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*Kjetil Nordby & Andrew Morrison*

# Designing tangible interaction using short-range RFID

**Abstract**

*Short-range Radio Frequency IDentification (SR-RFID) technology embedded in mobile phones offers interaction design practitioners the potential to design new forms of mobile experiences. The article presents a design oriented research study that seeks to develop affordances specifically in support of such practice. To do so the authors draw on Activity Theory. They present three levels of SR-RFID related design affordances: need related design affordances, instrumental design affordances and operational design affordances. Included also is what they label 'RFID based Tap and Hold'; a term used so as to frame tangible interaction on SR-RFID. A generative and descriptive model of Tap and Hold is proposed, as is a set of input techniques derived from the Tap and Hold model. Overall, the study suggests opening out from functional views of SR-RFID to ones that view it as a technology applicable for designers exploring potential new interactions. This is important since such work may be used to support the generation of new designs, an area often overlooked in research on RFID.*

*Keywords:* design activity, interface design, technology, affordance, Tap and Hold, SR-RFID

## Introduction

### *Towards designing for interaction*

In interaction design the shaping of novel interaction techniques has increasingly been seen as a driver for new user experiences. Today, companies like Apple and Nintendo are carving out new niches by pursuing the creation of novel interfaces as a means of differentiation and competitive advantage.

In the design of such new interactions, emerging interface technologies, such as Short-Range Radio Frequency Identification (SR-RFID), which may have properties not yet fully exploited in current solutions, may have a role as enablers of novel forms of interaction and engagement. However, such technologies are seldom analyzed or framed according to a designer's need to design novel interactions. This is a problem since limited understanding of a technology in terms of the design of interactions may lead to outcomes that do not take fully advantage of the technology's interactional potential.


Figure 1. Aspects of NFC interaction using inbuilt software on the Nokia 6131 NFC phone. The image on the left shows a simple transfer of a hyperlink from a tag. The centre image shows the same functionality in relation to an interactive poster. The image to the right shows the inbuilt interface on the Nokia phone.

We argue this is also the case for SR-RFID technology on mobile phones that support Near Field Communication (NFC). The term SR-RFID refers to very short range radio transmitters that can read and write information to small, wireless tags, known as RFID tags. Examples of widely used applications include door cards and public transportation payment systems. When SR-RFID is embedded in mobile phones, it is possible to design interfaces that rely on physical manipulation of mobile handsets in relation to RFID hotspots in the world (Figure 1).

Most current research in relation to interaction design addresses SR-RFID through usability-oriented perspectives. Such work refers to existing or proposed types of use that have their origins in Human Computer Interaction (HCI), extending to the domains of tangible interaction (Hornecker & Buur, 2006) and pervasive computing. This is important research, but not entirely oriented towards the support of early and exploratory design processes that aim to create novel means of interaction, and thereby as yet to be realised uses and experiences. In this article we follow a research by design view (see Sevaldson, 2010 this journal) on critical and experimental inquiry when investigating the design of tangible interactions. This is an approach that values various and intersecting modes of knowledge: practice in design research is partnered with critical analysis and reflection in and on action in shaping artifacts (Schön, 1983; Binder & Redström, 2006; Zimmerman & Forlizzi, 2008). Rather than rehearse what was extensively mapped by Sevaldson earlier in this journal on research by design, we point to a recent paper on research by design within HCI to more specifically anchor our research with technology. Zimmerman et al. (2010) acknowledge that research through design, as they term it, is prevalent in HCI, a position they arrive at by interviewing twelve leading designers in this domain. This was supported by an analysis of key projects and current approaches.

Our support for such an approach takes the form of a theoretical discussion of linkages of two major conceptual frames used in design research - activity and affordances - and their application in respect to the conceptual design of tangible interactions concerning SF-RFID. We present examples of what we call ‘Tap and Hold’ as a means of tangible interaction via SR-RFID. We also propose a generative and descriptive model of Tap and Hold, along with a set of input techniques that are derived from the Tap and Hold model. These three design-led activities are linked to core concepts in Activity Theory and are placed within what we call the notion of *design affordances*.

### *Focus and challenges*

In order to investigate the tangible capabilities of SR-RFID we pose the following question:

*What interaction design techniques and features may be developed to further the design of SR-RFID?*

This question presents us with two dominant challenges. First, it points towards the need for a theoretical understanding of how to support technology usage inside designer design activity. Second it warrants an investigation into the capabilities of RFID in light of making tangible interactions.

The first challenge is met by devising a theoretical framework that allows us to interpret technology in light of a designer’s interests in designing new tangible interactions. To do so we combine aspects of Activity Theory with an extension of the concept of affordances to encompass near field technologies. Activity Theory provides us a set of established analytical tools that enable us to connect people’s activity with a technology in the environment in which they act. Here we refer to Leont’ev’s three level of activity (Leont'ev, 1978). These are the activity, action and operational level. Mindful of Gibson’s concept of affordances centred in psychology (Gibson, 1977) we then follow the direction taken by Bærentsen and Trettvik (2002) in linking these three levels of activity to affordances. The results are need related, instrumental and operational affordances. We argue that this partnering of concepts and their application - via a research by design experimental study in a wider design-research project into RFID called Touch - is useful for understanding and synthesizing relationships between designers and an emergent technology.

We approach the second challenge by way of design driven inquiry where we engage with SR-RFID to uncover knowledge that may be hard to grasp outside processes of designing. Consequently, we are able to try out, examine and reflect upon the nature and potential of the technology from inside designing. Our design work involved a diverse group of designers and researchers from different domains, including interaction, communication, industrial and technology design. Analytically, we draw on aspects of cognitive psychology, activity theory, and practice-based design research methods and critique. Our reflections are also informed by our other research into media and communication studies and a body of design practice.

### *Outcomes*

In experimenting with the qualities and affordances of this emerging radio field technology - one that cannot be seen by the naked eye - we have arrived at a new conceptualization of the tangible characteristics of SR-RFID embedded on mobile phones. We formulate a move from 'touch' technology to the gestural moves of 'Tap and Hold'; a model of related input techniques is presented; and, we offer a set of input techniques. These results are described as important affordances for designing and as ones that may be further organized, via activity theory, with respect to the need-related, instrumental and operational levels of the design activity.

