DAILY CONTEXT-ADAPTIVE PRESENTATION DRIVEN BY PERSONAL DATA STORE

Efforts to transform living environments, such as cities and homes, into smart system using AI and IoT are advancing worldwide. This research envisions future living spaces in which devices surrounding each user autonomously select and present the most appropriate content and presentation device based on the user's context (e.g., behaviors and environments). However, because actual homes incorporate a wide variety of software and hardware from different providers, building such a system solely by content providers such as broadcasters would entail prohibitive effort. Therefore, we designed a flexible system architecture that links heterogeneous software and devices from multiple service providers and manufacturers via a user-managed Personal Data Store (PDS). The PDS aggregates sensor logs and service usage records tied to individual behavior, enabling unified context estimation. Finally, we developed a prototype to demonstrate end-to-end operation and confirmed the validity of the proposed architecture.

1. INTRODUCTION

The rapid spread of Internet media has made it easy to select and consume information that aligns with individual interests from an immense pool of content. However, because the time each person can devote to accessing and consuming information in daily life is limited, increased focus on highly interesting content necessarily reduces opportunities to encounter less-favored information. Consequently, the chances of coming across socially important or public-interest information – ideally shared widely – vary greatly between individuals[1]. This divergence in information exposure is recognized as a social challenge that contributes to the fragmentation of public opinion. Broadcasters have traditionally disseminated diverse, high-public-interest content via television and radio. Yet as people's information-access patterns have diversified, it has become increasingly difficult to ensure that such content reaches everyone through broadcasting alone.

In response, technologies are being developed to extend the broadcast platform and integrate broadcasting with various services and devices. This approach aim to create new touchpoints between users and broadcast content – not only when they watch TV programs but also across multiple everyday scenarios[2] [3].

One approach under consideration is the application of smart environment technologies – systems that leverage IoT devices and sensors to make living spaces context-aware. In recent years, efforts to develop smart cities and smart homes have advanced, laying the groundwork for these technologies[4]. In a smart living environment, users will be able to access a variety of personalized services tailored to their immediate surroundings with minimal effort. Such an environment also promises broadcasters the opportunity to deliver content across a wider range of daily situations and to more diverse audiences than ever before. For example, if a user watching a TV program in the living room needs to move to another room and the viewing is interrupted, a smart environment could detect that movement and automatically resume the program in the destination room – helping maintain the user motivation to continue watching. Smart environment technologies can also support everyday multitasking, where users perform two or more activities simultaneously. For instance, while a user is brushing their teeth, nearby devices such as a smart mirror could display the live broadcast or related content, allowing the delivery of information even during brief moments of daily routines[5]. By providing content on various devices close to the user in this way, opportunities to access public-interest information are expected to increase.

To realize such information presentation, a system is required that can appropriately estimate each user's context under their own varied living environments. Constructing an entire system – composed of diverse devices and sensors – solely by information providers such as broadcasting stations would demand considerable effort; therefore, it is considered more efficient to integrate with the smart technologies expected to proliferate in living spaces.

Accordingly, a system architecture is proposed to enables service providers, such as broadcasters, to offer context-adaptive information presentation that takes user behavior into account.

2. ISSUE AND SYSTEM REQUIREMENT

This section outlines the challenges that service providers, such as broadcasters, must address to enable context-aware information presentation in smart environments, along with the system's functional requirements. This paper focuses on two key issues.

2.1 ISSUE 1: CONTEXT ESTIMATION BY SERVICE PROVIDERS

In a smart environment, achieving context-aware service provision generally requires the following processes:

- Estimate the user's context based on sensing data from various devices and sensors distributed throughout the living space.

- Based on the estimated context, determine which services to provide and how to deliver them (for content services, decide what information to present and in which format).
- Control the surrounding devices to execute the selected service.

If a service provider intends to deliver offerings that span every part of a user's living environment, installing and maintaining a wide array of sensors in each home would incur prohibitive costs. However, even when devices and sensors are already deployed by other entities, reliable context estimation depends on metadata – such as each device's installed location, its operational status, and its association with a specific user or space. Implementing and maintaining that metadata management separately for each service provider would also be highly inefficient.

For these reasons, it is desirable for service providers to obtain and leverage context estimation results from an external system or platform, without having to perform the estimation themselves. This capability is defined as Requirement ①.

