

# Implicit Human Computer Interaction Through Context

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## Abstract

*In this paper the term implicit human computer interaction is defined. It is discussed how the availability of processing power and advanced sensing technology can enable a shift in HCI from explicit interaction, such as direct manipulation GUIs, towards a more implicit interaction based on situational context. In the paper an algorithm that is based on a number of questions to identify applications that can facilitate implicit interaction is given. An XML-based language to describe implicit HCI is proposed. The language uses contextual variables that can be grouped using different types of semantics as well as actions that are called by triggers. The term of perception is discussed and four basic approaches are identified that are useful when building context-aware applications. Providing two examples, a wearable context awareness component and a sensor-board, it is shown how sensor-based perception can be implemented. It is also discussed how situational context can be exploited to improve input and output of mobile devices.*

**Keywords:** context awareness, context sensing, implicit human computer interaction, perception, ubiquitous computing.

## 1 Introduction

The way people interact with devices is vital for their success. Looking at HCI it is apparent that interaction techniques are limited by the technology available. Furthermore the anticipated user groups influence the interaction metaphors to a large extent. Considering the shift from punch cards to interactive text terminals and also the shift from command line interfaces to graphical user interfaces (GUI) this was observable.

Bearing in mind current and upcoming technologies, such as increased processing power (even on mobile devices), availability of sensors

(ranging from simple temperature sensors to cameras), and the resulting perceptual capabilities as well as the fact that the main user group of current computing devices (e.g. mobile phones, PDAs, etc.) are non experts, we may observe yet another shift in HCI. Devices that have perceptual capabilities (even if they are very limited) will start the shift from explicit HCI towards a more implicit interaction with machines.

*A vision of future devices*

*We will be able to create (mobile) devices that can see, hear and feel. Based on their perception, these devices will be able to act and react according to the situational context in which they are used.*

In this paper it will be shown that this vision is not as far ahead as it seems. In our research we start with the perception of simple concepts and with their exploitation. Providing a number of examples and demonstrators it is discussed how basic perception could enable a shift from explicit towards implicit HCI.

## 2 Implicit Interaction

Observing communication between humans we can see that a lot of information is only exchanged implicitly. The way people interact with each other and also the situation in which they interact carries information that is often implicitly exploited in the exchange of messages. While in a conversation the behavior of participants as well as what happens in the surrounding environment supplies valuable information that is often vital for the understanding of messages. In many cases the robustness of human-to-human communication is based on the implicitly introduced contextual information, such as gestures, body language, and voice. Another example is redundancy between body language (e.g. nodding) and spoken languages (e.g. the word 'yes'). This implicitly

introduced knowledge is also used to disambiguate information, e.g. in a discussion with a student pointing at a computer the term 'sun' has a different meaning than the same term when on the beach together with friends; a more in depth discussion is given in [11].

## 2.1 Implicit vs. Explicit Human Computer Interaction

Considering current computer technology interaction is explicit – the user tells the computer in a certain level of abstraction (e.g. by command-line, direct manipulation using a GUI, gesture, or speech input) what she expects the computer to do. This is considered as explicit interaction.

*Definition: Implicit Human Computer Interaction*  
*Implicit human computer interaction is 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.*

The action of a user is always performed in a certain environment. Implicit interaction is based on the assumption that the computer has a certain understanding of our behavior in the given situation. This knowledge is then considered as an additional input to the computer while doing a task.

A simple example is the garbage bin [14] that scans in the bar code of products and reproduces the information for a suggested shopping list. The action performed by the user (e.g. throw away an empty can in a bin) is the same as with any other garbage bin. The recognition of the system (by scanning the bar code) and the built-in interpretation of the system (all things that go into the bin may be on the next shopping list again) make use of the action performed by the user. The user herself does not explicitly interact with the computer, thus the process describes an implicit interaction. As we see from the example implicit interaction is based on two main concepts:

- perception
- interpretation.

For most applications implicit interaction will be used additionally to explicit interaction.

There are other systems implemented that also facilitate the idea of implicit interaction on a

rudimentary level, e.g. automatic light control (switches on the light when it is dark and someone is walking by) and active badge systems (automatically open a door when someone with appropriate permission likes to enter the building). In current computer systems we can observe that agent technology is used to build systems that have a certain ability to act proactively. These approaches are mainly based on user profiles and usage information [13]. In these cases perception is limited to information gathered in the virtual space.