Our work sees affordances in relation to what technology offers designers. As a result, we address the affordances the technology offers designers as *design affordances*. Such an approach is not typical in either design or HCI research. We believe that such affordances are critical in the design of the further application of SR-RFID technology and its extensions into situated use. Focusing on the design affordances of an emerging mobile technology that is in the throes of being 'unpacked' makes it possible to offer designers knowledge for further application in creating innovative services and experiences.

### *Outline*

In the following section we present related research on SR-RFID so as to situate our study in relation to what has been covered so far. We then present the overall theoretical framework. This is followed by an overview of the methods used analysis of SR-RFID and potential interactions, with visualisations, followed by a concluding section.

## Towards a new understanding of SR-RFID

### *SR-RFID in interaction design related research*

In examining the construction of repertories concerning tangible interactions, our research differs from current approach to SR-RFID on mobiles inside HCI where there is a clear focus on interaction in relation to specific functions. Physical browsing serves as an important example of such research and was first demonstrated by Want and colleagues (1999). They equipped a portable computer with a short range RFID reader and enabled it to activate services by coupling it with tagged everyday objects. Much attention has been given to similar services embedded on mobile phones. For instance Välkkynen, et al. (2003) connected the term physical browsing to mobile phones and explored hyperlink selection methods for mobile terminals using touching, pointing towards and scanning an area. These researchers later found pointing and touching to function well for physical browsing, with touching preferred if the link was within reach (Välkkynen et al., 2006).

Further approaches have placed SR-RFID interaction as a selection mechanism (Rukzio et al., 2006; Välkkynen et al., 2003). However, Mäkelä et al. (2007) found that the select mechanism that triggers a hyperlink often surprises people since they expect some spatial relation between the tag and the data perceived on the screen. They discovered that people saw the device as a lens to view data. For us these studies raise questions about the overwhelming support of the select and browse mechanism and beg the question as to whether the spatial relationship and the physicality of the tag might allow more elaborate physical interaction than mere selection.

### *Current inquiry*

To find examples of such an approach we have expanded our search beyond mobile solutions and moved towards more general research that deals with tangible user interfaces within HCI. In this domain several studies show how SR-RFID is capable of detection when the short-range radio fields are starting or ending an intersection (e.g. Grønbæk et al. 2003; Rømer et al. (2003; 2004). This shows the potential for expanding the typical input vocabulary of SR-RFID on mobiles and thus leads us to argue that such events are significant opportunities for designing new interactions. The examples deal with particular applications oriented towards implementation but provide no overarching framework directed towards the support of creative design processes using SR-RFID. Closest to such frameworks are multiple toolkits supporting the implementation of tangible user interfaces (Ballagas et al., 2003; Greenberg & Fitchett, 2001; Klemmer et al., 2004). However, such approaches are concentrated on increasing programming performance and effective deployment of technology. This makes them only indirectly oriented towards the processes of design practitioners who often only interact with development tools through programmers.

In the next section we present a framework to orient SR-RFID technology towards design activity and that of practitioners in designing new interactions.

## Activity, affordances and design

Dorst (2004) notes that since most design problems are undetermined and will emerge during designing, problems need to be understood as situated ones that are seen through the eyes of the designer within a process. Since the forming of technology also may be seen as part of the problems facing designers we may extend this view to SR-RFID as well. An implication of this is that technology needs to be adapted to support processes of situated designing. In doing so the perspectives of the individual designer’s designing and how technology is seen, analyzed and applied within this activity comes into focus. These perspectives we seek to investigate by way of Activity Theory (AT).

### *On Activity Theory*

AT originates in part in the work of the Russian psychologist Leont’ev which introduced the core structure of an activity we use today. His work was based on Vygotsky’s which sees human cognition, and in particular mediated meaning making, as realized through social interaction and context, not lodged in the lone mind of the singular subject (Vygotsky, 1962, 1978). AT allows us to use activities as the centre of analyses and, following that, use activities as a lens through which we approach technology as a socio-cultural phenomenon.

AT provides a framework which we use to analyze, explore and redesign SR-RFID technology with the purpose of appropriating it to support the activity of designing. Earlier, AT has been applied in inquiry into Human Computer Interaction (e.g. Kaptelinin & Nardi, 2006), studies of work (e.g Engeström 2004), user-based needs (e.g. Miettinen & Hasu 2002), and especially in learning (e.g. Engeström, 1987; see more recently Engeström & Sannino (2010), and collections such as Sannino et al. (2010) and Daniels et al. (2010). Few AT driven studies have been carried out to investigate or support design practitioners' activities of designing. There are some cases such as the application of AT as a supportive framework in the design of navigation equipment (Bjørkli et al., 2007) and, recently, on knowledge and software development (Mørch et al., 2010) and in relation to jewelry (Guile & Okumoto 2007).

What is central to an AT view is that knowledge is built through social interaction and collaboration, including that relating to engaging with new tools and media (Engeström, 1999, 2001; Nardi, 1996). Activity itself is a core concept in this theoretical framework; focus is on the developmental and transformative character of human, situated activity, including the technological and its cultural and historical contexts and legacies. In this approach, the terms subject, object and tools/signs are key.

Subject formally refers to the important notion of agency in AT. This may refer to an individual or group. The issue of whose point of view is in focus. The term Object is also central. It refers to the purpose or motivation for an activity, or the goal to which it is directed. Tools and signs function as mediating artefacts – they may include internal or specific computer applications or artefacts or they may refer to meditational and representational signifiers, all in all concerned with the representational and communicative means of mediated meaning making.

A central concept in AT concerns levels of an activity, derived from Leont'ev. In AT an activity is seen as directed by a motive which gives it meaning. However, activities do not achieve a motivation immediately; activities are long term processes constructed in a series of steps. These steps are structured in relations of actions and goals. Each activity is realized by a set of actions that are conscious, goal-driven steps. Each of these actions is constructed by a set of operations that are unconscious procedures driven by conditions. Together the arrangement of activity, actions and operations gives us a way to understand and analyze activity.

AT centres technology as a subject for interpretation through the frame of activities. Our interest being designing, we see that via the design activity SR-RFID can be regarded as a tool that mediates the designing activity. Further, AT give us means to understand tools in relation to the three levels of an activity. Then the question becomes what does SR-RFID, seen as a mediating tool, offer the designer doing the designing? To account for the opportunities found in the relationship between the designer and SR-RFID inside the design activity we draw on the concept of affordance.

