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Tabletops: Interactive Horizontal Surfaces

Tabletop_multi-touch_user interaces_collaboration_hypecycle

Summary. Tables are part of our everyday lives. We use their surfaces at home, at work, to play, to eat, and for collaboration. Since a few decades, researchers envision and design interactive tabletops with computers and displays integrated into the furniture. This is a prominent way of making computers invisible and to instantiate the user interface as a physical interface: an interactive horizontal surface. Tabletop research, technologies, prototypes, and products are tightly coupled and in this article we synthesize historical information and map our findings onto a so-called hype cycle, usually representing the maturity and the visibility of specific technologies. We characterize the evolution in this domain, pointing out and tracing innovations as they stimulated and triggered key transitions in research and technology. This enables us to extrapolate the future of interactive tabletops.

1. Ubiquitous Surfaces

Today, after approximately twenty years since its inception, research and development of technologies and products in the domain of interactive horizontals displays has reached a certain level of maturity. This allows for a review and analysis of the tabletop phenomenon. Tabletops can be understood as the third element of Mark Weiser's concept of Ubiquitous Computing (Weiser 1991). That is, as "yard-sized" interactive horizontal displays they enrich the UbiComp setting through their unique characteristics such as unconstrained display orientation, the affordance of placing physical objects on them, a group interface with egalitarian access – the computer, as we knew it disappears. On the one hand, a vibrant research community is now established and several off-the-shelf products are available. On the other hand, tabletop systems remain a niche market despite nearly two decades since the first pioneering prototypes emerged. As we reviewed these twenty years of tabletop research, technologies, and products we discovered shifts. It is not unusual for information and computer technology to have long adoption periods (Buxton 2008, Computer Science and Telecommunications Board of the National Research Council 2003). As for this investigation, the mapping of our findings on the so-called hype cycle allows us to describe the current maturity of tabletop technologies and outline potential future trends and directions. With the advent of Samsung SUR40, (Samsung 2011) we foresee further products where a closer integration of display pixel and multi-touch sensors becomes key. Hence, we envision future systems to be thinner and thus far more integrated, perhaps as interactive tablecloth.

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2. Tabletop phenomenon

Based on previous research (Müller-Tomfelde & Fjeld 2010) we categorize the tabletop phenomenon into three areas: research, technologies, and products. The research areas encompass computer science, software and hardware engineering, Human-Computer Interaction (HCI), as well as Computer Supported Cooperative Work (CSCW). We recently counted Google Scholar hits for query terms such as "tabletop" or "horizontal display" to produce a list of the ten most cited publications. Some of them address collaboration scenarios, while others focus on technological aspects of tabletops. As for technologies, we identified major subcomponents used in tabletop systems, e. g., touch or display technology. As for products, some have been developed since the mid-1990s in joint efforts between research labs and industrial partners. Some of these were funded by national government agencies to facilitate the technology transfer from labs into a profitable market. In recent years more and more off-the-shelf tabletop solutions have become available (see selected systems in Figure 1).

Various models and approaches may describe how technologies and products find their way from early development to sustainable markets. For instance, the "performance S-curve" is a model displaying the increase of the technology's performance over time. Alternatively, the "adoption curve" shows how the market adopts new technology and classifies customers, e. g., into early and late adopters. Finally, the hype cycle describes the relative maturity of technologies within a certain domain (Fenn&Raskino 2008). While this cycle is based on objective figures such as performance values or market penetration, it also accounts for people's attitudes toward technologies and relies on the assumption that excessive enthusiasm, i.e., a hype precedes the maturity of technologies.

