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# Building Blocks for Designing Future Multi-Device Interaction

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**Abstract**

The paradigm of the Internet of Things predicts that not only typical computing devices but also mundane objects will soon cooperate to achieve certain goals and communicate with users. In this paper we present a new way of designing multi-device interaction to accommodate diverse types of devices and relations among them. We first held a design workshop wherein participants created new multi-device interaction ideas by using device cards. We then analyzed the ideas in terms of the roles of devices, relations of devices with the user/environment, data type and data flow direction. Based on the findings, we identified 10 device roles and developed the corresponding diagram building blocks, each of which clearly visualizes its interaction partner and data flow characteristics. Our own investigation and additional design workshop showed that the building blocks along with device cards can help quickly create and improve multi-device interaction ideas with completeness.

**Author Keywords**

Multi-device interaction; design workshop; device cards; device roles; diagram building blocks

**ACM Classification Keywords**

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

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Figure 1: Workshop participants generating multi-device interaction ideas with device cards

 Laptop	 Cloud Storage
 Desktop	 Television
 Smartphone	 Projector
 Camera	 E-Book Reader
 Music Player	 Pen Tablet
 Tablet PC	 Keyboard
 Media Recorder/Player	 Health Monitoring Band
 Server	 Handheld Game Console
 Physical Storage	 Navigation Device

Table 1: 18 observed devices from literature (among 111 devices used in our design workshop)

## Introduction

Weiser forecasted that various forms of computing devices around us would soon be interconnected and would interact with one another [16]. His vision has recently evolved into the paradigm of the Internet of Things, which predicts an environment in which not only typical computing devices but also mundane objects will cooperate to achieve certain goals and communicate with users [1]. These dreams are getting closer to reality with the advancement of computer vision, sensors, and communication technologies.

Pursuing these visions, a growing number of various multi-device interaction techniques have been proposed. However, most of them focus on specific tasks with specific devices. Examples include image sharing [9], information retrieval [5], and file transfer [13] with multiple tablet devices. The future multi-device environment will be more flexible than the current one and will make it harder to predict how to use what devices when and where [1, 4].

We thus aimed at developing a new way of designing multi-device interaction to accommodate diverse types of devices and relations among them. We first held a design workshop where participants created new multi-device interaction ideas by using device cards (Figure 1). We then analyzed the ideas in terms of roles of devices, relations of devices with the user and environment, and data flow. Based on the findings, we identified 10 device roles and developed diagram building blocks to be used in multi-device interaction design. Our own investigation and additional design workshop showed that the building blocks we developed are easy to learn and effective in expressing and improving multi-device interaction ideas.

## Related Work

To explore the design space of multi-device interaction, it is important to understand how people have been using multiple devices together. Field studies are mostly used to determine how many devices people use, why and how people use multiple devices together, and what problems they confront and when. At first, early adapters such as people working for IT companies and HCI researchers [3, 12] were observed and interviewed regarding their use of multiple devices. These studies discovered the problems with and need for the use of multiple personal computing devices with various form factors. As multi-device computing has become common, along with cloud services, normal users have also become a target of observation [14]. Mazurek et al. interviewed family members having difficulties with access control when sharing data via multiple devices and suggested design guidelines to resolve their problems [10]. Recently Jokela et al. conducted a diary study to extract multi-device usage patterns [7]. These field studies investigated real multi-device environments and user experiences, and then discussed only currently available device interactions and constraints. We included more devices that could be smart in the near future and collected ideas using them.

In an attempt to develop imaginary design ideas for use in the future, Brotman et al. proposed a smart domestic environment that can engage people in discovering problems, developing solutions, and implementing designs [2]. But this procedure takes a relatively long time, and the resulting ideas are fixed to the given space. In our design workshop, we provided participants with device cards that might stimulate their imagination so we could collect a lot of multi-device interaction ideas that were not limited to a target space

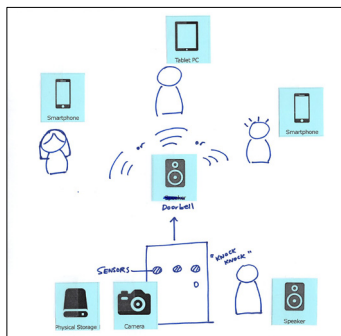


Figure 2: Idea sketch of a personalized doorbell system. When a visitor knocks on the door, the doorbell takes a photo of the visitor and sends the image to family members' portable computing devices with personalized ring tones.

