

CloudDrops: Stamp-sized Pervasive Displays for Situated Awareness of Web-based Information

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ABSTRACT

CloudDrops is a pervasive awareness platform that integrates virtual information from the Web more closely with the contextually rich physical spaces in which we live and work. CloudDrops consists of many interactive stamp-sized displays, each showing a tiny bit of digital information. The large number of displays and their small size allows the user to flexibly instrument, orchestrate and reconfigure her personal information environment. We show different form factors for stamp-sized displays, provide a device concept and a first implementation. We propose lightweight visualizations and interaction techniques that are tailored to the tiny device form factor. Moreover, we contribute techniques for associating these small displays with content that the user wants to stay aware of, including Web pages, contacts, and places. To demonstrate the capabilities of the platform, we present several application examples. A user study provides first insights into how CloudDrops enable users to create a personalized information environment by distributing stamp-sized displays over the entire architectural space.

Author Keywords

Pervasive displays; Awareness; Ubiquitous computing; Augmented reality

ACM Classification Keywords

H.5.2. Graphical user interfaces (GUI); Interaction styles.

General Terms

Human Factors.

INTRODUCTION

People intensively use physical space for accessing and remembering paper-bound information [9]. Transforming large parts of our formerly physical information environment into the digital realm has its obvious advantages that cannot be underestimated; but this also comes at a cost: we are giving up the notion of having an

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Figure 1. CloudDrops help users stay aware of dynamic Web-based information and support flexible spatial layouts in architectural space.

information item at a meaningful place and of using our entire surroundings for managing information.

Recent advances in pervasive display technologies enable high-resolution yet tiny, stamp-sized touch-displays that include processing power and networking capabilities. These self-contained devices are capable of displaying tiny information bits while being tangible and highly mobile, such that they can be situated at virtually any location. This opens up a physical design flexibility for awareness systems, which largely overcomes the possibilities of using a handheld device (such as a smartphone) or a static installation (such as a large screen or a projector). The end-user can flexibly arrange the set of stamp-sized displays, locate them at meaningful places and thereby easily instrument, orchestrate and reconfigure his or her personal information environment, to stay aware of digital information.

However, making use of such tiny displays for awareness applications poses various challenges. This includes the questions of how content should be mapped to displays, how it should be visualized on the tiny displays, and how the user can interact with content. It is also unclear how several displays can be used in concert and how displays can be combined with physical artifacts to support situated awareness.

We address these challenges and contribute CloudDrops, an interactive awareness platform that consists of many stamp-sized displays, which provide awareness of websites, contacts and places. The end-user can scatter the displays

throughout the architectural space, to ensure each piece of information is available at a meaningful physical location (see Fig. 1).

Each display represents one user-defined digital entity: a Web page, contact or place. CloudDrops provide visualizations that can be perceived at a glance such that the user can skim changes of Web pages, contacts and places by visually browsing through physical space. In addition, CloudDrops provide lightweight interactions.

Based on a 6-dimensional holistic view on the platform, we provide the following contributions:

- We propose different form factors for stamp-sized pervasive displays, provide a device concept and a first implementation.
- We provide visualizations and interactions for Web pages and Web applications that are tailored to the tiny display size. In addition, we show how CloudDrops can support synchronous and asynchronous communication with remote persons.
- We show concepts for associating digital content.
- We demonstrate the rich possibilities the platform is enabling by showing a set of activities and applications. Results from a field study provide first insights into how users create personal awareness environments with CloudDrops.

RELATED WORK

Awareness Systems

In their seminal work, Kirsh [14] and Hollan et al. [10] have shown the benefits of space for cognitive processes, including awareness and reminders. A large body of awareness systems builds on these foundations. Much work has been conducted that extends the traditional desktop screen with a separate awareness display [2, 13, 24]. NotificationCollage [8] extended this notion to support group awareness.

Instead of a single screen, a further stream of research proposes multiple statically mounted displays that are placed at various locations at home [5, 25] or at the workplace [4]. Another body of work contributes awareness systems that are integrated into a specific physical object, including mirrors [3], picture frames [20] and office doors [6].