We use the hype cycle model to integrate data of different quality into one model. The goal is to integrate alternative perspectives of the tabletop phenomenon into one representation to ensure a proper overview and understanding. The hype cycle model was originally invented to provide a snapshot

Figure 1: Important systems of the tabletop research of the last 20 years. The systems are (from left to right), top row: ClearBoard 1992 (Photo Courtesy of NTT Human Interface Laboratories)(Ishii & Kobayashi 1992), Active Desk 1992 (Photo Courtesy of Bill Buxton)(Buxton 1992),MetaDESK 1997 (Photo Courtesy of Tangible Media Group, MIT Media Lab)(Ullmer& Ishii 1997), middle row: BUILD-IT 1998 (Photo by Peter Troxler, permissions granted)(Fjeld et al. 1998),InteracTable 1999 (top and side view)(Photo Courtesy of Fraunhofer-IPSI/GMD-IPSI)(Streitz et al. 1999),DiamondTouch 2001 (Photo Courtesy of Circle Twelve, Inc.)(Dietz & Leigh 2001), bottom row: SmartSkin 2002 (Photo Courtesy of Jun Rekimoto)(Rekimoto 2002), Microsoft Surface 2007 (Photo Courtesy of Microsoft)(Microsoft 2007) and Smart Table Model 230i 2008 (Photo Copyright SMART Technologies. All rights reserved)(Smart Technologies 2008).

of a specific technology domain to guide investors. Visibility and expectations of technologies were plotted against their relative maturity. Based on our observations (Müller-Tomfelde & Fjeld 2010) we assume that the tabletop phenomenon also lends itself to be plotted on a hype cycle. Our cycle is based on factual findings supporting objective sampling of the current state of tabletops while predicting possible future trends and directions.

3. Mapping on the Hype Cycle

The idealized cycle is usually divided into five phases (Figure 2), and technology maturity evolves through all of them (Fenn&Raskino 2008): 1) While new technology triggers rising expectations, increasing numbers of research and media articles investigate and explain its potential. 2) Visibility and expectations peak and the technology becomes overrated due to excessive enthusiasm. 3) With failures and high prices comes disillusionment, and expectations reach a trough. 4) This is countered by consolidating technologies which are better understood and the expectations start sloping again until 5) the mainstream plateau is reached. In the following we explain our systematic mapping of selected tabletop research, technologies, and products on a time line against visibility and expectations in form of a typical hype cycle. While we plot the trigger, peak, and trough (1–3), the slope and plateau (4–5) may be expected in the near future.

Early lab tabletop prototypes appeared at the beginning of the 1990s, e. g., Active Desk, ClearBoard and DigitalDesk. Government funded research activities led to commercial products such as VisionMaker that further fueled research, such as metaDESK (see for an overview in (Müller-Tomfelde & Fjeld 2010)). In the late 1990s new technologies were explored and developed, e. g., Augmented Surfaces. Research teams experimented with bimanual interaction and Augmented Reality. Prototypes built for collaborative design and planning, such as BUIDIT-IT and InteracTable, stimulated an industrial research effort resulting in a commercial product in 2001. Meanwhile the research and development of multi-touch and multi-user technologies, e. g., DiamondTouch and