If we look concepts that are needed to facilitate implicit interaction three basic building blocks can be identified:

1. the ability to have perception of the use, the environment, and the circumstances,
2. mechanisms to understand what the sensors see, hear and feel, and
3. applications that can make use of this information.

On a conceptual level (1) and (2) can be described as situational context. And (3) are applications that are context enabled. In the next section context is discussed in more detail.

## 2.2 What is Context

The notion of context is used in many different ways. In our work we propose to regard situational context, such as location, surrounding environment or state of the device, as implicit input to the system. We use the term situational context to describe implicit interaction fragments. This extends the concept of context beyond the informational context into real world environments.

The word *Context* in general use has a multitude of meanings. Even within the field of computer science different disciplines, such as artificial intelligence, natural language processing, image recognition, and more recently mobile computing, have their very own understanding of what context is. In our work we found that very general descriptions of context as given by a dictionary and also synonyms found in a thesaurus come very close to our understanding. To illustrate this we like to provide the following definitions:

*Context n 1: discourse that surrounds a language unit and helps to determine its interpretation [syn: linguistic context,*

*context of use*] 2: the set of facts or circumstances that surround a situation or event; "the historical context" (Source: WordNet © 1.6)

**Context:** That which surrounds, and gives meaning to, something else.

(Source: The Free On-line Dictionary of Computing)

**Synonyms Context:**

*Circumstance, situation, phase, position, posture, attitude, place, point; terms; regime; footing, standing, status, occasion, surroundings, environment, location, dependence.* (Source: www.thesaurus.com)

To build applications that have knowledge about their situational context it is important to gain an understanding what context is. Current research in context-awareness in mobile computing shows a strong focus on location [1], [12]. Location is a concept that is well understood. Also the benefit of location-awareness is clearly given, at certain locations particular services are more important than others. An architectural approach, based on a smart environment is described by Schilit et. al. [17]. Other scenarios are using RF and GPS to determine the users location, e.g. [4], [15]. But, as pointed out in [20] context is more than location. We use the term *context* considering mobile computing in a more general way, as also suggested by [2], to describe the environment, situation, state, surroundings, task, and so on. A wider view of context is also given by [19]. They suggest to consider the way a device is used (mobile phone in the users hand, on the table, in pocket, etc.) to be treated as context.

### 2.3 Applications in Context

Analyzing the way people use ultra-mobile devices (e.g. personal digital assistants, smart mobile phones, handheld and wearable computers) it becomes apparent that the periods of interaction are much shorter than in traditional mobile settings. Notebooks – considered as mobile computers - are mainly used in stationary setting, e.g. one takes a notebook to a meeting and takes note and a salesman takes a mobile computer to a customer for a presentation. In general in these scenarios the application is used in a stationary setting between several minutes and hours. Whereas considering the usage of ultra-mobile devices interaction periods are often much shorter e.g. looking up an address takes

only a few seconds and making a note on a PDA is often in the range of several seconds up to some minutes. Also the fact that the applications are mainly used while doing something else or to carry out a certain task (like tools in the real world) calls for a reduction of the explicit human-machine interaction and creates the need to shift towards implicit HCI.

Knowledge about the situational context is of primary interest to the application, because we consider that the application will adapt to the context.

It can be observed that an application (mobile or stationary alike) is:

- (a) running on a specific device (e.g. input system, screen size, network access, portability, etc.),
- (b) at a certain time (absolute time e.g. 9:34 p.m., class of time e.g. in the morning)
- (c) used by one or more users (concurrently or sequentially),
- (d) in a certain physical environment (absolute location, type of location, conditions such as light, audio, and temperature, infrastructure, etc.),
- (e) social setting (people co-located and social role),
- (f) to solve a particular task (single task, group of tasks, or a general goal).

We consider the items (a) to (f) as the basic building blocks of context. For mobile applications especially (d) and (e) are of major interest. In mobile settings the physical environment can change while an application is executed e.g. making a phone call while walking from the office desk to the car park. The telephone application is running, while the noise level changes between office and outside.

