Built-In Device Orientation Sensors for Ad-Hoc Pairing and Spatial Awareness

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Abstract
Mobile devices are equipped with multiple sensors. The ubiquity of these sensors is key in their ability to support in-the-wild application and use. Building on the ubiquity we look at how we can use this existing sensing infrastructure combined with user mediation to support ad-hoc sharing with nearby devices. In particular, the paper proposes a technique for exploiting the built-in compass in mobile devices to aid the process of pairing them for ad-hoc sharing in a variety of proxemic arrangements and F-formations.

Author Keywords
Mobile Devices; Spatial Awareness; Proxemics; F-formations

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Introduction
Research prototypes on cross-device interaction enable real-time collocated sharing between devices on the web [3] and through spatial awareness of other devices [7, 4]. However, there remains a large challenge in designing such systems with a view to enabling ad-hoc social interactions - that is, systems that do not require assumptions about prior online relationships or systems that do not rely

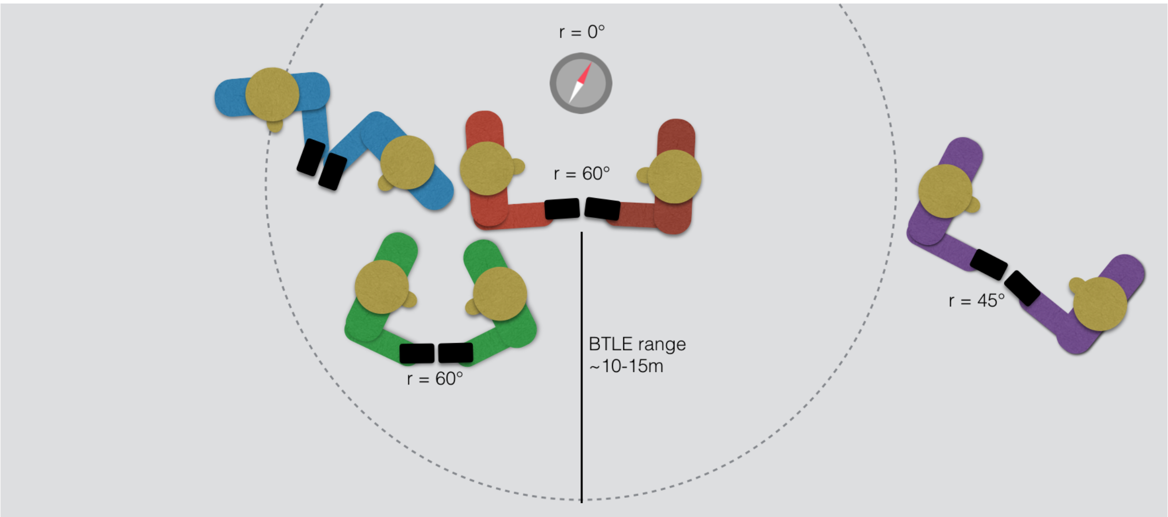

Figure 1: Sensor data to simplify device pairing and ad-hoc sharing in the wild. A sensor fusion technique using orientation data together with other inputs can provide a filtering algorithm for detecting devices.

on additional external instrumentation with sensors. State-of-the-art mobile technology has the potential of making pairing and sharing between collocated devices an easy and lightweight experience by utilizing sensor capabilities. Commercial apps make use of e.g. NFC [1], local networks [2], or by bumping devices together [3]. However, most available approaches still have limited cross-platform support.

In response to these challenges, we explore the potential of built-in orientation sensors in the design of a cross-platform interaction technique for simple setup and reconfiguration of the spatial relationship between devices. The paper contributes with three ideas for cross-device interactions: 1) an interaction technique for ad-hoc pairing of devices using web technologies and orientation sensors, 2) a preliminary outline of trade-offs to address with limited coarse-grained sensor information, and 3) a position on how knowledge of proxemics and F-formations can inform design of mobile interactions.