Small and Everywhere Displays

In contrast to static installations, tangible tokens do not suffer from high initial costs and can easily be moved around. There is a variety of work in this area. Passive tokens were used as tangible bookmarks [16, 18], as reminders [22] or for physically representing data [27]. Plink [26] uses passive paper and a digital pen for creating written links to digital data. Other work proposed tokens that can give visual feedback [27, 31] using a low-resolution display (max. 8x8 pixels). A class of work even proposed high-resolution displays [1, 17, 12, 23]. However,

these only work on surfaces with a small surface area (e.g. tables) and cannot be used in the entire architectural space. To overcome this limitation, previous work suggested projection based solutions [11, 15, 19, 31] and wall-sized displays [21].

Inspired by Mark Weiser's [30] vision of populating rooms with inch-scale, interconnected displays [29], CloudDrops integrate the physical flexibility of tiny, tangible displays into awareness systems, supporting flexible physical orchestration of Web-based information.

DESIGN CONSIDERATIONS

The design of an awareness platform consisting of stamp-sized displays that are situated in architectural space offers degrees of freedom in various dimensions. In this section, we provide an overview of the main design dimensions, which are used as the foundation for the CloudDrops platform. The design considerations are illustrated in Fig. 2.

Shape & Size

CloudDrops can come in a variety of shapes and sizes. The *size* of the display results as a trade-off between mobility and the amount of content that needs to be displayed.

Custom *shapes* for CloudDrops allow for novel affordances (e.g., a round shape supports interactions based on rotation) but can also provide a symbolic meaning. Consider for instance a CloudDrop in the shape of a heart to indicate that the display shows content related to a loved one.

In order to make CloudDrops attachable to a wide variety of surfaces with different material characteristics, we propose their backside to be magnetic, sticky or pinnable.

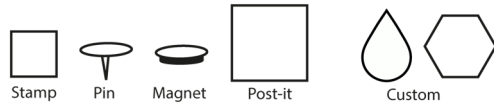
Dynamic Content

CloudDrops represent dynamic digital content, such as *websites and documents* or *contacts*. Thereby, each individual content is represented as a separate CloudDrop. This allows the user to flexibly attach each item on a physical place. In the other direction, it makes a *physical place* accessible remotely to provide situated messaging and communication

Association with Content

A CloudDrop is associated with a piece of dynamic digital data and shows its dynamics. Bringing this information onto the CloudDrop is somewhat challenging, since the tiny display size makes conventional information search hard if not impossible. Inspired by previous work [9, 33], we propose three ways in which CloudDrops can be associated with content: (1) Content from a *nearby device* with a larger screen (e.g., a PC, tablet, or smartphone) is associated with a CloudDrop by using a simple gesture. (2) The CloudDrop recognizes the object or surface it is attached to and displays dynamic *situated* information related to this object or surface. (3) Content is defined by one or more CloudDrop in the proximity, which together form a *group*. We will provide more details and examples for each of these associations below.

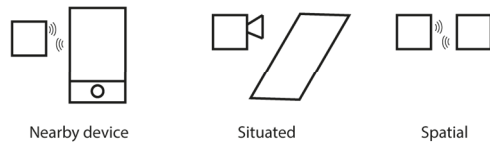
Shape & Size



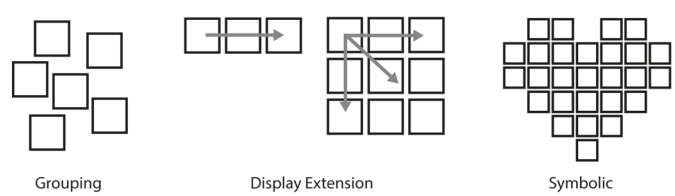
Dynamic Content

Documents/Web pages e.g. Shared docs Email Inbox Blogs	People e.g. Social networks Messaging	Physical place e.g. Fridge Office door
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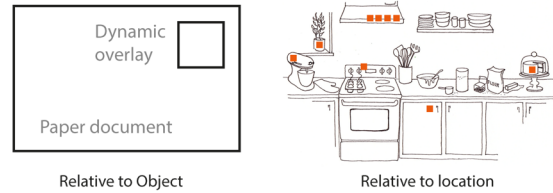
Association with Content



Spatial Arrangements



Situated Arrangements



Interacting with Content

Content-centric e.g. Star, sort open on big screen	People-centric e.g. reply, notify start conversation	Place-centric e.g. send message to location leave message at location
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Fig 2. CloudDrops design considerations.

