

Canella: Privacy-Aware End-to-End Integrated IoT Development Ecosystem

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Abstract—Applications for the Internet of Things (IoT) can derive sensitive information about people, so developers must protect users' privacy in compliance with privacy and data protection laws. However, developers face difficulties in addressing privacy issues as many applications exploit personal data in a problematic manner. We present Canella, an integrated IoT development ecosystem that is augmented with novel privacy-preserving components for developing privacy-aware IoT applications. Canella helps software developers meet privacy requirements during the development phase and during rapid prototyping, and it provides real-time feedback on potential privacy concerns. Canella aims at assisting developers to (i) better understand their code's behavior, (ii) better overcome privacy issues and comply with privacy and data protection laws, (iii) reduce time to incorporate privacy into an IoT application, and (iv) reduce the cognitive load of integrating privacy into an IoT application. Thus, Canella can result in a significant improvement in building privacy-aware IoT applications. (Demo Video)

Index Terms—Internet of Things, Privacy by Design, Software Development, Data Protection, Privacy Law, Usable Privacy

I. INTRODUCTION AND MOTIVATION

Applications for the Internet of Things (IoT) can derive sensitive information about individuals, so developers must ensure that data is maintained in accordance with privacy and data protection legislation. Nevertheless, developers still face many difficulties in handling privacy issues, leading to numerous applications exploiting sensitive data in a problematic way for a number of reasons. First, it has been found that developers do not treat privacy as a primary concern [1]. Second, developers have a partial understanding of what should be considered to protect users' data [2]. Finally, developers lack knowledge of their apps' data practices, which makes it difficult to design and implement effective privacy requirements [3].

Recent studies have revealed that developers face challenges when complying with privacy and data protection laws when the regulations' terms are ambiguous and it is hard to understand and apply these legal requirements [4]. Due to this, it becomes important to transform these privacy regulations into software requirements, a process known as Privacy by Design (PbD) [5]. Several researchers have proposed PbD principles, guidelines, strategies, and patterns to assist developers in effectively integrating privacy-preserving techniques into the development process [4]. The General Data

Protection Regulation (GDPR) [4] assures the importance of PbD and its applicability to all systems that process personal data, a characteristic of IoT applications. However, most guidelines are legal rather than technical. This makes them unsuitable for application-building tools, disconnecting them from developers' practical environment. Hence, there is a need to enrich existing developers' tools with privacy-preserving components. This will increase developers' awareness of how personal information is utilized and misused [4].

In this paper, we present Canella, an integrated IoT development ecosystem. It is augmented with novel privacy-preserving components that work together to help developers build privacy-friendly end-to-end IoT applications. Canella provides real-time feedback on potential privacy concerns and recommends privacy-preserving components to be integrated into IoT data flows. This can encourage developers to consider the potential effects of their applications and the possibility of using less risky options when dealing with personal data. As a result, this can reduce developers' cognitive load and the time it takes to incorporate privacy into an IoT application.

II. FOCUS GROUP FOR REQUIREMENTS GATHERING

As the PbD schemes are the mechanism to comply with privacy and data protection laws, Aljeraisy et al. have mapped the elements of the PbD schemes with the principles and individuals' rights of their Combined Privacy Law Framework (CPLF)¹. Thus, we conducted a focus group study with novice developers to explore the applicability and feasibility of designing and implementing these PbD schemes into different IoT development environments, such as Arduino, Blockly, and Node-RED, in a reusable manner. The participants were divided into 25 groups, with three members in each group.

The results of the focus group study led us to design and implement the privacy-preserving components of Canella based on the PbD guidelines suggested by Perera et al. [6]. This could refer to the clarity of the specifications of these guidelines in comparison to other elements of the PbD schemes as well as their context as they are specific to the IoT domain. After analyzing all participants' responses, we

¹The Combined Privacy Laws Framework refers to the selected privacy and data protection laws analyzed in Aljeraisy et al.'s study [4].

excluded the guidelines that were not properly supported by useful feedback. The resultant guidelines are shown in Figure 1. Each guideline complies with one or more of the CPLF principles. For example, a developer will follow the CPLF's Data Minimization principle when integrating Minimize Data Storage into an IoT application. In this paper, we decided to focus on the guidelines that are in line with the Data Minimization principle of the CPLF as a starting point for designing and implementing privacy-preserving components. These are as follows: (1) Minimize Raw Data Intake; (2) Minimize Data Storage; (3) Reduce Location Granularity; and (4) Category-Based Aggregation.