Point2Share focuses on ad-hoc sharing between devices. It uses orientation and distance between people as a way of spatially organising your sharing relationships. The interaction techniques are inspired by typical patterns in F-formations, such as face-to-face, corner-to-corner and side-by-side formations [2, 4] (see figure 1). It is inspired by Marquardt et al's explorations on F-formations and spatial awareness in GroupTogether [4] and takes off from their future work motivation that more easily deployable sensing modalities and inherent trade-offs should be investigated. The proposed techniques address two challenges for using

[1] https://developer.android.com/training/beam-files/index.html
[2] https://support.apple.com/en-us/HT203106
[3] http://bu.mp/

built-in mobile sensors to enable in-the-wild use: 1) insufficient knowledge of devices' spatial relations, and 2) balancing user and sensor input in design of interaction techniques. Before presenting Point2Share in more detail, we first provide a review of related work that helps situate our current system and its particular rationale, in the broader landscape of other systems.

Related Work

It has been suggested that knowledge of people's spatial relationships, or *proxemics*, based on sensor input, can be used for mediating interactions. *Proxemic interactions* is envisioned as devices with fine-grained knowledge of nearby people and other devices to enable more natural social interactions [1, 4]. However, in state-of-the-art mobile technology the available sensor information is much more coarse-grained than what can be provided in a lab with dedicated sensor technology. A range of pairing techniques and interaction techniques using sensors and spatial awareness have been proposed in HCI as well as in products. In the following, these are compared with their ability to scale for in-the-wild use.

Pairing Techniques for Collocated Sharing

In the current state of the mobile market, apps that make collocated sharing easier have moved from the apps in the mobile app stores into the operating system with examples such as Bump (acquired by Google), Android Beam and AirDrop. Common for all three is their exploitation of existing built-in mobile sensors. Bump enables one-to-one sharing by bumping phones together and detects collision with the accelerometer. Android Beam uses NFC and is a very compelling technology for ad-hoc sharing operating at Android system level. However, this is currently limited to Android devices. AirDrop also allows for wireless sharing between devices through Wifi and Bluetooth, however, it is limited to the Apple ecosystem of devices. Furthermore, Webstrates has been proposed as an experimental system with a flexible model and compelling applications for real-time collocated sharing. Webstrates are web-based substrates that can contain content, computation and interaction possibilities [3]. Pairing in Webstrates can be as simple as sharing a URL. However, sharing relations require prior setup, and this can be simplified and become more dynamic by the use of sensors.

Spatial Awareness

The notion of F-formations is a theoretical construct that articulates patterns of spatial configuration of people in social interaction. [2]. F-formations have been used by Marquardt et al to infer certain patterns from sensors to have system awareness of how a group of people orient towards each other and devices. This concept was explored through the GroupTogether system [4]. Although GroupTogether uses relatively lightweight sensor instrumentation of an environment, such a requirement nevertheless limits the more ubiquitous application of these ideas beyond that instrumented space. Other HCI systems have explored the fine-grained spatial awareness between devices. HuddleLamp [7] enables mobile devices to have spatial awareness of each other, enabling simple spatially intuitive content sharing between collocated devices. However, as with GroupTogether, there is a dependence upon additional external instrumentation that restricts its more ubiquitous use: HuddleLamp requires cameras in the surrounding environment and mobility of devices is limited to near the table surface.

In the wild – with no assumptions of instrumentation in the environment – the granularity of spatial awareness in the above-mentioned systems is not available. However, pinching has been suggested as a way of stitching displays together [6].This technique is very intriguing for in-the-wild

Technical Problems

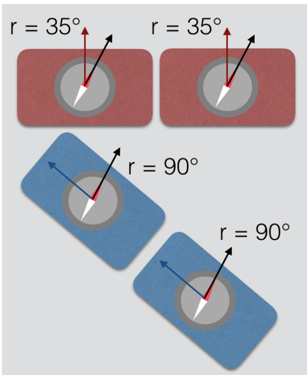

Figure 2: Correlating absolute orientation as implicit parameter for easy pairing.