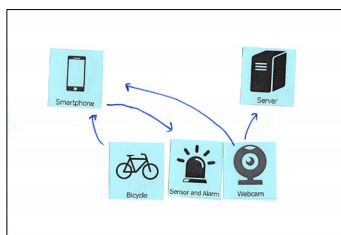


Figure 3: Idea sketch of a bicycle surveillance system. When the bicycle senses an attempted burglary, it sounds the alarm, takes a photo of the suspect, uploads the photo on the server, and notifies its owner via smartphone.

in a short period of time. Participants could easily select devices by using the corresponding cards in a process very similar to dragging device icons in software interfaces to connect available multimedia devices [8, 11, 15]. In addition, they could sketch links and make annotations beside the device cards to complete diagrams similar to the *device landscape diagrams* that Santosa and Wigdor created to represent each user's distributed workspace [14].

### Multi-device Interaction Design Workshop

To collect a wide range of multi-device interaction ideas incorporated with everyday devices that might be smart in the near future, we held a design workshop inspired by *business origami*, a brainstorming method to develop system ideas composed of nodes and links by arranging 3D paper objects on a table and by drawing flow links [6].

We provided a set of cards, each of which was printed with a device pictogram and device name, and let participants arrange and glue some of device cards on paper and sketch connection lines (with any forms of annotations, including arrows and text) with pens to create multi-device interaction ideas (Figure 2 & Figure 3). If participants wanted to use additional devices not provided in our device set, they were allowed to make and use new device cards by sketching on empty cards or existing cards.

The list of devices on our device cards were deliberately chosen to envision potential future multi-device environments. We first included the 18 devices that commonly appeared in the four field study papers [3, 7, 10, 14] (Table 1). Those devices represent current smart devices. We then studied all the product

categories of a global online market (Amazon.com) and selected 93 core products. They represent potential smart devices of the future. Thus, there were a total of 111 devices on our list.

We recruited eight undergraduate students as participants (aged 21~25, four design majors, four non-design majors). They were seated at the same table and asked to make creative and useful multi-device interaction ideas that might be realized today and/or in the near future. The workshop lasted two hours and resulted in 61 multi-device interaction ideas using 441 device cards.

### Findings from the Design Workshop

We examined the multi-device interaction ideas resulting from the design workshop in terms of device usage patterns. Our findings are as follows.

#### *A device can have multiple roles*

Some devices are used for different purposes simultaneously. For example, the doorbell in the personalized doorbell system in Figure 2 recognizes a visitor, sends a customized bell ring, and activates the camera on the door.

#### *Relation with user/environment classifies roles*

Roles of devices differ according to how they interact with the user and/or environment. For example, smartphones can help users intentionally produce and/or consume digital content, whereas they can raise an alarm to users who do not pay attention to them. Some devices functioning as sensors can actively collect certain information from the environment, and some devices, like lamps, can do their own jobs in the environment.

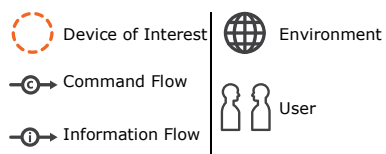
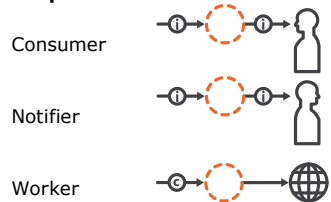


Table 2: Diagram elements to compose building blocks

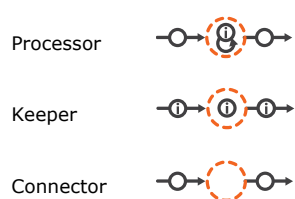
**Input roles**



**Output roles**



**Connection roles**



**Miscellaneous**



Table 3: Device role diagram building blocks

*Data type and flow direction clarifies relation*

Roles of devices can be more clearly identified if the kinds of data that go in and/or out are indicated. Many participants in the design workshop added arrows to depict the direction of data from one device to another device. For example, the arrows in Figure 3 show that the smartphone receives data from the bicycle and webcam and sends a command to activate the alarm. Some participants used marks similar to Wi-Fi symbols, as shown in Figure 2 to represent that the doorbell sends bell rings to family members.

**Device Roles for Multi-device Interaction**

Reflecting the findings in the previous section, we defined 10 device roles, each of which has a clear purpose with a specific interaction partner(s) and a specific data type(s) and specific flow direction(s).