2.2 ISSUE 2: UTILIZATION OF THE USAGE STATUS OF MULTIPLE CONTENT DELIVERY SERVICES

Users engage with multiple content delivery services in their daily lives. By combining usage logs from several services, it is possible to improve the accuracy of user behavior estimation – which is essential for context-adaptive information presentation. In practice, however, usage logs (such as viewing histories) are typically siloed within each individual service. As a result, it is difficult to reference or utilize those logs across different services.

Therefore, the ability to access and integrate usage logs from multiple content delivery services is defined as Requirement ②.

3. SYSTEM ARCHITECTURE

Based on the issues and requirements identified above, a system architecture for context-adaptive information presentation that takes user behavior into account is proposed.

3.1 PROPOSAL OVERVIEW

In the proposed architecture, the core components are
- Sensing and display devices distributed throughout the living space, and
- A Personal Data Store (PDS) and an ontology-based behavior estimation engine, both hosted in the cloud.

Here, the PDS is a user-managed repository for usage logs collected from multiple services. With the user's consent, these logs can be combined and shared with service providers or other authorized entities for downstream processing. The ontology defines and organizes relationships between concepts – when applied to behavior recognition, it enables seamless integration and interpretation of heterogeneous logs from different sensors and services[6,7].

Drawing on Egami et al.[8], we classify behaviors into two tiers:
- Low-level behaviors, which can be directly inferred from individual sensor readings (e.g., "walking," "turning on a coffee maker"), and
- High-level behaviors, which consist of sequences or combinations of low-level actions (e.g., "taking a break").
- Behavior estimation proceeds by first detecting low-level behaviors and then aggregating them into high-level patterns.

The system's runtime operation consists of three main steps:
1. Detection of low-level behaviors from real-time sensor data,