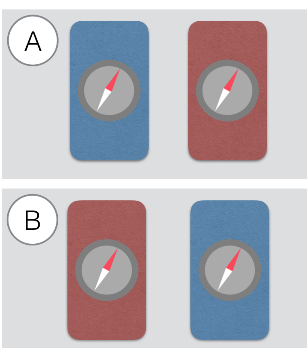

Figure 3: The problem of inferring relative orientation. There is no way from the sensor data to infer the difference between blue device being to the left (A) or to the right (B).

applications. What should be noted about this interaction is that it requires devices to be in contact in order to make the connection. For some social situations, this might not always be a proper way of interacting. And furthermore, this technique requires fully manual recalibration when users move a device.

Point2Share: Interaction Techniques

We developed Point2Share to demonstrate how the above-mentioned issues could be overcome in future systems. The system is web-based to enable use on any mobile platform. Point2Share enables users to share content by transferring from one device to another in a way that the two displays extend each other. The system uses synchronised web clients powered by the Webstrates infratructure [3]. Content could be anything from work-related documents or a youtube video to contact information, or even permissions and control units for remote controlling another client. Point2Share currently involves two interaction techniques that are based on orientation awareness: *pairing* and *reconfiguration of spatial sharing relation*.

Filtering Algorithm for Ad-Hoc Pairing

In order to have the two displays of the mobile devices extend each other, they must first be paired. Pairing is based on the assumption that orientation is an indicator of intention [1, 4]. Users can think of their mobile device as a pointer pointing towards the target they want to pair with. To generate a match we propose a sensor fusion technique combining multiple implicit parameters for pairing. A single pairing data point contains *orientation* information from the compass, *proximity* information from Bluetooth and pairing requests from within a limited *time window*. A server can use these data points to pair two devices and distinguish their pairing from others. Assuming that two users are holding their phone in ordinary portrait mode in their hands, the absolute orientation of two devices can be used to infer that they are pointing towards each other. Use of orientation data is illustrated in figure 2 and in (video) figure 4. However, in the wild, situations might occur where multiple people are pairing with similar sensor data points. As an example illustrated in figure 1, the red pair can be distinguished from the purple in both absolute orientation and proximity, but red and green have similar orientation data pairs and are all in proximity of each other. If they are also trying to pair within the same time window, there is no way to fully infer the correct match. However, in this case a filtered list of possibilities will be presented to all devices, and the users have to choose between a list of people. When the two users have selected each other from the filtered lists, they are assigned a shared webstrate for real-time sharing. Bottom line is that when sensor data is insufficient, the user will be prompted to make the decision from presented information.

Reconfiguring Relative Orientation

In the pairing we assume that the top edges of the device are pointing towards each other. We cannot be sure from sensor data because of the problem illustrated in figure 3, but it can be a fair assumption when in the pairing process. However, to support greater flexibility in the spatial relation between devices after pairing, we can allow for reconfiguring the spatial device relations with a quick recalibration. Since this *reconfiguration* mode is separated from the *pairing* mode, the following technique can assume that this is only about relating two devices to each other.

In Ballendat et al's conceptual framework for Proxemic Interactions they mention *orientation* as a dimension of proxemics [1]. They distinguish between absolute and relative orientation. What we want is to have some notion of relative orientation between two people, but we only have absolute

Initial Prototypes

https://youtu.be/1vZZzPd6KnE

Figure 4: Pairing using orientation as part of the input to a filtering algorithm. This short video figure demonstrates how absolute orientation can be used as input for pairing.