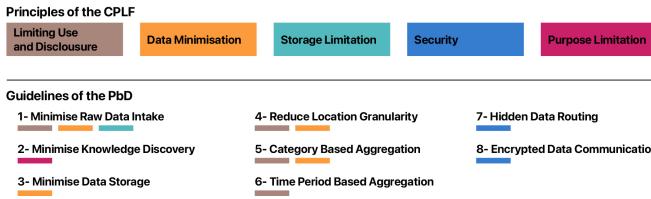


Fig. 1. The Relationship between Applying these PbD Guidelines and Compliance with the Principles of the CPLF.

III. DESIGN AND IMPLEMENTATION OF CANELLA

A. Architecture of Canella

The architecture of Canella is based on the IoT architecture in terms of how data moves through an IoT application. Typically, data moves from sensing devices to gateway devices and then to the cloud infrastructure. This pattern is usually comprised of three components, which are edge nodes, fog nodes, and cloud nodes, and these all have different computational capabilities. As shown in Figure 2, Canella utilizes two widely used community IoT development tools:

Blockly—is an open-source library developed by Google for adding block-based visual programming to an application. The Blockly editor provides a user interface and a framework to generate code using interlocking and graphical blocks [7].

Node-RED—is an open-source flow-based visual programming development tool originally developed by IBM for integrating hardware devices, APIs, and online services. It provides a browser-based flow editor to (1) drag, drop, and connect nodes in the pallets or (2) import JavaScript code [8].

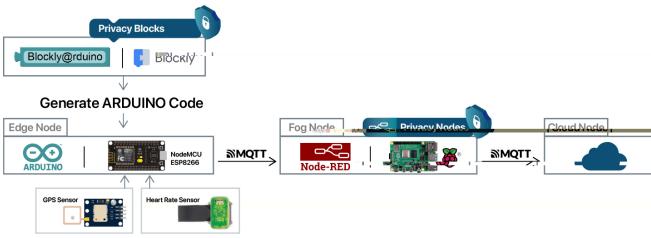


Fig. 2. Canella's Architecture.

Figure 2 depicts Canella's architecture, which particularly utilizes Blockly@rduino [9]. It is a visual programming editor based on Google's Blockly that has been forked to generate Arduino's C/C++ code. The Blockly@rduino represents the edge of an IoT application in Canella, using a microcontroller

(NodeMCU ESP8266). The Node-RED is the fog of an IoT application in Canella that performs data processing and storage. It is based on a single-board microcomputer with complex computational capabilities (the Raspberry Pi). The Node-RED can directly access data from sensors connected to an Arduino board in several ways (e.g., via a serial port number or WiFi using a protocol called MQTT). Then, the Node-RED sends the analytical information to the cloud through WiFi using the MQTT protocol for storage purposes.

Canella's goal is to help developers handle privacy issues on the edge and fog nodes of an IoT app to reduce privacy risks before data is sent to the cloud node. As a result, we created **privacy blocks** in Blockly@rduino and **privacy nodes** in Node-RED (Figure 2). Together, these privacy-preserving components help IoT developers meet privacy requirements throughout the data lifecycle when building IoT applications.

B. Design and Implementation of Privacy Components

In this section, we demonstrate the design and implementation of the PbD guidelines. In particular, each **privacy block** and **privacy node** corresponds to a specific PbD guideline that is in line with CPLF principles. We define the shape of a block, its field, and its connection points. Likewise, we specify the node's properties, edit dialog, and help text. To assist developers in protecting personal data without compromising the IoT application objective, we suggest different choices for users' data values. **Privacy blocks** and **privacy nodes** are designed to be generic enough to be used in any IoT application. Canella provides detailed information for developers about the objective of each **privacy block** and **privacy node**. In the same way, it supports information about compliance with privacy and data protection laws on each **privacy block** and **privacy node** to raise developers' awareness of privacy and data protection regulations.

Reduce Location Granularity: Granularity refers to the level of detail represented by the data. High granularity refers to detail at the atomic level, while low granularity zooms out into a summary. The dissemination of location can be considered coarse-grained, while the full address can be considered fine-grained, which poses more privacy risks. The Reduce Location Granularity performs reverse geocoding to convert longitude and latitude into a human-readable address. Accordingly, we designed its block and node to suggest to developers three GPS coordinates for reducing location granularity to a postcode, city name, or country name, requiring an API key to access the Google Maps API (Figure 3).