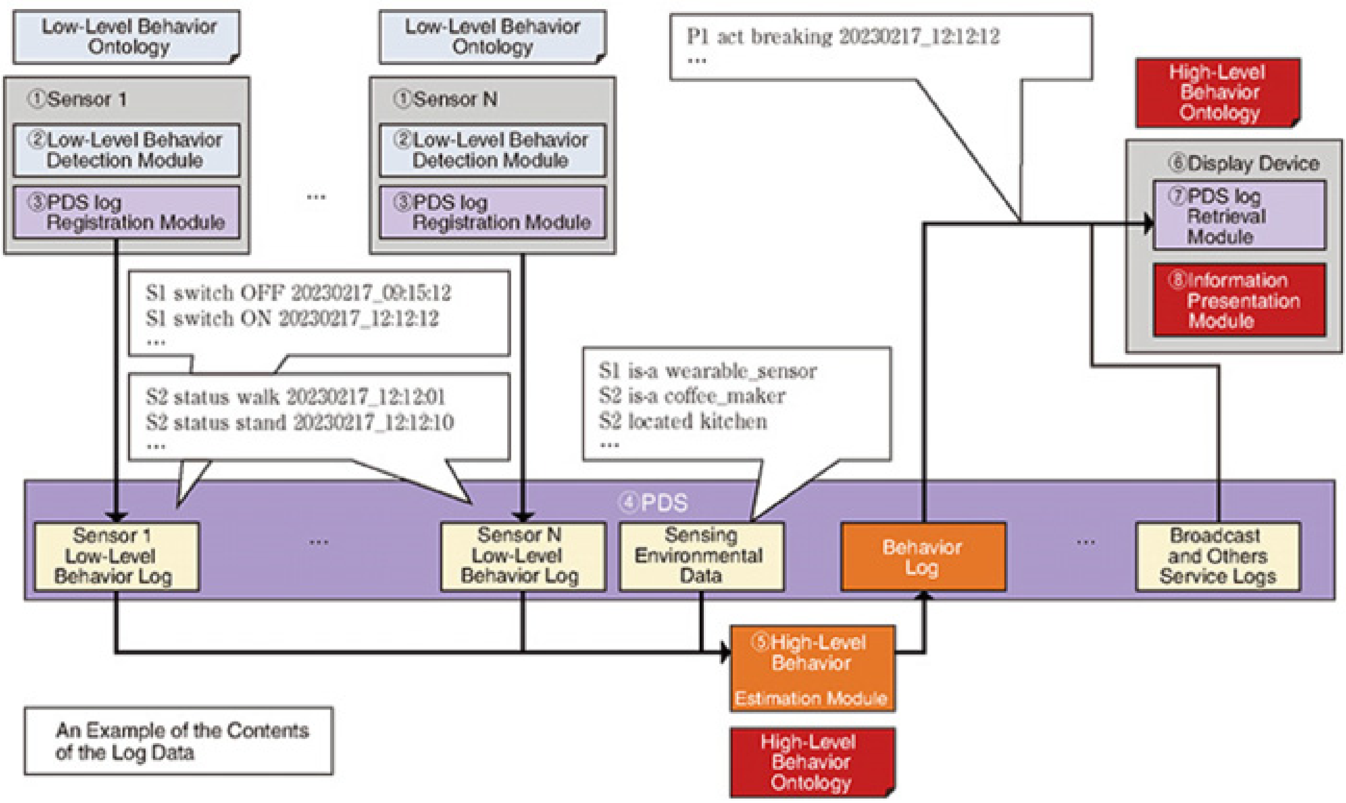

Figure 1: System Architecture

2. Inference of high-level behaviors via the ontology engine, and

3. Selection and execution of context-appropriate information presentation, which determines both the content to display and the target device(s) based on the inferred behavior and the user's service-usage history.

3.2 SYSTEM CONFIGURATION

The overall system configuration is illustrated in **Figure 1**. Each component is described below:

(1) Sensor (Figure 1 ①)
Detects the user's surrounding environment – including the user's actions – via various devices and sensors.

(2) Low-Level Behavior Detection Module (Figure 1 ②)
Maps raw sensor readings to the appropriate low-level behavior vocabulary defined in the ontology, thereby identifying discrete actions (e.g., "walking", "switching on a coffee maker").

(3) PDS Log Registration Module (Figure 1 ③)
Structures the detected low-level behaviors according to the ontology schema and registers them in the user's Personal Data Store.

(4) PDS (Figure 1 ④)
Maintains logs of low-level behaviors detected by sensors, high-level behaviors estimated downstream, and usage histories from various services. Each user has a dedicated PDS that aggregates all their sensor and service logs.

(5) High-Level Behavior Estimation Module (Figure 1 ⑤)
Collects low-level behavior logs and structured sensing-environment metadata (e.g., sensor types, installation locations), then infers the current high-level behavior by referencing the high-level behavior ontology. The resulting high-level behavior entries are then structured and stored in the PDS.

(6) Display Device (Figure 1 ⑥)
A web-capable device (e.g., tablet, smart display) that runs web applications to present information to the user.

(7) PDS Log Retrieval Module (Figure 1 ⑦)
Periodically polls the PDS for updates to low- and high-level behavior logs, as well as pre-specified service usage logs, retrieving them in structured form whenever changes are detected.

(8) Information Presentation Module (Figure 1 ⑧)
Determines which content to present and how to present it – based on the retrieved behavior and usage logs – and then executes the presentation. It also consults the high-level behavior ontology to interpret low-level actions in context.

3.3 RESPONSE TO FUNCTIONAL REQUIREMENTS

(1) Response to Requirement ①
As described in Section 3.2, a two-tier behavior model – low-level and high-level – is employed, with their relationships defined in an external ontology[8]. The end-to-end workflow from sensing to information presentation is divided into three stages:

- Low-Level Behavior Detection Module: identifies low-level actions from raw sensor data.
- High-Level Behavior Estimation Module: infers high-level behaviors by aggregating sequences of low-level actions with reference to the high-level behavior ontology.
- Information Presentation Module: selects and executes the appropriate information delivery method, using both high-level behavior results and usage logs from multiple services.

Each module's inputs and outputs conform to the ontology schema, enabling loose coupling – the Information Presentation Module can operate solely on the estimated behaviors without needing insight into the internal workings of the Behavior Estimation Modules. For real-world deployment, we assume that service providers (e.g., broadcasters) operate the Information Presentation Module, while platform operators (e.g., smart-home or smart-city infrastructure providers) manage the High-Level Behavior Estimation Module.

(2) Response to Requirement ②
Also per Section 3.2, all behavior logs and multi-service usage logs are aggregated in the user's PDS as structured data. The PDS Log Retrieval Module continuously monitors the PDS and, upon detecting updates, fetches both behavior logs and the user-authorized service usage logs. These structured data feed into the Information Presentation Module, which then determines the most context-appropriate presentation strategy. Because behavior logs adhere to the high-level behavior ontology, this architecture seamlessly supports information-presentation decisions that account for both the user's activity and their cross-service usage history.