Spatial Arrangements

CloudDrops support three types of spatial arrangements (see Fig. 2). *Grouping* is a means for the user to partition the information space, thus enabling him to actively manage it [14]. For example, users can create groups for semantically related items, or group items in a temporal order to stay aware of the state of a process. They can move CloudDrops into their focus of attention, and easily move them back to the periphery. Secondly, CloudDrops can be aligned to form a larger *extended display surface* of a custom shape and size. The display can then show details that were not possible to display on a single CloudDrop. Lastly, spatial arrangements can also physically represent a *symbolic meaning*.

Situated Arrangements

CloudDrops enables users to create situated information spaces [7] in an ad-hoc fashion. By adding one or several CloudDrops on a physical *object* or, more generally, at a specific *location*, users can display rich contextual information in-situ.

Interacting with Content

CloudDrops offer a bidirectional communication channel such that users can directly react to an update. Interaction should be fast, lightweight and easy to perform. *Document-centric* interactions provide a simple means for directly manipulating the document (e.g. to prioritize it) or to open it on an external display for more detailed manipulations. *People-centric* interactions allow the user to quickly communicate in an asynchronous fashion and seamlessly switch to synchronous communication if needed. *Place-centric* interactions encompass ways for the users to send a message to a CloudDrop, which is attached to a remote location.

CLOUDDROPS

Device concept

We realized the concept of a CloudDrop in two working prototype versions (Fig. 3). Each emphasizes different aspects of the concept of a CloudDrop. In order to visualize and interact with information from the cloud, a CloudDrop contains a small touch-sensitive display. The display is big enough to show a small piece of information, which can be consumed at a glance. Users can personalize the appearance of a CloudDrop with custom casings. As examples, we chose a drop shape and a more neutral square shape.

Similarly to how magnets are used on whiteboards or fridges, a CloudDrop can be attached to various objects, sticking to them with its magnet and adding additional information to those objects. Our prototype B has a camera on the backside (see Fig. 3 reverse side), which is used for easy association between the CloudDrop and the underlying object by taking a picture of the object.

While a CloudDrop can be used on its own, as a tiny drop, CloudDrops are often used in groups. A “puddle” of CloudDrops can act as a bigger, coherent entity, for instance to provide more detailed information or to provide

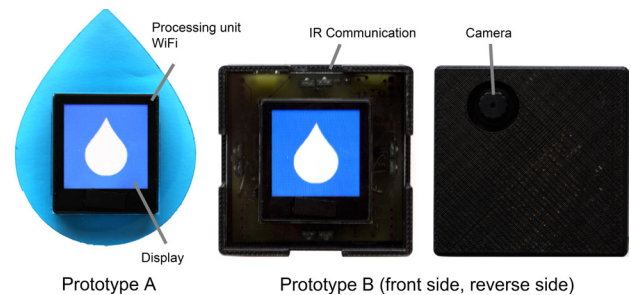


Figure 3: CloudDrop prototypes.

increased visibility for notifications. Our prototype B is capable of recognizing nearby CloudDrops.

Implementation

In our prototypical implementation, each CloudDrop has a full-color touch-sensitive screen with a diagonal of 1.5 inches and a resolution of 160x160px. It features a 600Mhz processor, a built-in accelerometer and WIFI connectivity, and an RFID tag attached. Prototype A weighs 32 grams and measures 2.1x2.9x0.5 inches. Prototype B weighs 73 grams and measures 2.1x2.1x1.25 inches. It features an infrared sensor on each side with a maximum range of 4cm for neighbor detection. Once a neighbor is detected, they exchange their ID and the side along which they are facing each other via a custom infrared protocol. All CloudDrops are connected to a central server. Other computing devices recognize a nearby CloudDrop using an RFID reader. The rechargeable battery lasts for approx. 8 hours during typical usage.