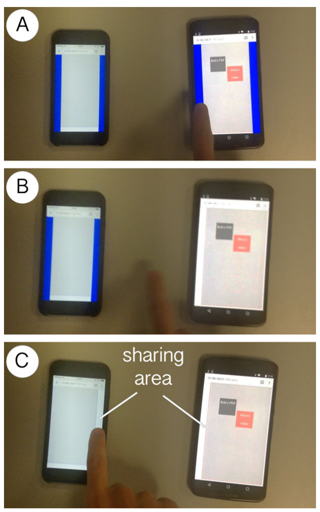

Figure 5: Setup of side-by-side configuration. Two devices are detected as being side-by-side due to similar orientation values (A). A tap on the Android device on its left edge (B) and a tap on the iPhone on its right edge (C) sets up a natural sharing relation where Alice and Bob can share content with spatial cues

orientation (i.e., a phone's orientation relative to North). The final step of going from absolute to relative orientation between two devices is to have knowledge of which side the other device is on relative to your device. With a single tap on the edge (blue edges in figure 5), the user provides the input indicating which direction the sharing relation points towards. Limiting to two facing formations between devices – side-by-side and face-to-face depicted in figure 7 – allows for a spatial flexibility in that the switch between the two modes only happen at a certain threshold. Thus, it does not restrict the devices to be in a very particular relation to each other, but rather just within the semi-circle that is within the limits of the 180-degree threshold.

Transferring Content Between Devices

Pairing sets up a spatial relationship between two devices. Users can then share between devices by *dragging* between them, where one device display appears as an extension of the other, like the *portals* technique in GroupTogether [4]. This is demonstrated in figure 6. It is currently implemented in a prototype, where two users each have a web client viewing different parts of a shared canvas. They have virtual documents that are only visible on each their visible part and can drag between them. By dragging content to the white area at one edge of the display, a user sends a document in this direction towards the other paired device. Sharing a canvas is susceptible to privacy issues, however, this could be implemented in a way that would keep users' content outside of the shared canvas until they intend to share.

Point2Share: Applications

While the design space for Point2Share is yet to be fully explored, we outline initial example applications to illustrate what Point2Share would enable for ad-hoc sharing. The flexibility of web-based infrastructures such as Webstrates

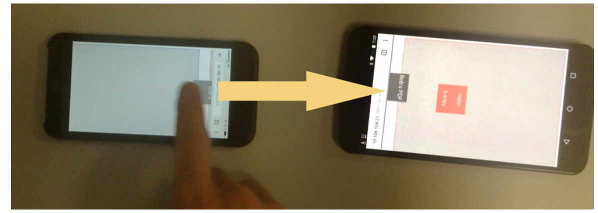

Figure 6: Transferring with spatial awareness between devices, as in portals [4].

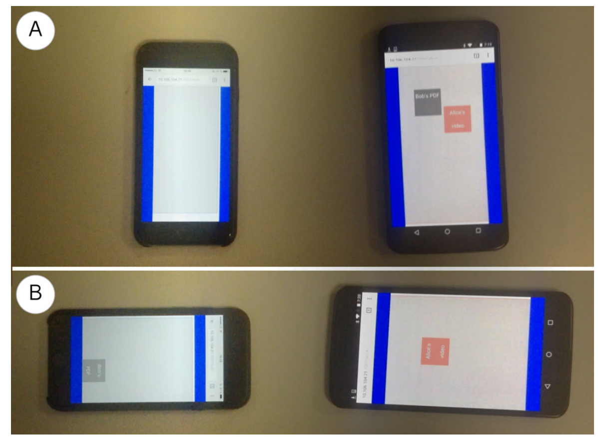

Figure 7: Two supported F-formations: side-by-side (A) and face-to-face (B).

[3] combined with built-in mobile sensors enables applications for a variety of different proxemic arrangements.

