency other than the operator's own

user: the human who interacts with an artifact or system

window of interaction: a framing of the general conditions under which humans are able to interact