Our implementation is compatible with standard Web protocols and major application platforms. CloudDrops can display and interact back with content from Web pages, Gmail, GoogleDocs and Skype. For associations with the Google Chrome browser and Skype, the nearby computing device runs a client application that communicates with the CloudDrops web server.

CONTENT AND INTERACTIONS

CloudDrops are designed to be visible at a glance. Therefore, all screen real estate is devoted to content. The CloudDrops platform allows the user to display and interact with content from three main classes: related to documents, related to people, and related to places.

Web Pages and Documents

CloudDrop offers three visualizations for Web pages, documents and Web applications:

Entire Web-page: A CloudDrop can be associated to monitor global changes of a Web page. The display notifies the user once any update is happening anywhere on the page.

Dynamic Snippet: Often it is only a small part of a page that the user wants to stay aware of. Consider e.g. an ongoing auction at eBay. The user might be interested in just following updates of the price of the article. To do so, CloudDrops can be associated to a small snippet of a Web page and update in real-time if this information changes. Figure 4a shows an example, in which the CloudDrop displays the current price of an article on eBay.

Web Application: Besides standard Web pages, there is an increasing number of powerful Web applications, such as online mail clients or collaborative text editing tools. Many of them have a programmatic interface that offers access to more detailed awareness information. CloudDrops integrates with several standard Web applications to provide rich awareness information. This is illustrated in



Figure 4. Content types and their visualizations, as they are supported by a CloudDrop.

Figure 4b, c and d: for a Google Doc, a CloudDrop shows the number of revisions since the document was last accessed on a Web browser. For a GMail inbox, it shows the number of unread emails and, if available, the photo of the person who sent the last one.

In addition to information updates, CloudDrops act as a backchannel and provide a lightweight way to interact with the associated content. For instance, the user can star an email directly on the CloudDrop. For the full set of interaction possibilities, the Web page or document can be opened on a bigger screen. This is done by holding the CloudDrop close to another computing device while touching on the CloudDrop's display.

People

CloudDrops support awareness of people and interpersonal communication. While many cloud-based communication services could be integrated with CloudDrops, we chose Skype because it supports synchronous and asynchronous communication as well as status messages. After associating a CloudDrop with a contact, the CloudDrop shows the picture of the person, her status message, and her online status (Fig. 4e).

Asynchronous communication: The user can stay aware of the person by means of her status messages and online status. The user can send an emoticon directly from the CloudDrop. Since incoming text messages are accessible on the CloudDrop, emoticons also act as a quick answer.

Synchronous communication: For synchronous communication, the user can make a phone call by holding the CloudDrop close to a PC, tablet or smart phone and touching the "call" button. The call is then initiated on the other computing device. Since the entire communication is handled via Skype, the remote partner does not need to have CloudDrops in order to participate in the communication. Finally, the platform supports lightweight communication in-between two CloudDrops. Suppose that a CloudDrop is at the user's location, while another



Figure 5. Varying the degree of awareness information by adding or removing CloudDrops to a puddle.



Figure 6. The CloudDrop adds dynamic information to the paper document.

CloudDrop is at the remote user's place and both are associated with the other user. Like knocking on a physical door or a porthole, the user can touch the display; then the remote CloudDrop lights up. This enables rich and direct communication patterns, e.g., fast knocking in urgent cases or knocking in a specific rhythm to share a mood. If the user wants to get the remote partner's attention more explicitly, she presses on the display and shakes the CloudDrop. In this case, all surrounding CloudDrops at the remote location glow periodically.

Physical place

CloudDrops that are associated with a physical place can show messages that are remotely sent to the location. To do so, the user sends an email with the location description as subject and the message in the email body. If people leave more messages at this location than there are CloudDrops available, they periodically change the messages displayed.