### *On affordances*

Gibson originally introduced affordances as a relational quality between the organism and the environment. 'The affordances of the environment are what it offers the animal, what it provides or furnishes, either good or ill' (Gibson, 1977). This highlights affordances as opportunities or limitations for action that a subject might perceive. Here perception is used in a wide view based not only on sensory input but also mental processes. Affordances are not properties of any object, but particular aspects that exists in the relationship between subject and object (Chemero, 2003). As a consequence, end users will have a different perspective on affordances than that of designers.

Norman used the term affordance in *The Psychology of Everyday Things* (Norman, 1988) differently from Gibson. Norman steered affordances towards perceptual properties of an object which hinted on possible or intended use. Norman's take on affordances can be seen as the information that describes the affordances to the user. Norman later modified his view and describes his earlier writings as dealing with perceived affordances (Norman, 1999). This adaptation of the term affordance in HCI has received wide attention but is at odds with Gibson's meaning of an affordance as a relational quality between the organism and the environment. In HCI affordances have been seen in relation to users of systems or artefacts. McGrenere and Ho (2000) note that Gibson's affordances are action possibilities that either are present or not. Our interest in supporting a designer's use of a specific technology may also be seen through the perspective of an affordance. After all, seen from the perspective of a designer, he or she is also a user of the environment in the pursuit of making a new design. For a designer the SR-RFID technology then is a concrete piece of the environment that offers intended and possible affordances that support the designer's activity of designing (or planning) an artefact – one that eventually will present users with other affordances. As McGrenere and Ho (2000) argue, we may see the technology as a part of a larger system of nested affordances.

***Design affordances***

In our work we seek to support design activity by creating what we label design affordances. A design affordance may be defined as what the technology offers the designer in the activity of designing. A design affordance may exist for people other than designer alone. However, design affordances are purposely created with the intent of supporting the design of new artifacts.

In using technology in the activity of design, experimenting and reflecting on the technology's offerings plays a major part. However, much of the process of designing falls outside Gibson's notion of action possibilities. To deal with this, we propose it is useful to address affordances through activity theory. Looking at affordances in relation to AT, Bærentsen and Trettvik (2002) argue that Gibson's affordance focused on the operational level of activity. Thus, in an activity theoretical perspective, we may address Gibson's action possibilities as operation possibilities. This poses a limitation to activity were cultural and sociological aspects of activity are not taken into account in the view of affordance. Bærentsen and Trettvik propose this can be overcome by adapting the concept of affordance to all three levels of activity: activity, actions and operations. They introduce three levels of affordance: need related affordance, instrumental affordance and operational affordance. This helps us differentiate the kinds of knowledge related to designing we can create by defining design affordances in relation to all levels of design activity. These activity oriented affordances function as externalized design knowledge that can be shared and can act as mediating tools.

Design affordances may be suitable for other niches of human activity. However, design affordances represent a set of intended affordances seen as particularly appropriate for designers. With SR-RFID, the intended affordances presented by proponents of the technology (e.g the NFC forum) are directed towards specific kinds of technology use (for example smart posters or ticketing) rather than the design new interactions. We may overcome this problem by creating design affordances that specifically support such designing.

Work by Kuutti (1995) may be used to get at what type of design affordances can support each level of activity. Kuutti argues that HCI mostly deals with the operational aspects of activity and much can be gained by orienting HCI towards actions and activities as well. Kuutti makes a contribution to such directions by presenting a classification of activity that supports possibilities for information technology. Kuutti organizes the work predominantly around the activities of the users. However, there is no contradiction in using the same approach and in regarding the designers as the early, experimental and exploratory users of technology. As mentioned earlier, the technology then becomes a mediating tool for design. We can then use Kuutti's classification of support possibilities for technology in relation to tools. In the following sections we present our approach according to the levels of activity, action and operations inspired by Kuutti's classification of potential ways of supporting activity.

*Need related affordances for designing*

To support the activity level of design we may create tools that can inform or draw attention to the needs behind designing for a particular technology. Need related affordances can be used to frame the technology according to the motivation of the activity (Bærentsen & Trettvik, 2002). By scrutinizing technology in relation to the activity of designing we might create grounds for alternative interpretations of need than what is presently afforded to the community of HCI experts and interactions designers and researchers. The activity level is important as it points to the identification of potential needs that lie between material and designer.

One major affordance for designing SR-RFID interaction today is to provide touch as an easy to use transitional interaction moving users from tag to screen based interaction. We see the making of new need related affordances as the construction of new tools to expose the motivation behind the activity in concert with Kuutti's (1995) notion of constructing new tools to support the activity level. In the case of RFID this is not to merely follow given practices but to see how the technology might be manipulated to create possible interactions not provided by the touch approach.

*Instrumental affordances for designing*

To support tools on the action level, we see a need to support manipulative and transformative actions and to make tools and procedures visible and comprehensible (Kuutti, 1995). Instrumental affordances may be provided in the form of interaction models. By interaction model we mean a model that explains how interaction proceeds on an operational level (Beaudouin-Lafon, 2004). In performing an action a person conducts a conscious plan of the action to be performed by using a model. This phase is called orientation (Kuutti, 1995). Our interaction model aims to support this by providing an externalized model to inform the orientation phase of an action. We are particularly interested in designing models with high generative power, thereby supporting the design of new operations. By doing so, interaction models become models of instrumental affordance, visualizing possibilities, limitations and relations and through that supporting manipulative and transformative actions.

*Operational affordances for designing*

We relate the operational level to automating routines (Kuutti, 1995). In our case this is automating part of the designing of interactions. We interpret input techniques, output techniques and interaction techniques as operational affordances (Bærentsen & Trettvik, 2002). This is an area HCI research has often covered and we see Graphic User Interface (GUI) widgets and GUI components as examples of such affordances. This moves parts of designing interaction from an action level to an operation level, thereby freeing up design resources by providing readymade designs available for designing.