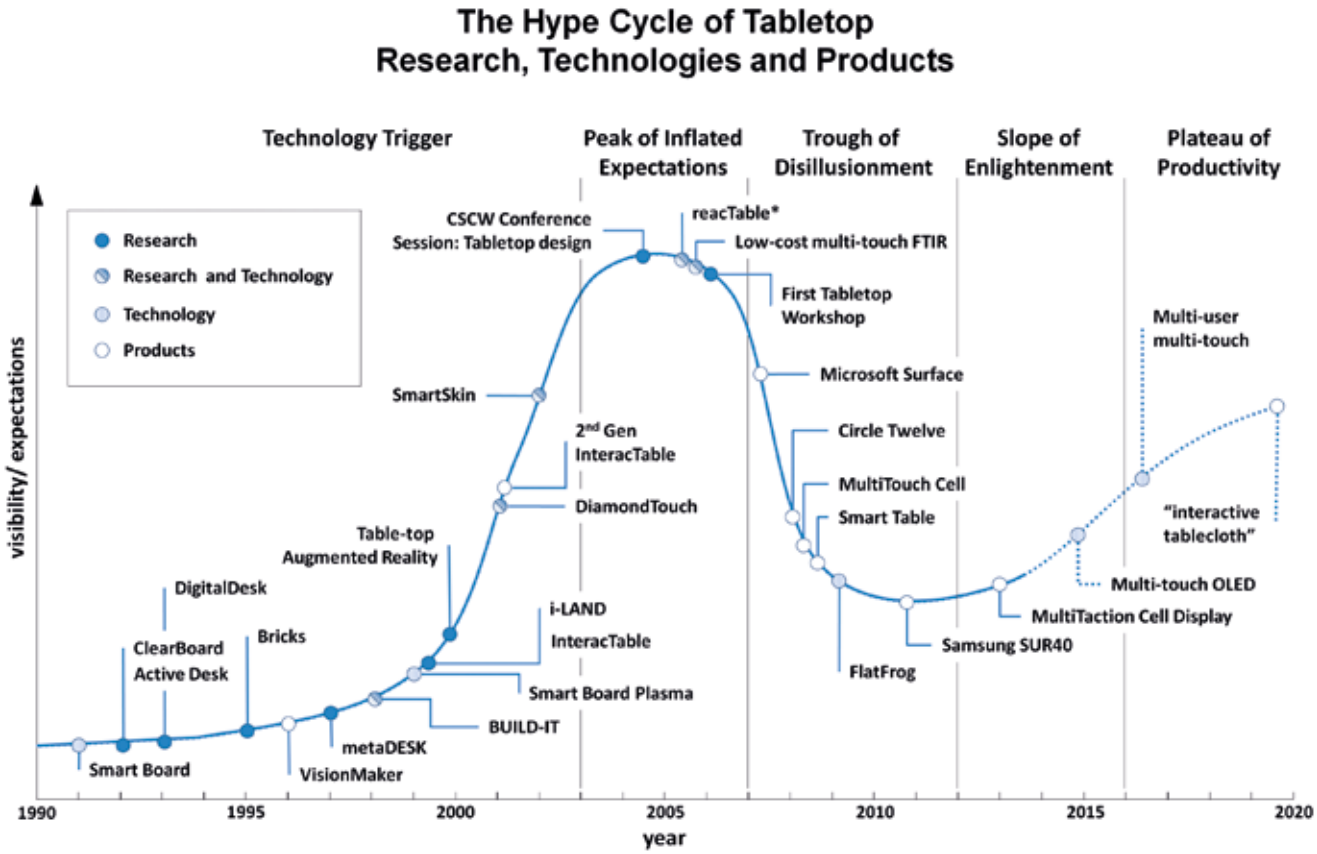

Figure 2: The hype cycle of tabletop research, technologies, and products over a period of 30 years.

SmartSkin, boosted interest in tabletop systems.

The 2004 CSCW conference had several papers addressing tabletop research as well as a session on tabletop design. A year later two important publications addressed tangibility on tabletops, reacTable*, and robust low-cost multi-touch technology. These works were followed by outstanding media coverage and thereby fuelled the interest in and expectations of tabletops. Also at this time the research community initiated the "Workshop on Horizontal Interactive Human-Computer Systems" which became a conference two years later.

In 2007 Microsoft launched Surface, followed by CircleTwelve's DT107 (the commercial version of the DiamondTouch), and the Smart Table in 2008. These products were more mature than prototypes presented at the peak and were all based on different multi-touch technologies. However, the high prices of these products dampened public enthusiasm and even disillusioned some. Other new products entered the market at even higher prices, e. g., MultiTouch Cell. Recently, novel multi-touch technologies operating as a simple multi-touch overlay to any existing displays were introduced. This puts the trough of the hype cycle at around 2011.