### 2.4 Identifying Implicit Human Computer Interaction

To identify applications that can be improved by implicit HCI input and output of the application and the real world environment in which it is executed have to be analyzed. Then ways to capture the situational context must be assessed. Furthermore mechanisms for the interpretation of the situational context have to be found. Finally the reaction of the application has to be defined. The following questions help to identify these points:

- What happens around an application while the application is in use? Are there any changes at all?
- Do the surroundings (behavior, environment, circumstances) carry any valuable information for the application? Does it matter for the application?
- Are there any means to capture and extract the information in a way that is acceptable for the application or device (processing cost, sensor cost, weight, etc.)?
- How to understand the information? What interpretation and reasoning is possible and useful. What is an appropriate way for the application to react?

Putting all of these together we can set up the algorithm in figure 1. The algorithm works as follows:

On 1:  $C$  is the set of surrounding conditions that carry information that is useful for the application. Each element  $C_i$  stands for one condition, e.g. location, temperature, current user, device orientation, etc. The set is created by asking what condition change in the environment.

On 2:  $D$  is initialized – at the beginning no sensing devices are identified.

On 3: For each  $C_i$  the accuracy  $A_i$  and the update rate  $U_i$  that are needed to make the measurements useful are defined. Then a sensing device that matches these requirements is identified. If the cost for the identified sensing device  $D_i$  is acceptable, then the vector describing the condition, the sensing device, the required accuracy and update rate is added to the set  $D$ . For conditions that cannot be sensed the cost is infinite.

On 4: If any conditions that are feasible to measure exist then for each of these conditions one or more range values that are meaningful (temperature between 15°C and 25°C, location is inside my office, user is moving, etc.) are identified and for these ranges the reaction of the application (switch to notepad, etc.) is defined.

## 2.5 Modeling Implicit Human Computer Interaction

To specify applications that facilitate implicit HCI it is inevitable to have a specification language to describe situational context linked to events/change that occur in the application. In our recent work we found it helpful to use a notation that is human readable as well as easily to process using a computer. We decided to use a markup language that is specified in XML for this

```

1. create the set C
2. set D = {}
3. for each  $C_i \in C$ 
    define  $A_i$  // accuracy
    define  $U_i$  // update rate
    identify  $S_i$  // a sensor device
        // that is appropriate
    if cost( $S_i, A_i, U_i$ ) is acceptable then
         $D = D \cup \{(C_i, S_i, A_i, U_i)\}$ 
    fi
next
4. if  $D \neq \{\}$  then
    for each vector  $D_i$  in D
        define a set of application reaction  $R_i = \{(I_{ij}, R_{ij})\}$ 
        //  $I_{ij}$  is input range, application reaction pairs  $I_{ij}$ 
        //  $R_{ij}$  is application reaction
    else
        // implicit interaction is not used
        //(either no condition that are useful or too costly)

```

Figure 1: Identifying Implicit HCI.

purpose. Extending the SGML based description model introduced by Brown in [2], [3] we added two more concepts - grouping context with matching attributes and trigger attributes to make the description more expressive and suitable for our projects. See figure 2 for the XML data type definition (DTD).

In the `<context>` section contextual variables are used to describe the conditions. These variables are made of two parts, the first is used to specify the context sensing module, in figure 5, the sensor module (`sensor_module`) and the palm pilot (`pilot`) and in the second part the variables provided by this module.

In the `<action>` section function calls are used to specify the action to be carried out in case the trigger evaluates to true. These calls are also hierarchically structured; specifying the device, the application, and the function to be performed.

Depending on the platform (e.g. context sensing module in a microcontroller) we use a different implementation language.

If contexts are composed of a number of components we found it very helpful to have a mechanism to bundle certain contextual variables in groups and select a matching semantic for each group description. For matching in a group we provided the following semantics: `one` (match one or more of the variables in the following group), `all` (match all variables in the following group), `none` (match none of the variables in the following group). All groups within the context description must evaluate to true to cause the trigger.

We discriminate three different triggers: 'enter a context', 'leave a context', and 'while in a context'. The 'enter' and 'leave' triggers take a time value that specifies the time after<sup>1</sup> which the action is triggered if the context stays stable over this time. For the 'while in a context' trigger the time indicates the interval in which the trigger is fired again.