4. PROTOTYPE IMPLEMENTATION AND VERIFICATION

To validate the proposed architecture, a partial prototype was developed and its end-to-end operation was tested using a representative service scenario.

4.1 VERIFICATION SCENARIO

Figure 2 illustrates the verification scenario. It is assumed that Users A and B are each at home. In User A's residence, a TV is installed in the living room, and a coffee maker plus a smart display are in the kitchen. The TV logs viewing behavior and content metadata to the acting user's PDS; the coffee maker likewise logs its on/off operations. The smart display is a web-browser-capable device for running applications. User A also wears an IoT sensor that can identify low-level behaviors (e.g., standing, walking). In User B's home, a TV is likewise present, and User B has granted User A permission to read their viewing logs. The detailed sequence of interactions and required system processes is shown in **Figure 2**; it is omitted here for brevity.

4.2 CONFIGURATION OF THE PROTOTYPE SYSTEM

The core data-exchange flows between modules were implemented via the PDS. (see **Figure 3**). The Information

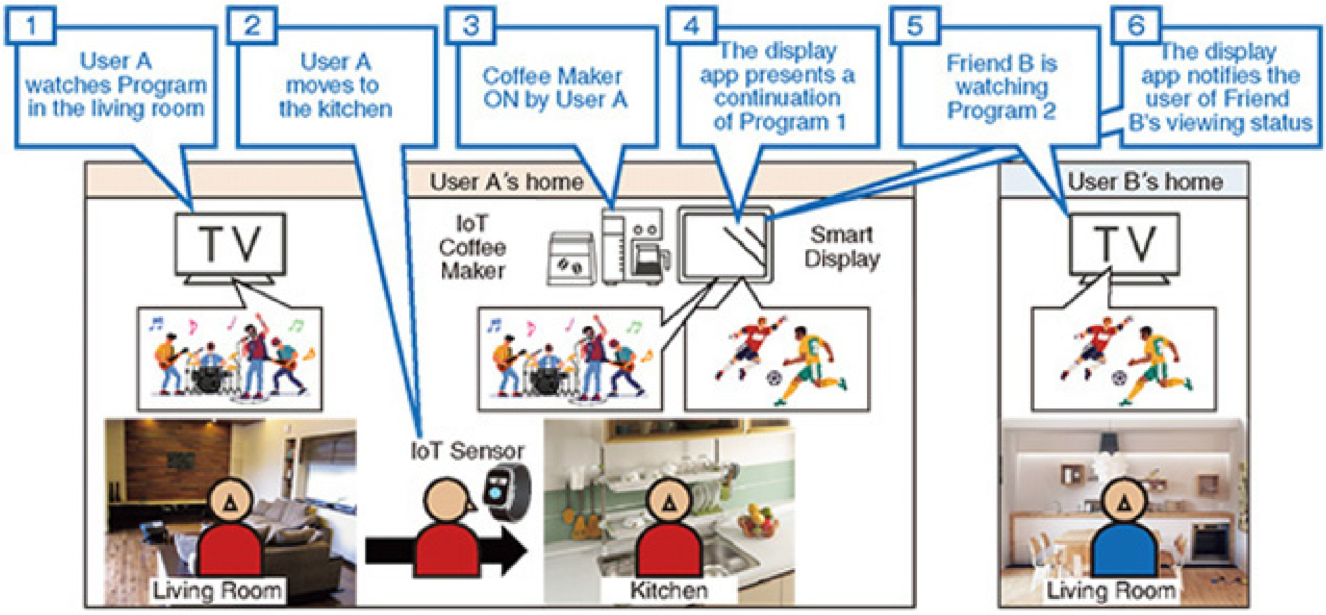

Figure 2: Verification Scenario

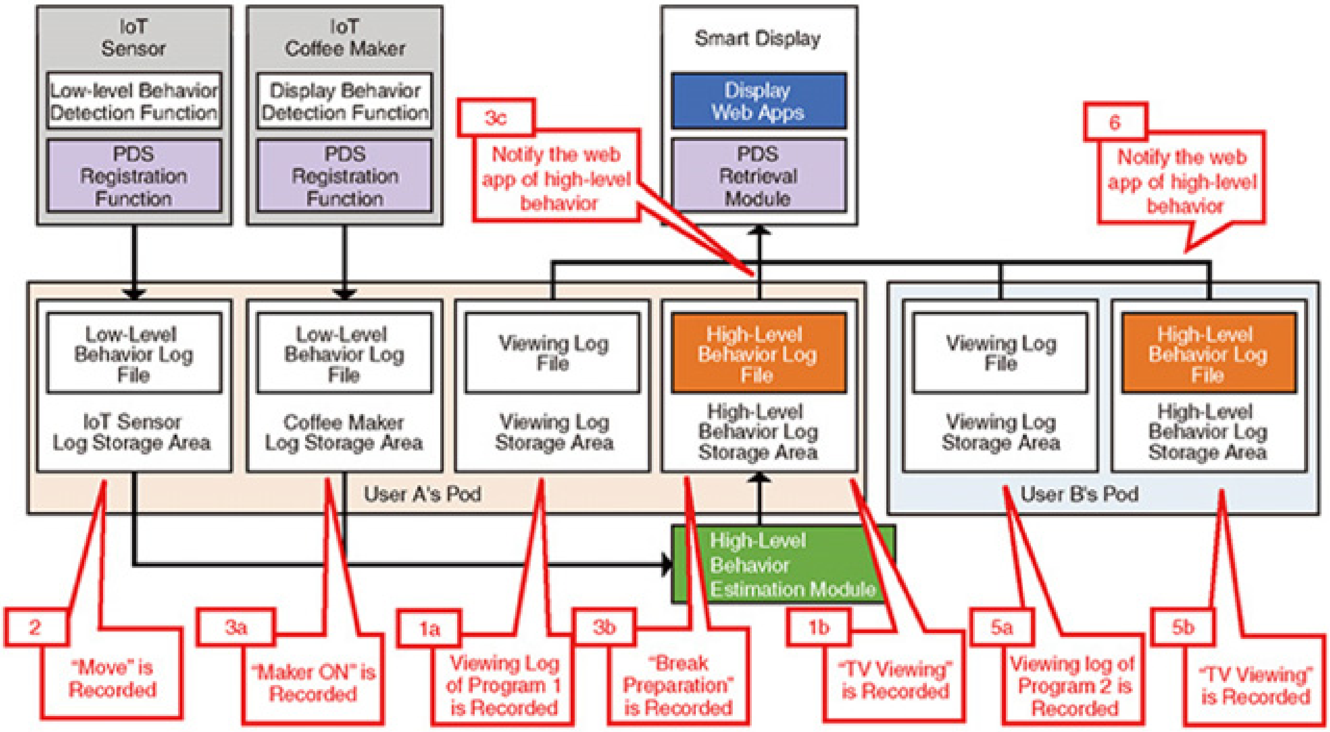

Figure 3: Configuration of the Prototype System[*1]

[*1] The numbers, such as "1," shown in Figure 3 correspond to those used in Figure 2.