*Input roles*

- Controller: a user intentionally operates it to make a command(s) to control another device. e.g., smartphone, keyboard.
- Producer: a user intentionally operates it to produce new content that would be sent to another device. e.g., smartphone, camera.
- Observer: it actively collects information from an environment (including a person(s)) to send to another device. e.g., webcam, health monitoring band.

*Output roles*

- Consumer: it receives information from another device and gives it to the user to intentionally utilize it. e.g., smartphone, tablet PC.

- Notifier: it receives information from another device and gives it to the user who was not paying attention to it. e.g., alarm, smartphone.
- Worker: it receives a command(s) from another device to perform its own job in an environment. e.g., charger, lamp.

*Connection roles*

- Processor: it receives data from another device and processes the data and then sends the data to another device. e.g., smartphone, server.
- Keeper: it receives information from another device and stores the information for retrieval by another device. e.g., server, cloud storage.
- Connector: it receives data from another device and relays the data to another device. e.g., server, cloud storage.

*Miscellaneous*

- Carrier: it carries another device. e.g., drone, car.

**Multi-device Interaction Building Blocks**

To help interaction designers easily and intuitively assemble smart devices with corresponding roles and effectively visualize the combined multi-device interaction scenarios, we made a diagram building block for each device role. Table 2 shows a few diagram elements. The arrows represent the two types of data flows, which can be differentiated by the first letter on the line. The pictogram for a user shows a direction to represent whether the user interacts with a device consciously or not. We developed 10 device role building blocks using the diagram elements, each of which clearly visualizes its interaction partner(s) and data flow characteristics (Table 3).

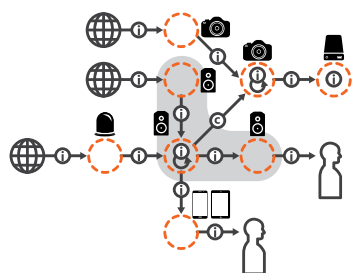


Figure 4: Redrawn diagram of the personalized doorbell system

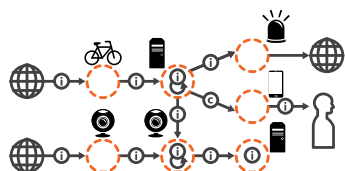


Figure 5: Redrawn diagram of the bicycle surveillance system

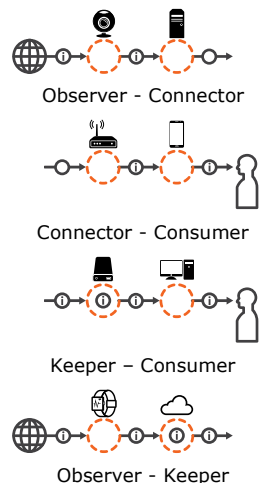


Figure 6: 4 most observed role-role pairs (with device examples)

### Building Blocks for Analysis

To see if it would be possible to clearly visualize and analyze multi-device interaction ideas with the developed diagram building blocks, we applied them to the 61 ideas from the workshop. Examples are shown in Figure 4 and Figure 5, which are redrawn diagrams of the idea sketches in Figure 2 and Figure 3, respectively. In the original idea sketch in Figure 2, the doorbell appears connected with many surrounding devices, but it is not clear how the doorbell relates with the other devices. However, Figure 4 explains lucidly that the doorbell (in the shaded area) plays multiple roles—it functions as an observer by seeing the visitor, a processor by handling the photo and sending the customized bell rings to the smartphones, and notifier by ringing the bell. On the other hand, Figure 3 does not show the interaction flow of the bicycle surveillance system, whereas Figure 5 does—information flows from the bicycle, through the server, to the smartphone, alarm, and webcam.

### Role-role pair analysis

To determine which device-connection patterns appear frequently in multi-device interaction, we counted the numbers of device role-role pairs in the interaction ideas from the workshop. Our device role building blocks can be connected only when data types and flow directions are compatible. Thus only 37 role-role combinations are valid among possible 55 combinations from 10 device roles. We found 647 role-role pairs in total from the 61 interaction ideas and confirmed that all of the 37 types existed in them. The most frequently appearing patterns were observer-connector (55 times), connector-consumer (50 times), keeper-consumer (48 times), and observer-keeper (40 times) pairs (Figure 6). Those four patterns constituted 29.8% of the total.