ASSOCIATION WITH CONTENT

The platform offers three distinct ways of bringing content onto a CloudDrop:

Content from a nearby device

A CloudDrop can be associated with a specific dynamic part of a Web page. The user selects some snippet of the web page in a browser on a PC, tablet or smart phone, holds an empty CloudDrop close to the computing device and then touches its display. The CloudDrop displays this snippet and continuously updates when the snippet gets changed on the website. The same principle also works without selection to stay aware of updates of the entire website. A CloudDrop is associated with a contact in Skype, Gmail or GoogleDocs the same way as is done with web documents.

Situated content

CloudDrops can be attached and associated to *macro-locations* such as walls, doors or desks. To do so, the user selects or enters a textual description of the location on the CloudDrop (e.g., "office door"). This location information is automatically propagated to other CloudDrops that are added in its close vicinity.

Used as interactive stickers on *micro-locations*, such as documents or photos, CloudDrops can augment static objects with dynamic information. In our current implementation, a CloudDrop gets associated with a physical document by taking a photo of the document's QR code with the built-in camera. The QR code contains a

reference to additional digital information, which can then be visualized on the CloudDrop. Future implementations could also identify objects using smart tags (RFID, iBeacons) or could use advanced computer vision techniques for marker-less association.

Grouping

By grouping, the user can vary the amount of visible information by adding more CloudDrops, forming a puddle. For instance, adding a CloudDrop next to the user's inbox displays the most recent email; each additional CloudDrop adds one more recent message (Fig. 5). Similar to associating with emails, CloudDrops added to a blog website show a history of posts; CloudDrops added to a Google Doc provide a history of revisions; CloudDrops added to a macro-location offer more space for displaying messages sent from remote locations.

Delete association

To delete an association, the user shakes the CloudDrop. This will reset the CloudDrop, which then displays a drop and is ready to be associated to new content (Fig. 3 left).

ACTIVITIES & APPLICATIONS

In the following, we present the various ways in which CloudDrops support awareness and communication.

Staying aware of websites, applications and services in the cloud

A common role for CloudDrops is to monitor news sites for changes, check whether a blog or newsfeed got updated, stay aware of new emails in a user's inbox or check if a collaborator has worked on a shared document.

This basic functionality allows the end-user to realize a wide variety of designs, supporting many applications. For instance, CloudDrops associated to various TODO documents can be brought in by group members and attached to the whiteboard. They can be rearranged to fit the group's priorities and keep group members aware of the current stage of completion as they pass by (Fig. 1, left).

Adding digital functionality to physical documents

CloudDrops can enhance physical documents by adding a dynamic digital part. Figure 6 shows a bus schedule with a CloudDrop attached to it. It continuously updates information such as arrival time of the next bus/train or status updates such as delays and cancellations. This principle applies to a wide range of objects, including a restaurant flyer on which the CloudDrop shows the menu of the day or a postcard to which the CloudDrop adds live images of that location.

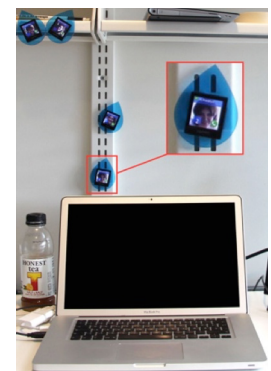


Figure 7. Spatial arrangement of CloudDrops on the user's desk

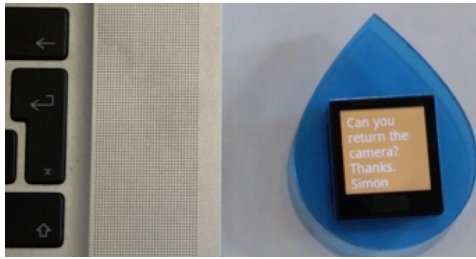


Figure 8. A user places a task visibly on his coworker's desk.

Staying aware of and communicating with people

As an application example, consider a family photo that is attached to the fridge and covered with CloudDrops for each family member (similar to Fig. 8c). Each time they pass by the fridge, family members get reminded of their loved ones, get an update on where they are or how they are doing at the moment, and also have a way to communicate with them directly. This principle applies to other locations, such as a desk to stay aware of co-workers (see Fig. 7).