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<sup>1</sup> The parameter indicating the time after that an action is performed is often 0 (immediate context action coupling) or positive. In certain circumstances, when future situations can be predicted (e.g. you drive your car into the parking, the context walking will appear soon) a negative value does make sense, too.

```

<!ELEMENT context_interaction
      (context , action )>
<!ELEMENT context (group+ )>
<!ELEMENT group (#PCDATA )>
<!ATTLIST group match
      (one | all | none ) #REQUIRED >
<!ELEMENT action (#PCDATA )>
<!ATTLIST action
      time CDATA '0'
      trigger (enter | leave | in )
              #REQUIRED >

```

**Figure 2: Data Type Definition**

```

<context_interaction>
  <context>
    <group match='one'>
      sensor_module.touch
      pilot.on
    </group>
    <group match='none'>
      sensor_module.alone
      pilot.pen_down
    </group>
  </context>
  <action trigger='enter' time='3'>
    pilot.notepad.confidential
  </action>
</context_interaction>

```

**Figure 3: Context description**

In figure 3 an example of a description of a context and an action is shown. The context description consists of two groups of contextual variables. In the first group the match semantics is that at least one of the variables must be true, in this case either the device is touched or the state of the device is on. In the second group the match semantics is 'none', which means that the contextual variable `alone` must not be true and that the user must not have touched the screen with a pen.

If the context evaluates to true, an action is triggered. Here the semantics is that if the context is entered and is stable for at least three seconds then the action is performed.

The complete description means that if the device is on or in the users hand and if the user is not alone and he is not touching the screen with the pen then after three seconds the display should be hidden by an image as depicted in figure 6 (d) in the later section.

### 3 Perception

There are several ways to equip devices with perceptual capabilities. The range of complexity to consider is very wide, starting from simple sensors that know the way a device is held [18] to complex audio and video analysis. We identified the following four basic approaches:

- device-databases (e.g. calendars, to-do-lists, address books, profile, etc.)
- input to the application running (notepad - taking notes, calendar - looking up a date, etc.)
- active environments (active badges [10], IR-networks, cameras, audio, etc.)
- sensing context using sensors (TEA [5], [21], Sensor Badges [1], GPS, cameras, audio [16], etc.)

The perceptual capabilities can be located in the device itself, in the environment or in another device that shares the context over a network (e.g. body area network).

In the remainder of this section we concentrate on sensor based perception, also knowing that in most scenarios a combination of all four cases is the way of choice. First we introduce two sensor devices developed in our group and then provide some information on other sensor based devices that supply contextual information.

#### 3.1 Context Awareness Component

In this part a wearable context-awareness component that integrates low-cost sensors is described. Simple methods are used to derive context information from sensor data. The derived context is application-independent and can be exploited by other wearable or personal technologies in a body network, for instance wearable computers, mobile phones, digital cameras, and personal digital assistants.

Here we chose to address a number of contexts that relate to how interruptible the user is. These contexts describe only a certain aspect of real world situations but they are general in the sense that they can be exploited by a range of applications. Such context is for instance implemented and used in the audio wearable described in [16], mimicking the human ability to recognize situations in which it is rude to interrupt, for instance when a person is engaged in a conversation or giving a talk. Context

information of this kind is also useful for other applications, for instance calendars, email notification, pagers and mobile phones can make use of any context that gives an indication of whether or not it is a good time to interrupt a user.

The specific contexts that we chose for our study are based on aural information: user speaking, others speaking, noisy, and quiet. And based on movement of the user: walking, running, stationary. Movement context was included as it gives an indication as to whether a user can be interrupted visually.

For recognition of aural and movement contexts, we integrated two microphones and an accelerometer in our design. One of the microphones is placed near the user's throat, the other pointing away from the user. With this configuration the distinction of speaker and environment is feasible with minimal processing cost. The acceleration sensor is used to discriminate whether a user is standing still, walking or running.

The sensor placement considerations led us to build the context-awareness component into a tie – it may be considered to build them into other accessories worn in similar ways (e.g. jewelry, neckerchief, or necklace). We also liked that a tie stresses the component's design as accessory rather than as stand-alone device, see figure 4.