***Summary of approach to affordances***

Our approach to design affordances is summarized in Table 1. By combining activity theory and affordances we have placed the affordances for design in relation to each level of the activity of designing and, equally important, linked the affordances with each other. Ultimately, this makes it possible to create new instruments and operations, or to question the very motivation behind current affordances.

| Level of activity | Affordance type | Example of design affordance |
|---|---|---|
| Activity | Need related | New framing of technology to design |
| Actions | Instrumental | Modelling possibilities & limitations |
| Operations | Operational | Providing ready-made design examples |

Table 1. A system of design affordances. The left column describes the levels of an activity. The middle one shows the corresponding affordance type. The right column shows examples of what may be considered a design affordance.

## Design & research methods

An AT framework allows consideration of different levels of activity in the support of designing. In this research we adopted methods that enabled us to design SR-RFID as a set of mediating tools in support of motivational, operational and instrumental affordances. Fundamentally, our approach towards SR-RFID is situated within both an analytical framework from research and an interaction design framework from design practice.

In following a research by design approach (see Sevaldson 2010, this journal) we draw on Schön who describes designing as conversations with materials (Schön, 1983). He argues that materials “back-talk” to the designers when they engage with them in the process of designing. Schön refers to the “materials of the situation”, thus giving support to a wide definition of materials in design. However, the reflective process he proposes is also valid for our more limited approach to technology. Schön’s approach underscores the importance of engaging with technology by the act of designing to be able to see and understand it. This position promotes methods where reflection in and on design is an integrated part of the research effort.

Akin to this view, Wolf et al. (2006) have proposed that creative design approaches need to be employed to address ill-defined problems in HCI. Zimmerman et al. (2007) propose that creative designers use their strength of addressing under-constrained problems to aid the HCI community.

We coordinated an iterative development process that moved between designing and analyzing. The design methods generated data in the form of software prototypes and interaction design sketches. The research methods resulted in abstract descriptions of near field driven interaction in the form of a model of near field input and a series of input techniques (see Nordby 2010a, 2010b). In the following section we first present the methods for designing and second the research methods we used.

### *Methods for designing*

Central to our design approach is the use of software prototypes as a means of exploring the design material. Lim et al. (2008) suggest that prototypes are extensively used in designing as a means of traversing a design space: “Prototypes stimulate reflections, and designers use them to frame, refine, and discover possibilities.” Prototypes are fundamental in our approach to the NFI material for design. They may also be considered a method for provoking material “back-talk”.

In our design and research, prototypes were realized in collaboration between a software engineer and two interaction designers from the Touch project that investigated RFID (see: www.nearfield.org). The cooperation was constructed around a series of planning and evaluation workshops with emphasis on generating innovative solutions. Studies in HCI have shown that such collaborative efforts may support creative activity (West, 2002). To design the prototypes, a range of design techniques were used by the two interaction designers in the team. Predominantly, our focus was on the generation of interesting concepts of use and interesting interactions. This was done through various, and sometime collaborative, brainstorming and sketching activities. In addition, we used existing interaction techniques from other domains to generate new opportunities. We did this by cross-checking near field technology with interaction techniques from other interaction domains like physical buttons or graphical GUIs. For each analyzed interaction technique, we tried to design a near field technology driven equivalent. The resulting concepts and interaction techniques were sketched as pictures of interfaces, descriptions of user actions or schematic drawings of interactions. These were collaboratively refined and further developed into applications we could prototype.

Thematically, designing was centered on four separated prototyping efforts which each took a different approach towards SR-RFID. Our approach was to adopt an iterative design methodology that is widely regarded inside HCI as an efficient means of increasing design quality (Nielsen, 1993). However, our iterations focused on making fully new designs rather than refining a particular design direction. This was important as we were not pursuing 'good design', but rather better understanding of the materials involved in designing through provoking material "back-talk". As such, our prototypes can be considered technology probes that allow us to investigating the technologies in context with our research goal (Hutchinson et al., 2003).

This approach had two main benefits. First, it allowed us to continuously change the prototyping themes in direct relations to the evolving research findings in the project. Second, each prototype theme helped in the discovery of new aspects of interaction and worked as a way of 'triangulating' the material affordances by using multiple angles of approach. The prototypes encompassed a range of demos with increasingly sophisticated levels of development. During the course of the experimentation, the design efforts shifted from a focus on creative development to analysis of the interaction models developed by the research methods.

### *Research methods*

The interaction data generated from the design stages were studied by way of three analytical approaches: 1) Describing the interaction techniques, 2) Creating an interaction model, and 3) Developing input techniques. These approaches were applied iteratively.

#### *Describing interaction techniques*

We first produced descriptive diagrams of the interaction techniques developed in the study. Diagrams are used for problem solving, generating potential configurations and communication of information, (Blackwell, 1998) and are a common approach to investigating complex problems in interaction design. Describing detailed interactions through diagramming has been conducted earlier in HCI but is typically linked to GUI development (Chen, 1993), but not near field concerns.

In our work, diagrams described the interaction techniques abstract from context but ones focused on perceived user input and output. We separated them into base events that one could initiate by manipulating the near fields and input or output related functions that were triggered by the events. Much effort was put into producing one overarching diagramming format to describe all particular tangible interactions performed with near fields.

The process of describing interaction techniques was as follows: 1) Identifying and interpreting individual interaction techniques found in the data from the design phases, 2) Identifying all user initiated events in the techniques, 3) Identifying what types of input and output functions were triggered through the events, and 4) Describing each interaction technique by placing the events and functions in a diagram that related them to spatial movement and user choice. We found the diagramming to be a very useful method and a key part of externalizing the design and development processes in our research.

*Creating an interaction model*

To move from particular interaction techniques to interaction models that could explain and possibly generate more techniques, we proceeded with the following steps. 1) We listed all events and functions found in the techniques, 2) Analyzed the relations between events and functions, 3) Categorized the functions according to basic behaviour and used the categories as abstracted functions, 4) Prioritized these to work with the input related functions, and 5) Designed a model in the form of a diagram explaining the relation between spatial movement, events and functions.

The model was developed iteratively and each step of evolution was checked for consistence by comparing it to the interaction techniques we had diagrammed earlier. We finally chose to focus on the input side of interaction moving from a wide interaction perspective to a more focused input perspective. We did this to limit our scope and because the near fields used in near field technology are directly related to input events but only indirectly related to output. Generation of such models is common in HCI in order to explain complex relationships in interaction. For instance, Beaudouin-Lafon (2004) proposes interaction models as a way of analyzing interactions. Buxton et al. (1990) use interaction models to compare touch input with other input techniques.