4. Characterizing the evolution

It is not unusual that the adoption of novel HCI technology requires more than one or even two decades. Bill Buxton argues that product innovation is "low-amplitude and takes place over a long period". In his emphasis "on refining existing as much as on the creation" of new technologies, he refers to the 30 year history of the mouse pointing device (Buxton 2008). Also, the National Research Council (USA) states in their 2003 report on Innovation in Information Technology that there is a "long, unpredictable incubation period between initial exploration and commercial deployment" (Computer Science and Telecommunications Board of the National Research Council 2003). Dating the start of the tabletop phenomenon to the early 1990s, a mainstream tabletop market could emerge around 2020.

In the technology trigger phase of tabletops, government research funding and industry cooperation were key in the development of systems and products. However, these products were highly customized and too expensive for wider adoption. The tabletop peak period is characterized by extended publication and research activities, as well as highly visible media presentation, e. g., of multi-touch technologies. In the post-peak period off-the-shelf solutions become available as well as performance improved second-generation products. The "climbing of the slope" starts with the launching of new technologies such as the Samsung SUR40 in the trough. This points towards a closer integration of display pixel and multi-touch sensors, that still needs to be further improved,but may allow future systems very small form fac-

tors, envisioned as "interactive tablecloth".

Reviewing the application domains envisioned for tabletop systems shows that the hype introduces a shift. The majority of scenarios before the peak were addressing the use of interactive tabletops in office environments, especially supporting small group collaborations. Instead, post-peak domains have focused on the educational sector, hospitality, entertainment, performing art, and domestic use (Figure 3). Shifts from the prevailing approaches or paradigms to new ones, i.e., transitions, can have either a more scientific or more technical character. We identify and trace three such key transitions (Müller-Tomfelde & Fjeld 2010):

- 1998 – From lab prototypes to real world collaborative applications
- 2001 – From single-touch to multi-touch and tangibility
- 2009 – From projection to direct display technology

The emphasis of early 1990s research was on laboratory prototypes. At the end of the same decade, some of these ideas were picked up again, but this time transformed into a new research context. Rather than being confined to labs as prototypical set-ups, novel approaches emerged emphasising group work in office environments. The BUILD-IT system from 1998 and the InteracTable of the i-LAND project from 1999 represent this transition in the direction of research.

The first touch-based devices connected to computer systems essentially replaced mouse-based input and, as such, the processing of input events was done in the same manner. Reliable multi-touch technologies were introduced with the DiamondTouch in 2001, a device that "allows multiple, simultaneous users to interact in an intuitive fashion". The tangibility aspect on tabletops also became a popular research topic at that time.

One of the crucial factors related to the construction of a tabletop system is the display, which has led technology. Since the 1990s data projectors have been widely used to build interactive tabletops. By the end of the 1990s, large size Plasma Display Panels (PDP) became commercially available and led to the InteracTable, the first tabletop system without the bulkiness of a rear projection. Recently, large sized LCDs (diagonal > 40 inch, 101.6 cm) have become available integrating multi-touch sensor such as the SUR40 technology. This development is leading the path to slim form factors of tabletop systems such as the

Figure 3: Tabletops have unconstrained display orientation and the affordance of placing physical objects on them. They provide egalitarian access and are an ideal collaborative interface for home, office and entertainment applications.

MultiTaction Cell Displays by MultiTouch Ltd.(MultiTouch 2012).