The hardware of our context-awareness component is built around a TINY-Tiger microcontroller, which offers four analog inputs

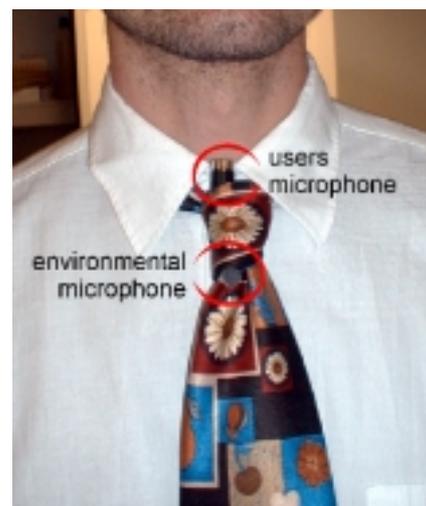


Figure 4: Context-Awareness Tie.

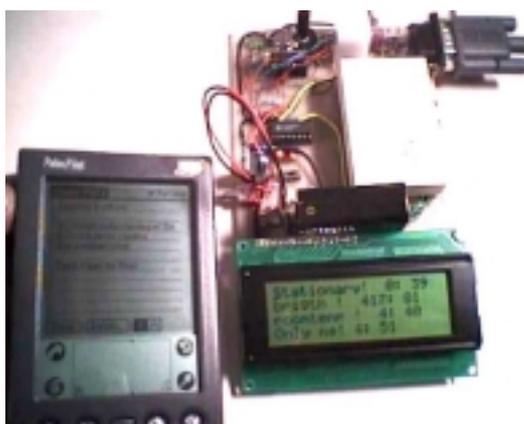
and two serial lines. The two signals from the microphones are amplified and connected to the analog inputs. To measure the motion we used a two-axis accelerometer (Analog Devices ADXL202). A more detailed description has been published in [22].

The software is realized in Tiger-BASIC, a multitasking basic dialect for the TINY-Tiger. It reads and analyzes sensor data in a time window of about four seconds. The methods to analyze the signals are deliberately simple; they work within the time domain and are based on basic statistical measurements. Based on the features calculated from sensor data the contexts are detected.

The communication is based on a serial line connection using 9600 bit/s, in a simple request-reply manner. The client requests the contextual variables from the context-awareness component that sends back the variables together with the values.

Experimentation with the context-aware tie showed that contexts were recognized in a very reliable way. Both 'user speaking' vs. 'others speaking' and 'stationary' vs. 'walking' vs. 'running' were discriminated correctly. A key finding is that sensor placement can be used effectively to increase reliability and to reduce required processing.

The device can provide information on the situational context of the user for other personal technologies in a body area network. Using this device the implicit HCI can be facilitated.



**Figure 5: Context Sensing Device and PalmPilot**

### 3.2 Sensor Board

Using this Board we collect data on the situational context by using a combination of low level sensors. In this project we built a context recognition device equipped with a light sensor, acceleration sensor, a passive infrared sensor, a touch sensor, and a temperature sensor. All sensors, but the touch sensor are standard sensors and produce analog voltage level. The touch sensor recognizes the human body as a capacitor and supplies a digital value. The heart of the device is a *BASICTiger* microcontroller that reads from all the physical input channels (it offers four analog digital converters and a number of digital IOs) and statistical methods are applied to recognize contexts. The board is depicted in figure 5. The PDA requests contextual variable while the application is idle, e.g. catching the `NullEvent` on the PalmPilot.

### 3.3 Related Work on Context Sensing

In robotics this way of perception is widely used but with a different objective – giving machines the ability to operate autonomously.

For the use with handheld devices the project TEA [5] developed a sensor board (equipped with 8 sensors, light, acceleration, pressure, temperature, etc.) that supplies contextual information; communication is done via serial line. The application described is a mobile phone that recognizes its context (in users hand, on the table, in suitcase, outdoors) and it adapts ringing modes according to users preferences in that situation [19].

Using a similar approach a system to facilitate indoor location awareness based on low level sensors is described in [8]. The system reads data from different sensors (acceleration, light, magnetic field, etc.) and provides location information.

In [7] a cup is described that has an acceleration and temperature sensor build in together with a microcontoller and infrared communication. The cup is aware of its state (warm, cold, on a table, drinking, moved). The information from a number of cups communicated to a server is then used to supply information about the group of users. All these projects focus on a completely sensor based approach to context awareness.

A jacket that knows if it is on the hanger or with the user is presented in [6]. The sensor jacket has

woven in sensors that give information if the user is wearing the jacket, what movements the user is making, etc. As one application correcting movements in sports (automated tennis coach) is suggested in the paper. In this project the development of robust sensing technology is very central.