*Specifying input techniques*

The last analytical stage consisted of using the model to reinterpret the earlier described interaction techniques as input techniques and to further create entirely new input techniques. This shifted the focus on the models from descriptive to generative ones, thereby aiding creative developments in the design stages. Beaudouin-Lafon similarly argues for developing interaction models with generative abilities in HCI to aid designing (Beaudouin-Lafon, 2004). The reinterpretation was done by using the elements from the new model to describe the input techniques that were used in each interaction technique, in an abstract way. These input techniques were then diagrammed by using a redesigned version of the aforementioned interaction model.

Furthermore, the interaction model aided the creation of new input techniques in two ways. Firstly, it acted as a method for sketching interactions by providing a basic language for describing the elements and relations of near field input techniques. Secondly, the model served as an analytical tool to understand and generate new ways of structuring the functions in relation to user initiated motion so to allow for differentiated inputs. In the next section we present the research results in the form of affordances for designing in relation to the levels of activity.

## Affordances for designing interactions with short range RFID

Our research points to a gap between examples of end users' usage of SR-RFID technology and toolkits that support the implementation of interfaces. However, we have found no studies oriented towards supporting designers' processes of conceptualising new designs using SR-RFID. In the following section we present a set of design affordances that we argue may be used to fill this gap.

### *Need related affordances: from Touch to Tap and Hold*

To move towards what SR-RFID offer designers we suggest it is useful to separate the physical interaction affordances of RFID enabled phones from topical functions. In doing so SR-RFID comes out as a tool designers may use to allow people to interact with the physical world by manipulating the proximity of RFID tags and readers. We have earlier investigated such proximity based approach in relation to an inquiry into interactions driven by three or more RFID enabled artifacts (Nordby 2010a).

By focusing on tangible interaction, we move away from the predominant perspective in HCI-inflected research on SR-RFID from a focus on interface types to that of interactions themselves and their design. This is important for interaction design since the potential tangible interactions that can be provided by way of SR-RFID is crucial knowledge directly related to interactions designers' activity of designing novel experiences.

Our need related affordance is presented through the concept of 'RFID based Tap and Hold' (hereafter addressed as 'Tap and Hold') which demonstrate the basic tangible opportunities of SR-RFID. The term itself is based on the type of tangible interaction that we observed through our design inquiries. In previous work we have already introduced Tap and Hold as one of six form-making qualities that may be assigned to what we address as near field driven input (Nordby, 2010b). Such input is general for all forms of interaction that involves the short-range radio fields that are part of SR-RFID's makeup. The concept of Tap and Hold is also relevant for mobile phone driven interaction.

In relation to mobile phones, the concept of Tap and Hold provides some means to expanding the current understanding of SR-RFID. Tap reflects on users moving a phone in and out of a field, while Hold describes keeping the phone over a tag. We suggest that the concept of Tap and Hold more sharply captures the tangible potential of SR-RFID and at the same time demonstrates this potential by associating it to the 'Drag and Drop' of the GUI. Tap and Hold interaction is commonly associated with pen or touch screen-based interaction (Rekimoto et al., 2003; Wu & Balakrishnan, 2003), but as our work show, may equally well be associated to RFID based interaction.

Manipulation of the radio fields of SR-RFID (the near fields) is crucial to Tap and Hold interaction. Our attention on instrumental and operational affordances inside Tap and Hold targets only how physical manipulation of the near fields themselves can propel user input into a system. Thus we do not address the combination of input and output into interaction techniques but instead focus on the exploration of input techniques as we see these as the basic unit of 'tap and hold' interaction. For designers this shows how an alternative need related affordance may reveal material technology opportunities that might otherwise be hidden for them. Thus 'Tap and Hold' can show how the technology may cater for a different set of needs than what are offered through touch or selection.

### *Instrumental affordance: A model of Tap and Hold*

Tap and Hold related instrumental affordances may be understood by means of a descriptive and generative model for tap and hold driven input techniques for SR-RFID (Figure 2). The model presents the elements that provide the affordances and the relationships between them. Inspired by the nature of the interactions made possible, we call this model the Tap and Hold Model.

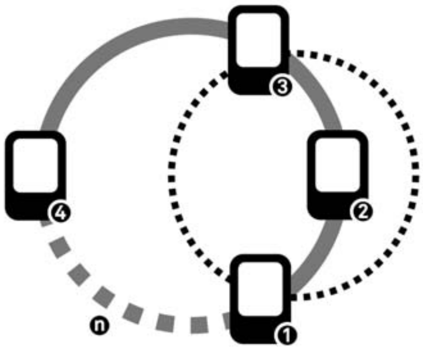


Figure 2. The Tap and Hold model of single tag input. 1) Tap In, 2) Hold In, 3) Tap Out, 4) Hold Out and n) marks the number of times the phone enters the field.

The basic structure of the model focuses on a device going in and out of one radio field. The sequence starts at (1) and ends on (4), whereafter it might start a new loop. The numbers in the model represent the input events we interpret from the spatial relationships between the reader and the tag. (1) Tap In and (3) Tap Out represent the act of entering and leaving the field. Technically constructed by combining Tap In and Tap Out (2), Hold In and (4) Hold Out refers to when a device is inside or outside of a field. We found it useful to single out this behaviour since the phenomenon of keeping a device inside or outside a field commonly appears in the input techniques we created.

The Tap and Hold model may be further elaborated by adding functions that start on the various events of Tap and Hold. (Figure 3) We have chosen two main functions Run (1) and Cycle (2) and three supporting functions Wait (3), Confirmation (4) and Stop (5). The supporting functions can be used in relation to the first two.


Figure 3. Functions of events in Tap and Hold: 1) Run, 2) Cycle, 3) Wait, 4) Confirmation, and 5) Stop.

Run (1) is the basic function in the system. It constitutes a call to start another function. Run will start something on Tap (Run on Tap) or Run something continuously while activated in Hold (Run on Hold).