One-to-One Relationships

As outlined in the prototype, the pairing can happen between two devices and easy reconfiguration can allow for arranging in a variety of F-formations. In the demo application, two people can share between their devices by dragging a digital document towards the direction of the other person's device in physical space. The interaction of pointing towards another device provides an embodied way of sharing an object. This would allow for a natural way of sharing contact information or business cards in a face-to-face formation. Objects for sharing could also take other forms, like permissions or control elements, similar to the proposals in [3]. In a side-by-side (or corner-to-corner) formation, users might be able to stitch their device displays together. This could enable sharing relations like looking through a merged photo album with photos from the same vacation, or a merged list of suggestions based on two people's Netflix profiles like proposed in [8].

One-to-Many Relationships
The prototype from this paper explores one-to-one relations. However, it is not hard to imagine extending this to one-to-many relationships. A different kind of proxemic arrangement could be in group scenarios, where users can quickly switch between sharing to a public display or their neighbor. This would require a setup where users have calibrated their relative orientation to the public display by once pointing towards it from their position in a meeting room or auditorium. Afterwards they would be able to point in that direction and drag content to the shared screen. This would provide quick reconfiguration of proxemic relations ranging from sharing in a more intimate/personal space with the person next to you or in a more social/public space with a group. A drawback of this approach is that it requires recalibration when a user moves.

Discussion

Current State of Web-based Sensor APIs
An important point about the implementation is that it is done with web technology. For mobile interactions in the wild it is desirable that different mobile platforms are able to communicate. Fortunately, the device orientation data is available from within a web application. The device orientation API is available for web applications. Currently, however, Bluetooth for proximity sensing is not part of the implementation and would still in status quo have to be implemented in a native mobile app. However, the future is pointing towards Bluetooth coming to web apps [4], and there are currently tools for easy development of cross-platform Bluetooth support [5].

Proxemic Interactions and Interaction Proxemics
Situating the Point2Share system alongside other proximity-based sharing apps offers an opportunity for some reflections on proxemics as they relate to interaction. If we consider Beam, Bump and JuxtaPinch we can see how these entail a particular socio-spatial relationship between people that is bound up in the spatial characteristics of the pairing and exchange mechanisms. All three of these systems require the devices to be physically close or touch in order for sharing to occur. These proxemic characteristics of the devices then entail the users of the devices to also be physically close. This is intriguing in the sense that permissions for sharing are dealt with implicitly – that is, such deliberate physical closeness reflects a certain social familiarity or intimacy between the sharers that implies the trust necessary for content exchange.

However, these proxemic requirements of the system also limit some of the spatial flexibility under which collocated exchange might happen. The Point2Share system, while acknowledging the social benefits of systems requiring physical closeness, seeks to offer more spatial flexibility while still maintaining a sensibility to proxemic relations between devices and people as outlined in the concept of Interaction Proxemics [5]. It does so by not making systems

[4] https://developers.google.com/web/updates/2015/07/interact-with-ble-devices-on-the-web?hl=en
[5] https://github.com/randdusing/cordova-plugin-bluetoothle

decisions purely on basis of implicit parameters. Rather the pairing/filtering technique of Point2Share addresses a key issue with using imperfect contextual information for implicit interactions by proposing a suggestive method that balances user and system input for informed decision making. Users are prompted to make decisions together with the sensor data to make the simplest possible pairing process, provided with only limited sensor data. This is different from most of the techniques proposed on proxemic interactions, e.g., [1, 4]. In this way, the system affords greater flexibility in the ways that people can configure themselves with respect to each other to enact their social relationships. At the same time it allows these people to exploit certain proxemic characteristics and configurations to make the ad hoc collocated sharing of content simple and more intuitive.

Conclusion and Future Work

This paper takes an initial step in exploring orientation awareness using the compass for social device interactions. Initial prototypes have confirmed that it is possible to use the compass for comparing device orientations for pairing and distinguishing between two spatial device configurations. The sensor data is coarse-grained and thus puts a limit on the decisions we can make on the basis of it. A full prototype with proximity detection needs to be built to test the robustness of the proposed interaction technique with the heterogeneity of built-in mobile sensors.

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