Departing from our natural inclination towards working with sheet-of-paper sized displays there may be future developements of "tiled tabletops". This is much line with Mark Weiser's remark that a natural way of working with documents is (re-) organizing them on a physical desk. Similarly, "tiled tabletops"enable its users to extract and re-integrate content and to seamlessly work in private and shared views. Trends towards such solutions can be seen in research (Cheng & Wagner 2009, Alexander et al. 2013, McGrath et al. 2012) and in products, where e. g. ASUS PadFone 2 combines phone and tablet into one single modular device.Finally, tangible tabletops are still limited to physically bound size and shape. In a collaborative planning, of for instance, a city- or a land-scape, it may be of critical use to interact with clay-like sensed materials on the table (Ishii et al. 2004). Hence, with "self-shaping tabletops", we suggest integrating the complementary concepts of interactive material sand tangible tabletops. This goal is feasible, as indicated by research in self-folding materials(Liu et al. 2012). For instance, Nokia Research recently promised a graphene Electrostatic Tactile (ET) system that is a "fully programmable electrostatic tactile feedback system capable of delivering a range of tactile textures to a mobile display. The ET system can be overlaid unobtrusively on top of a display screen to deliver localized control of friction, which can be synchronized with images or icons on the display. Since there are no moving parts in the tactile stimulation (skin is directly stimulated), the ET system is extremely efficient in terms of energy consumption" (Radivojevic et al. 2012). We believe that such ET solutions can be important components in future mobile tabletop solutions, where displays can take on any form (Girouard et al. 2013).

5. Future tabletops

Seamless integration of mobile (smartphone and tablet, see (Piazza et al. 2013) and fixed interactive devices, such as tabletop is emerging as key for user interface research, design, and engineering to take the critical leap towards the "disappearing computer". In line with Mark Weiser's 1991 vision of tabs, pads, and boards, the deployment of mobile phones, tablets, and interactive surfaces throughout our Post-PC society is massive. Hence, most infrastructural, educational, and research activities rely critically on a solid understanding of *how* the integration and use of such an ecosystem of artifacts is achieved. We see a strong need for finding a new paradigm for managing physical objects on horizontal interactive surfaces and for better understanding interactions above surfaces beyond hovering. Converging with this evolution, the area of interactive tabletops is reaching a level of productive maturity. Thus, the successful use of multi-user multi-touch tabletops will critically rely on our understanding of *how* handheld physical tools and artifacts, sometimes termed *tangible user interfaces*, can be "brought to the table" and instrumented to work fluently with tabletops (see Figure 4). While interactive tables promise huge potentials for example for task-critical collaboration, they remain to be understood, instrumented, and validated to work in such contexts. This requires trans-disciplinary insight into human action, cognition, and collaboration. Other contexts or applications for tabletops might emerge in the area such as hospitality and retail business. An orthogonal task is to study *how* to port the collaborative capacity of fixed tabletops to the mobile arena. Future research needs to systematically address this agenda of research topics. This is much in line with the contemporary research trend called "Bring Your Own Device" (BYOD)(Ballagas et al. 2004) where personal portable devices play a key role when users communicating, collaborating, as well as accessing cloud-based services.

In the upcoming decades we will see a wide adoption of tabletop technologies (see dotted line in Figure 2). Ultimately, affordable and reliable products will appear complementing the networked lifestyle environment of future consumers and prosumers. Until then, however, novel technologies will emerge and reinforce current trends. Firstly, the further physical integration of sensor and display technologies may lead to Organic Light Emitting Displays (OLEDs) combining their outstanding display and production characteristics with those of multi-touch interaction technology. Flexible displays technologies are on the brink to allow to new stunning designs in the domain of smart phone (Mone 2013), and will pave the way for thin and large form factors combined with high resolutions for tabletop displays that will fuel research, applications, and user interest. Secondly, a new unobtrusive technology for detecting multiple users' multi-touch may be developed to better support group interactions at tabletops. The now over a decade old multi user touch technology (Dietz & Leigh 2001) based on capacitive coupling will become updated in the near future leveraging on new portable devices' technologies such as e-wallets, RFC, or body area networks. These impulses in the area of display and interaction technologies will lead ultimately to the advent of an interactive tablecloth surfaces and the wider adoption of tabletops from 2020 onwards.

Figure 4: Mobile settings and uses of portable technologies (left to right): café, office, and camp (Piazza et al. 2013).

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