The Cycle (2) function is a slightly different version of the Run function. It works similarly but allows a change in value on Tap or continuous change of value in Hold. The value can have any range and cycle according to many patterns. For instance, it can repeat the same count range, cycle until end of range, cycle endlessly, cycle randomly or ping-pong cycle within the range. One can interpret the Cycle as a program that starts, but we insert it here as a different phenomenon because of its importance from an interaction design perspective. The cycle adds major input possibilities by allowing users to add a specific value to the system by tangible interaction with one tag. This differentiation between Run and Cycle becomes more pronounced in the more complex interaction techniques where we see that a combination between Cycle and Run can afford versatile tangible interaction.

The next three functions Wait, Confirmation and Stop, only work in relation to the previous two, modifying their behaviour. Wait (3), is a function that gives an option to enact a function at a specific time. It starts a countdown towards the initiation of another function. This countdown can be stopped at any time by the user activating other events. One example is a countdown that starts on Tap In. If a Tap Out is performed before the time limit the Run can be aborted. Confirmation (4) specifies that two events must be activated to perform a Cycle or Run function. For instance a Confirmation placed on Tap in can mark that another Tap In must be performed for a Run to start. Stop (5) is associated with a Run on Tap or a Cycle on Tap and allow stopping of the aforementioned function when activated by an event.

Together these basic functions constitute the Tap and Hold Model. The model provides an overall map of the input affordances we have constructed through an experimental process of investigating the physical intersections of the radio fields.

### *Operational affordances: A set of input techniques*

Operational affordances take the shape of input techniques which we describe as how the device needs to be spatially manipulated in relation to near fields to perform input events. Figures 4, 5, 6 and 7 present simple schematic illustration that represents the input 'moves', with the image of a near field enabled phone and the field (dotted line) and explanatory text. Tap interactions are shown in the form of a phone resting outside the field with an attached line. Hold is represented with a phone inside the field. The illustrations marking a phone inside and outside the field indicate that both Tap and Hold are used in that specific interaction. Finally, the illustrations show various functions attached to the different events derived from the interaction of the near fields. These are compositions of the functions presented in the instrumental affordances.

The affordances are split into four main sections: Tap (Figure 4), Hold (Figure 5), Multi-tap (Figure 6) and Tap and Hold (Figure 7). The visualizations below make apparent the otherwise invisible connections between mobile handsets, the SR-RFID fields and related functions that are important for understanding the design affordances.

The first two affordance categories represent the most basic building blocks of input techniques we found in relation to the Tap and Hold input model. They represent techniques based on a single Tap or a single Hold event. The latter two encompass more advanced methods which relying on multiple Hold or / and Taps to perform certain kinds of input. Since there are multiple ways of combining the more basic Tap and Hold input techniques, a wide range of techniques can be devised inside these categories. In the Figures 6 and 7 we present a selection that we found useful in our work.

In the context of Tap and Hold we found another interaction event that we call Failed reading. Overall, in the context of the experiments, we left this event unexplored due to its difficulty of execution. We have chosen to mention it, however, because it does represent an input method which might provide inspiration to designers despite its difficulties. In this move, the action involves passing the phone over a tag at such speed that the system starts to read the tag but is not able to finish the reading. The Nokia RFID-enabled phones use this event to trigger an error message. However, one can envision that this event can be used for other purposes.

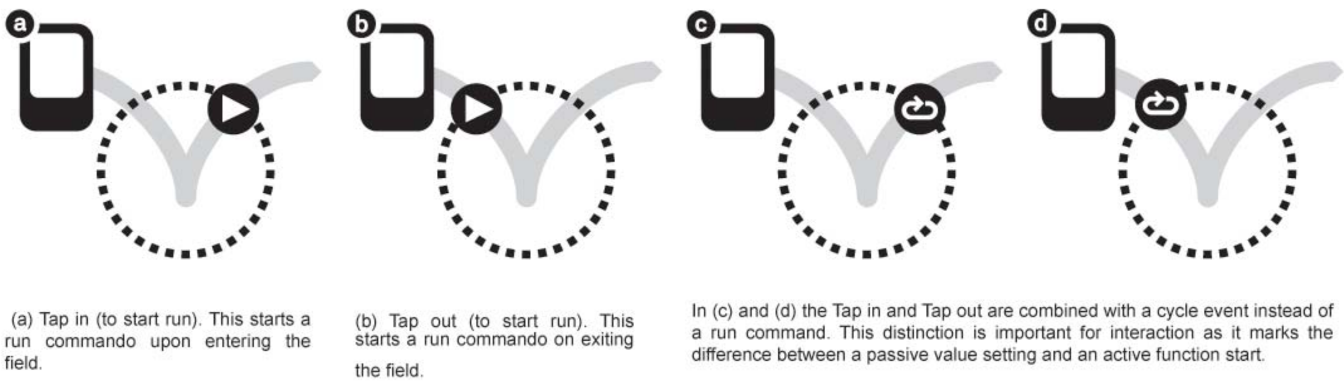
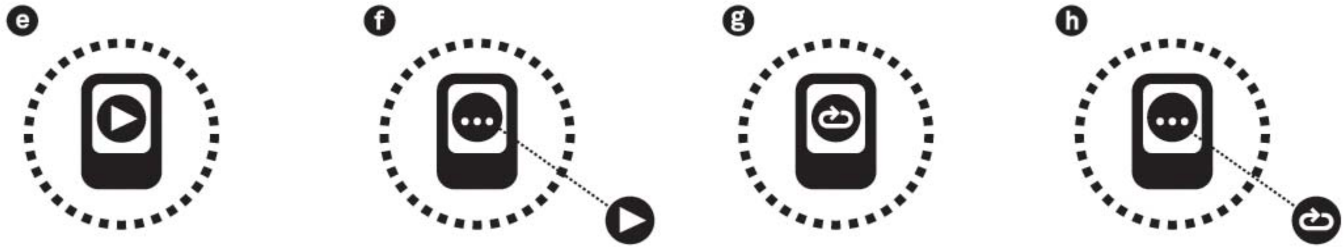



Figure 4. Tap represents two major input techniques: Tap In and Tap Out. The name represents the start of an event based on whether a device is leaving or entering a field.