Minimize Raw Data Intake: IoT apps should convert raw data into secondary context data to avoid privacy violations. We designed the Minimize Raw Data Intake block to reduce the amount of raw data it receives by taking the average of the sensor data values over a specified period of time. Developers can choose different types of data to minimize as well as units of time (seconds, minutes, and hours) and are required to input a number value for a selected time to calculate the average of the data (Figure 3). In Node-RED, however, it only reduces the amount of raw data by calculating the average

of the sensor data values over the number of sensor data values, as it receives data after the user completes a particular workout. This guideline also advises building a platform that actively discourages developers from accepting raw data. In Canella, we apply this by developing warning messages in the blocks that collect sensitive (e.g., heart rate) and personal (e.g., location) data in Blockly@rduino to encourage developers to avoid accepting raw data into the application.

Category-Based Aggregation: This guideline suggests reducing the granularity of the raw data. We designed the category-based aggregation block and node to aggregate data based on its average. It suggests different types of data for developers to categorize, as well as different categories based on the data type selected. For example, to categorize heart rate data, the block and node suggest two categories: *status* (low, normal, or high), or *range* (60–80 BPM) (Figure 3).

Minimize Data Storage: This guideline suggests reducing the amount of data stored by IoT applications. We designed Minimize Data Storage to suggest different data types for developers to choose which data to delete (Figure 3). Logically, this block or node can be used once secondary contexts are derived. This can be utilized when another privacy-preserving component is added to an IoT application’s data flow.

Privacy Law Validator: A Privacy Law Validator node recognizes data practices when sending data from Blockly@rduino to Node-RED. It checks the compliance status of the received data. Three data statuses are displayed: (1) a red circle, indicating a privacy issue (the format of the received data does not comply with privacy and data protection laws); (2) a yellow circle, indicating partial compliance² with privacy and data protection laws; and (3) a green circle, indicating compliance with privacy and data protection laws.

IV. DEMONSTRATION

To demonstrate Canella, we present a fictional use case for a Fitness-Tracking IoT application. It is a helpful system that enables trainees to track their activities easily. It also assists trainers in monitoring trainees’ progress and encouraging them for their wellbeing and safety. Figure 3 demonstrates the system’s components: a wristband (with GPS and a heart rate monitor), a trainer server where trainees are registered to monitor their activities, and a cloud that is managed by a third party. Developing such an application requires privacy compliance. The challenge for developers is to integrate privacy-preserving techniques into the data flow of an IoT application during the development phase, which Canella might facilitate.

This demo will show the running Canella (Demo Video). To illustrate how Canella works, we built custom blocks for building the Fitness-Tracking IoT application in Blockly@rduino. In Node-RED, we have created a dashboard to allow trainers to track their trainees. The demo will go through the architecture of Canella, presenting the used hardware components, Blockly@rduino, and Node-RED. We will show how to use Blockly@rduino to create a Fitness-Tracking IoT application.

²Partial compliance means that there is a chance to add an extra layer of privacy-preserving techniques to the received data.

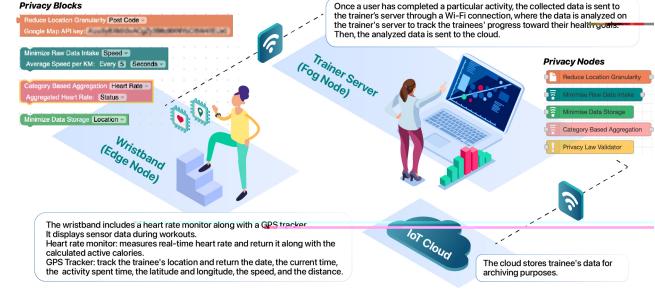


Fig. 3. Integrate *Privacy Blocks* and *Privacy Nodes* into the Data Flow for the Fitness-Tracking IoT Application During the Development Phase.

We will also demonstrate the real-time warning messages that we developed in the blocks that collect personal or sensitive data to notify developers about potential privacy issues. In addition, we will present the *privacy blocks* that we created in Blockly@rduino and how they could be added to the data flow before the data is stored in Blockly@rduino or sent to Node-RED. Then, we will show the interactivity between Blockly@rduino and Node-RED. Following that, we will present the *privacy nodes* that we have created in Node-RED as well as their edit dialogues. Furthermore, we will present the Privacy Law Validator node that could be used to check the compliance status of the received data with privacy and data protection laws. Finally, we will illustrate two examples of how to integrate the *privacy nodes* into the received data before the data is stored in Node-RED and sent to the cloud.

For instance, based on the use case, the exact location where athletes may have performed the activity is not necessary. Therefore, developers need to pick up the Reduce Location Granularity block to reduce location granularity from latitude and longitude to a postcode before sending the location to Node-RED. Once Node-RED receives the data, developers should integrate the Reduce Location Granularity node into the data flow to reduce the location granularity from a postcode to a city name before sending the data to the cloud. By doing so, the user’s data is protected, and the objective of the Fitness-Tracking IoT application is not affected.

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