Presentation Module runs as a web application in a PC browser. The IoT sensor and coffee-maker interfaces are each realized as web applications that register structured behavior logs into the PDS. PDS functionality follows the W3C Solid[9] specification; the PDS server was implemented using the software listed in[10], and the PDS Log Registration/ Retrieval Module was implemented using the software described in[11].

4.3 RESULTS

It is confirmed that the prototype (**Figure 3**) executed the scenario (**Figure 2**) as intended. The full pipeline – collecting sensor logs in the PDS, detecting low- and high-level contexts, selecting the appropriate presentation strategy based on those inferences, and executing content delivery – ran smoothly, demonstrating the architecture's validity.

In this prototype, the ontology from Egami et al.[8] **was reused**; further ontology refinement **should be carried out** to support an even broader range of contexts. In addition, clarifying the mapping between inferred context and users' preferred presentation modes – and embedding that mapping into the Information Presentation Module – should further enhance user satisfaction.

5. CONCLUSIONS

To increase opportunities for users to encounter diverse information, an architecture for a context-adaptive information-presentation system has been proposed, in which content delivery is tailored to user behavior in smart environments. A subset of this architecture was prototyped and validated against a realistic scenario. Future work will focus on advancing the Behavior Estimation and Information Presentation modules and on the detailed design of both low- and high-level behavior ontologies.

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