Leaving information at remote locations

Physical information is naturally bound to a location. An office worker can place some CloudDrops on her desk, allowing co-workers to leave messages at this location from a distance (Fig. 8). Remote CloudDrops can show localized status messages while the user is on the go. Figure 1 illustrates this with an interactive door notification that lets co-workers know when the user will be back.

USER STUDY

We conducted a first informal user study to learn about how the platform is used in a natural setting.

Methodology

We conducted an explorative user study in 5 households with a total of 8 persons (4m, 4f; 2 artists, 5 students, 1 employees). The participants were all familiar with smartphones. We visited the participants at their homes. We first gave a short introduction into the system's functionality. The participant's task then consisted of using CloudDrops in his/her home. We asked the participant to associate CloudDrops with persons, applications and Web pages and place them at any suitable location in the apartment. We used a think-aloud protocol. Field notes and photos were taken. Each session was concluded by a semi-structured interview and lasted approx. 2 hours.

Results

All participants were very positive about CloudDrops and enjoyed using them. For instance, P7 reported: "[It makes digital things] distinct, in flux, tangible and spatial."

CloudDrops were intuitively placed at many different locations in the home. This included highly visible locations that participants pass by frequently, e.g., the fridge, desk, and bathroom. It also included dedicated objects that were augmented with specific digital functionality. For instance, one participant augmented her guitar with a CloudDrop that directly links to her guitar teacher. CloudDrops were also placed into existing

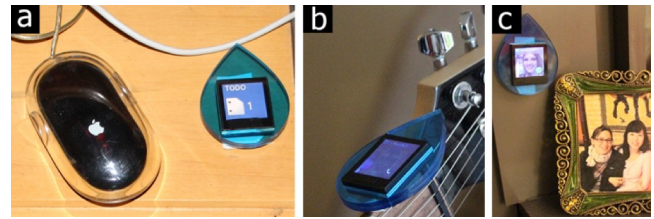


Figure 9. Emerging practices performed by users: a) P7 placed a CloudDrop associated to a TODO document prominently on her desk. b) P3 attached a CloudDrop associated with her guitar teacher onto the guitar. c) P1 attached a CloudDrop onto a picture frame to stay aware of her friends.

information ecologies, e.g., to add digital information to paper documents on the fridge.

CloudDrops associated to websites and applications were used in very versatile ways, taking the contextual richness into account. For instance, P2 placed a CloudDrop as a shopping list on the fridge. P1 attached a CloudDrop on her fridge to stay aware of a blog about recipes. CloudDrops with documents were often placed on the table in the living room or close to the desk (see Fig. 9a). P7 commented: "*It has the potential to return the [digital] desktop to the tangible space of my desktop.*" After spatially placing multiple CloudDrops around her desk: "*it relieves the temptation to be distracted by the multiple tabs [in my web browser] that I have always open.*"

In particular, the association to a person increases the social presence, as reported by P7 after looking at a status message: "*It so nice to be with somebody without being physically there [...] we can leave the channels to our homes open*" We observed that CloudDrops associated to persons were prominently placed in the field of view of the participant or on objects that are closely connected to that person (see Fig. 9b, c).

All participants responded very positively to the device size and its shape. The size was perceived as very handy and participants immediately took and rearranged them after the brief introduction. In addition, P6 reported that there are rare cases in which she would prefer to have some additional, bigger CloudDrops to make specific content more prominent. The shape of a drop was perceived as visually appealing and meaningful in ways not intended by us: P2 attached the CloudDrop such that it pointed towards an object he wanted to be reminded of.

CONCLUSION AND FUTURE WORK

We presented a platform for situated awareness of and interacting with Web-based information. Our findings show that by scattering CloudDrops throughout the architectural space, people design a highly personalized and highly localized physical/digital information environment that supports awareness of persons, websites and applications, as well as interpersonal communication. Future work should examine in more detail how people use tiny displays in architectural space over extended periods of time.

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