### Treating impossible pairs

While converting the original multi-device interaction idea sketches to diagrams with our building blocks, we could see that some role-role pairs are impossible. One example is a controller-consumer (e.g., keyboard to monitor) pair because a controller sends a command(s) as output and a consumer receives information as input. We found 123 impossible role-role pairs (19.0%) of 12 kinds. Most of them involved missing a connection role(s), and processor roles were often missing in the impossible pairs. Once impossible role-role pairs were detected, we could fix them by adding appropriate building blocks. The idea shown in Figure 7 is a temperature control system based on images captured by a webcam. In the original idea sketch, a webcam, thermostat, and air conditioner were connected in a series. They were supposed to be an observer, observer, and worker, respectively, and resulted in two impossible role-role pairs. We corrected the diagram by introducing a processor and having it process information from the two observers (webcam and thermostat) in parallel and send a command(s) to the worker (air conditioner) (Figure 7). Our building blocks make it possible to reveal unclear connections between devices in multi-device interaction ideas and to easily correct them.

### Building Blocks for Design

To see the usefulness of our building blocks in designing multi-device interactions, we held an additional design workshop.

### Methods

We prototyped a digital tool to create and develop multi-device interactions ideas by simply making our building blocks and device cards into stencil shapes in



Figure 7: Fixing an impossible role-role pair example by introducing a missing device role (in purple)

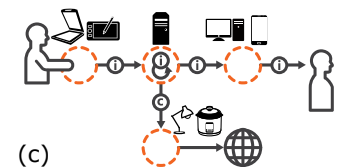
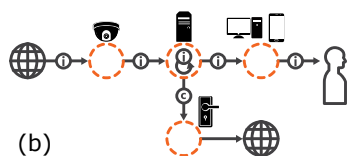
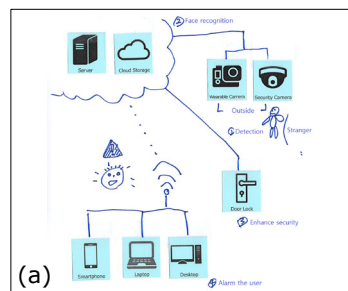


Figure 8: Multi-device interaction examples designed with our building blocks

Microsoft Visio. Users could easily search/browse, components to make multi-device interaction diagrams.

We recruited four of the eight undergraduate students who had participated in our first workshop (we will call them P1, P2, P3, and P4). We first explained the 10 device roles and corresponding building blocks to them and showed them how to change pen-and-paper idea sketches into digital diagrams in our prototype system and fix them correctly. We then asked them to do the same with two of their own original idea sketches. Once they were familiarized with the tool, we asked them to create two new ideas from scratch. Finally, we closed the workshop with a semi-structured interview to get feedback.

**Results**

All participants easily learned how to use the tool and could quickly express multi-device interaction ideas using our building blocks and device cards, revise them, and complete them (Figure 8). *“It’s fun. Anyone can easily make his idea and clearly show it to others”* (P2).

Figure 8a is P2’s original idea sketch of a system that detects a suspicious person prowling outside of a house, tightens up security, and notifies the house’s owner. Some uncertainties in Figure 8a regarding device connection and data flow were resolved in Figure 8b, which was a remake of the original idea with our prototype. In addition, unnecessary devices in Figure 8a, such as cloud storage and a wearable camera, were removed in Figure 8b. Figure 8c is P2’s new idea for a system that recognizes a user’s daily plan memo and makes available devices help the user fulfill the plan on time directly or indirectly. The user’s interaction to input the information and the system’s information-

processing structures are clearly shown in the diagram. On the other hand, P2 effectively suggested design alternatives by putting multiple devices together that could perform the same roles.

The strengths of our tool pointed out by the participants include the completeness of resulting ideas (P1, P2, P3, P4), the feasibility of resulting ideas (P3), the speed of ideation (P2), and the clearness of input and output data flow (P2).

The participants suggested that we add the ability to express the context of interaction, such as the status of the user and environment (P1, P3, P4), add popup windows to show the attributes of data (P1, P4), distinguish characters (P3), and give serial numbers to depict the sequence of interactions (P3).

**Conclusion & Future Work**

With the expectation of highly flexible computing environments in the future, we aimed at developing a way of designing any multi-device interaction that is not limited to goal and device type. Based on analysis of imaginary interaction ideas, we identified 10 device roles and developed corresponding diagram building blocks that were supposed to jointly describe any multi-device interaction scenario. In a small-sized design workshop we could see participants became quickly adept at using the tool and easily created new multi-device interaction ideas with completeness. For future work, we aim to 1) confirm the usefulness of our tool with larger-sized design workshops, 2) develop a standalone design tool with suggestive interface, and 3) seek smart ways of collaborative design to discover design problems and find solutions.

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