#### 4 How Can HCI benefit from Context?

HCI for mobile devices is concerned with the general trade-off between devices qualities (e.g. small size, light-weight, little energy consumption, etc.) and the demand for optimal input-output capabilities. Here implicit HCI can offer interesting alternatives.

##### 4.1 Output in Context

Over recent years the output systems for mobile devices became much better; features such as stereo audio output, high-resolution color screens for PDAs and even on mobile phones as well as display systems for wearable computers are commercially available. Also unobtrusive notification mechanisms (e.g. vibration) have become widely used in phones and PDAs. Still on the lower end devices with very poor display quality enter the market. Situational context can help to:

- adapt the output to the current situation (fontsize, volume, brightness, privacy settings, etc) [19].
- find the most suitable time interruption [16], [22].
- reduce the need for interruptions (e.g. you don't need to remind someone to go to a meeting if he is already there.)

##### 4.2 Input in Context

Considering very small appliances the space for a keyboard is very limited what results in bad usability. Other input systems, such as graffiti and handwriting recognition have been developed further but still lack in speed and accuracy [9]. Advances in voice recognition have been made in recent years, but for non office settings (e.g. in a car, in a crowded place, sharing rooms with others, and in industry workplaces), the recognition performance is still poor. Also privacy and acceptance issues are a major

concern. Implicit HCI does not solve these problems in general but can help to:

- adapt the input system to the current situation (e.g. audio filter, recognition algorithms, etc)
- limit need for input (e.g. information is already provided by the context and can be captured)
- reduce selection space (e.g. only offer appropriate options in current context)

##### 4.3 ContextNotePad on a PalmPilot

To explore ways of implicit communication between users and their environment with mobile devices we built a context aware NotePad application. The system uses the perceptual capabilities of the sensor board, described in the previous section and provides an application that is very similar in functionality as the built-in notepad application on the PalmPilot. Additionally the application can adapt to the current situational context and can also react in this way to the implicit interaction. The application changes its behavior according to the situation. The following context adaptations have been implemented.

- **On/Off.** The user has the device in her hand. In this case the application is switched on, if the user is putting the device out of her hand it is switched off after a certain time. It assumes that if the user takes the device in her hand she wants to work with the device.
- **Fontsize.** If the device is moved (e.g. while walking or on a bumpy road) the font size is increased to ease reading. Whereas while having the device in a stable position (e.g. device stationary in your hand or on the table) the font is made smaller to display more text at the same screen, see figure 6(a) and(b).
- **Backlight.** This adaptation is straightforward but still not built in current PDAs. By monitoring the light condition the application switches on the backlight if the brightness level in the environment is below a certain threshold. Accordingly if it becomes brighter the light is switched off again, see figure 6(c).
- **Privacy settings.** If you are not alone and you are not writing (or touching the screen) the content on the display is hidden by an image, see figure 6(d). To sense if someone is



Figure 6: Adaptation to Context a) small font, b) large font, c) backlight, d) privacy

walking the passive infrared sensor is deployed.

Currently we decrease the size of the context-awareness device to make it feasible to plug it into the pilot to allow proper user studies.

## 5 Conclusion and Further Work

Based on observations of new sensing technology, available sensors and anticipated users a new interaction metaphor is proposed. Implicit HCI is defined 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. It is further identified that perception and interpretation of the user, the environment, and the circumstances are key concepts for implicit HCI. Furthermore applications that exploit this information are required.

Perception and interpretation are considered as situational context. Therefore we motivate a broad view of context, and also suggest that the context is described from the perspective of the application. To identify applications that can make use of situational context and thus can facilitate implicit HCI a number of questions are raised and an algorithm is suggested. It is based on the central questions: what happens around the application, how can this be sensed or captured, how to interpret this information, and how can applications make use of it.

From current projects we learned that there is a need for a simple specification language for implicit HCI, based on situational context. We propose an XML-based markup language that supports three different trigger semantics. The language is easily human readable and also easy to process.

Basic mechanisms of perception to acquire situational context are discussed. In the first example a wearable context awareness component build into a tie is described. Also a sensor-based context-awareness device is introduced. Both devices supply context to other devices over a simple request reply protocol over the serial line.

In a further section benefits of implicit interaction trough situational context to HCI are discussed. In an example implementation the feasibility of the concepts introduced earlier is demonstrated.

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