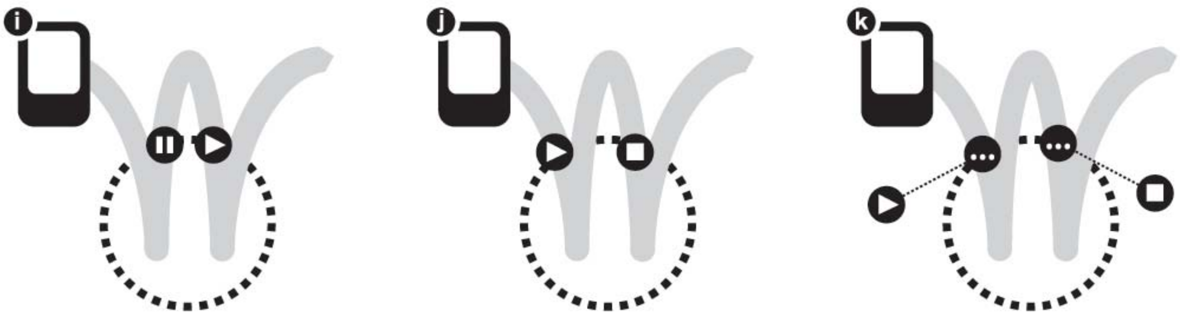



(e) Hold to run represents an event that order an event to run while a device is resting within a field range. For instance, the device plays music while a device is resting on a tag, but stops instantly upon removal.

(f) Hold to start run enables the start of an event after holding the device over a tag for a pre-determined time span. The interaction comprises a timer that starts to run towards a limit on Hold. By removing the device from the field before reaching the time limit, the event aborts. By staying inside the field until the time limit, the events start instantly.

(g) Hold to cycle and (h) Hold to start cycle are each similar to the previous three moves except the start is replaced with a value cycle. The first cycles the value continuously upon holding. The second start one cycle upon timer completion.

Figure 5. Hold is a combination of Tap In and Tap Out encompassing an activity marked by detecting when a reader is staying inside a field. We single out this phenomenon since it seemed to represent a major input method from an interaction point of view despite being a combination of Tap In and Tap Out.

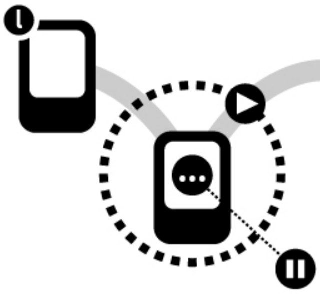



(i) Double-tap is similar to double clicking in GUIs. It covers input where the first tap "primes" a tag and the second tap executes the event. One performs the double clicks on either Tap in or Tap out and this can include a time limit for the second tap. We can construct double tap interaction techniques which on first tap communicate the current function of the tag that provides information to the user on whether he or she should activate it. For instance, most types of select interaction with SR-RFID today are based on showing a link after tap executed by the keypad. Double tap could allow execution entirely through physical manipulation.

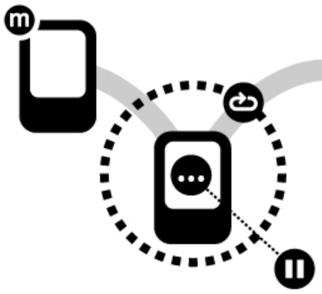
(j) Tap start-tap stop is similar to holding in that the first tap starts a process while the second tap stops the same process. The process starts on either Tap in or Tap out.

(k) Tap wait start gives the option of canceling an event. A timer starts on Tap in or Tap out when the timer reaches a range limit an event will start. If a Tap in or Tap out is preformed before the timer limit is reached, the process is abandoned. This delayed function allows a second chance to cancel a process.

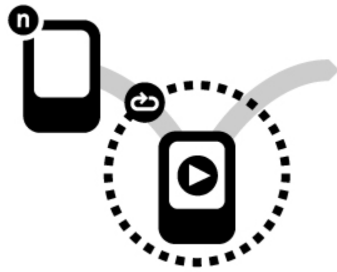
Figure 6. Multi-tap encompasses input techniques that consist of a combination of Tap techniques.



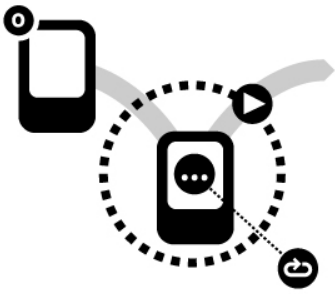

(l) Hold to start on exit. This event starts on exit after the device is held inside the field until a time limit is reached.



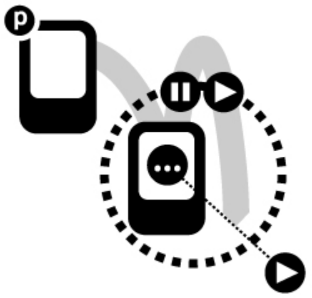

(m) Hold to cycle on exit. This is similar to the one above except a cycle is triggered in stead of a start.



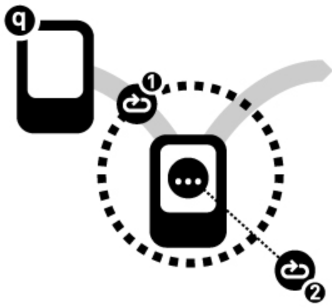

(n) Hold with cycle on tap. The actions performed during the hold change on Tap in or Tap out. An example of this is a music player that plays on Hold and changes tune on each Tap out.



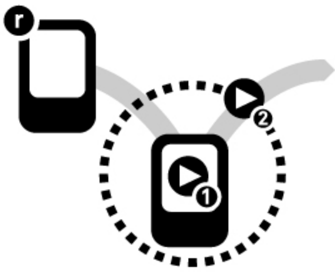

(o) Activate on up with hold to cycle. This combination of Tap out and Cycle on hold allows selection of event and start of event in one singular action of moving the device through a field. The event starts on Tap out, but by holding the device over the tag, the events that start on Tap out cycles according to one of the cycle rules. This allows a tag to include multiple actions accessible on one single tag pass.



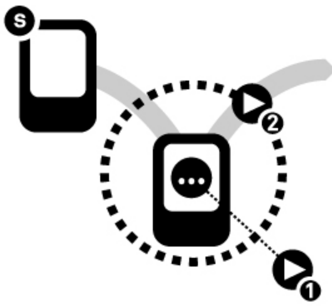

(p) Hold to start or double tap. By combining Double tap with Hold to start, one enables two alternative starting methods on a tag. The system allows a start on Hold to start, but if the time limit is not reached the system cancels the action and starts a Double tap on Tap out in the same sequence. In this case, the event starts during the next Tap in.



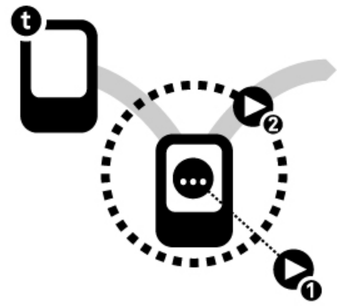

(q) Hold to cycle with tap to change. This is a combination of Hold to cycle and Tap in to cycle. On Tap in it would cycle the value one time. If the phone is kept inside the field until the end of a time limit, it will continue to cycle while inside the field. This is similar to clicking on some scrollbars in GUIs were one click moves the scrollbar one step, but holding the button for a certain time starts a continuous scroll.




(r) Preview then start encompasses a Hold combined with Tap out. This represents two processes were the first runs during the Hold and the next event starts on Tap out. One example of usage concerns interaction techniques where we show a preview of the tag related service on Hold and starts the same service on Tap out. This does not add any real choice for the user, but it provides a different aesthetic feel of the interaction than a Tap in action.




(s) Tap or hold. When the device enters the field a timer starts. If the phone is removed before the time limit, a Tap out is performed. If the device is held over the tag after the time limit, a Hold to run starts. This cancels any proceeding event on exit.




(t) Tap or hold to start. This combines Tap out and Hold to start. If the phone is held in the field, one event will start. If the phone is removed from the field before the time limit is reached, another event will start.

Figure 7. Tap and Hold list techniques based on combining the two basic input techniques.

### *Tap and Hold revisited*

The examples above show instances of how a technology may be interpreted as a set of design affordances. These are not the only affordances the technology offers the designer. We suggest these affordances are of particular interest to the designer engaged in designing new interactions using short-range RFID.

Tap and Hold limits the focus on SR-RFID on mobiles to the physical manipulation of the radio fields of SR-RFID and how they can be transformed to user input. Such a view may be seen as a contrast to current offerings seen HCI which predominately constitute SR-RFID interaction as a selection mechanism. This renders SR-RFID interaction as a brief transitional interaction (often described as touching) that links physical objects to services predominantly supported by other interaction modalities. In doing so, the focus tends to gravitate towards broader aspects of SR-RFID interfaces rather than the physical interaction itself. Such an approach serves current developments well in that it offers an identifiable user centered view on current technological solutions. As such, they may be seen as parallel need related affordances that focus on other aspects of SR-RFID interaction than what Tap and Hold offers. Seeing SR-RFID interaction as selection or touching, maps well with values held inside HCI which seeks to create robust usable systems. In contrast, however, we argue that by introducing Tap and Hold as a need related affordance, we can provide a framework that encourages a focus on how the technology is capable of affording designers tools to design tangible interactions.

The differences between using Tap and Hold as opposed to Selection or Touch become even more prominent if we consider the instrumental and operational affordances following them. Tap and Hold has clear orientation towards particular forms of interaction. However, Touch or Selection points towards just one of the operational affordances of Tap and Hold (e.g. Tap In). This makes sense if we assume the needs Touch relates to are geared to providing simple transactional interactions. Then, the instrumental and operational affordances that might be associated to it are of a wider scope than tangible interaction alone. This would include values such as user acceptance and situated interaction. Both affordances may be considered useful for designing. However, Tap and Hold specifically lends itself towards interpretation of tangible opportunities of SR-RFID, while Touch (or Selection) is oriented towards the wider scope of user oriented properties of SR-RFID in the context of practical application. This contrasts affordances directed towards the investigation of technology itself with affordances related to technology in use.

For designers, we suggest Tap and Hold can supplement the existing need related affordance of Touch or Selection. However, we argue, that Tap and Hold, as a design affordance, is of particular interest for designers engaged in shaping new interactions.

## Conclusion

Through practice-based inquiry that incorporates robust analytical frameworks we have investigated SR-RFID on mobiles in relation to what an emerging technology offers designers. The study applied the concept of affordance, informed by perspectives from activity theory, to experimental designing. This is important as designers move between the three levels of activity, actions and operations in their designing. In a vertical process the questions why, what and how are constantly intertwined in the search for new angles to a situation. Such movement between doing, seeing and reflecting is essential in designer's reflection in action (Schön, 1983). As a consequence, we suggested affordances be oriented to not only support each of these activity levels, but to show the relations between them.

Our study found that SR-RFID may be divided into three levels of affordances related to enabling the design of tangible interactions. First, these affordances comprise a need related affordance framed by the term Tap and Hold, which encapsulates the tangible opportunities of interactions driven by the radio fields which make up a core component of SR-RFID. Second, the study presented an instrumental affordance comprising a model of input affordances and 20 operational affordances representing distinct input techniques framed by the model. Third, concerning operational affordances, the term RFID-based Tap and Hold may supplement the more general term Touch or Selection in light of the richness of interaction affordances found within the SR-RFID design space we conceptualised and realised.

In doing so, we have established that SR-RFID technology has the potential of supporting input methods which can expand current views of SR-RFID enabled interactions on mobile phones. We suggest design affordances for SR-RFID have considerable potential to instruct and inspire innovative developments of new interactions. These may also be considered when evaluating new approaches to user's engagement with this technology. We further suggest that these design affordances may be incorporated in designer's repertoires as aids to their own acts of designing tangible interactions.

The processes of practice informed research on design affordances may take into account not only that affordances are directed towards designers, but that the design activity encompasses more than operational behaviour. We propose this may be achieved by developing tangible interactions via short-range RFID that may structure opportunities inherent in technology suited to the multiple levels of the designer's activity and engagement in emerging processes of design.

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**Kjetil Nordby**
PhD student
Oslo School of Architecture & Design, Institute of Design
Email address: Kjetil.Nordby@aho.no

**Andrew Morrison**
Professor
Oslo School of Architecture & Design, Institute of Design, and University of Oslo, InterMedia
Email address: Andrew.Morrison@aho.no

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