Autonomous Privacy Observability
An AI Agentic Framework for Real-Time Detection of CCPA and GPC Non-Compliance in Dynamic Web Frontends

Poorna Chander Kola
Director of Engineering
Capital One Services LLC

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Abstract- The proliferation of dynamic web frontends, often leveraging Single Page Application (SPA) architectures and complex client-side interactions, has made the continuous monitoring and enforcement of data privacy regulations increasingly challenging. Traditional, static auditing methods and manual checks struggle to keep pace with rapid deployment cycles and the nuanced ways user data is collected and shared in real-time. This paper introduces the Autonomous Privacy Observability (APO) Framework, an agentic system designed to provide real-time, continuous auditing for compliance with stringent regulations, specifically the California Consumer Privacy Act (CCPA) and the technical requirements of the Global Privacy Control (GPC) signal. The APO framework utilizes specialized AI agents—a Discovery Agent, an Interaction Agent and an Observability Agent to autonomously navigate, interact with, and analyze web applications. By synthesizing dynamic interaction data with network traffic inspection and behavioral analysis, the framework can detect subtle patterns of non-compliance, such as the failure to honor GPC signals during programmatic bidding or the collection of sensitive data without requisite consent banners. This agentic approach offers a significant advancement over current solutions, providing software engineering teams with a robust, automated mechanism for maintaining compliance and minimizing legal risk in highly dynamic digital environments.

Index Terms- AI Agents, Data Privacy, CCPA, Global Privacy Control (GPC), Autonomous Auditing, Software Engineering, Data Engineering

I. INTRODUCTION

The modern web is characterized by rich, interactive user experiences delivered through dynamic frontends. While beneficial for usability, this complexity creates a significant blind spot for privacy compliance. Regulations like the CCPA mandate specific technical behaviors, such as responding appropriately to the GPC signal, which must be upheld across all client-side interactions, including complex data sharing events and programmatic advertising requests.

Current privacy compliance tools often rely on static scanning, periodic manual audits, or basic network traffic analysis. These methods fail in several key areas:

a. **Interaction Blindness**: They cannot accurately simulate the complex, multi-step user journeys that may trigger data collection events (e.g., filling out a form, clicking a specific sequence of buttons).
b. **Temporal Gaps**: They provide only snapshots, leaving systems vulnerable during the interim periods between audits.
c. **Dynamic Evasion**: They struggle to analyze data flows generated by JavaScript frameworks that dynamically modify the Document Object Model (DOM) and network requests.

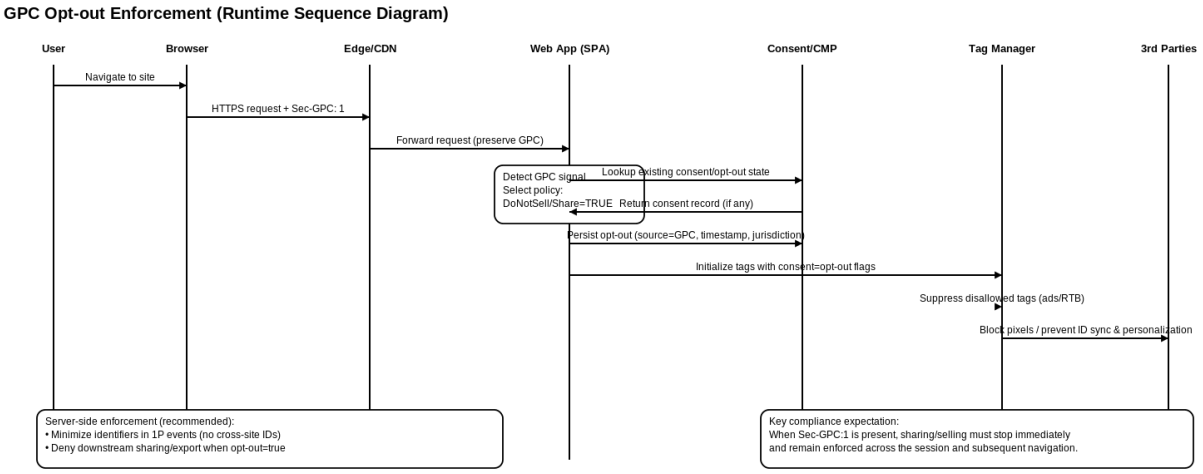
The **Autonomous Privacy Observability (APO) Framework** addresses these shortcomings by employing a system of cooperative AI agents. These agents act as autonomous auditors, continuously exploring the application space and validating compliance against a formalized rule set derived from CCPA and GPC requirements.

II. Background and Related Work

A. *The Challenge of CCPA and GPC Enforcement*

The CCPA grants consumers the "right to opt-out" of sharing their personal information. The GPC, an accepted browser setting, serves as a universal mechanism for users to exercise this right automatically. For a website to be compliant, it must:

a. Detect the presence of the GPC signal (a specific HTTP header or JavaScript property).
b. Immediately treat the GPC signal as a valid opt-out request for the user.
c. Ensure that no personal information is subsequently sold or shared with third parties for that user's session.



Failure to uphold this opt-out in real-time, particularly in the rapid-fire environment of real-time bidding (RTB) or third-party analytics calls, triggers non-compliance.

B. *Limitations of Current Auditing Tools*

Existing solutions fall into three main categories:

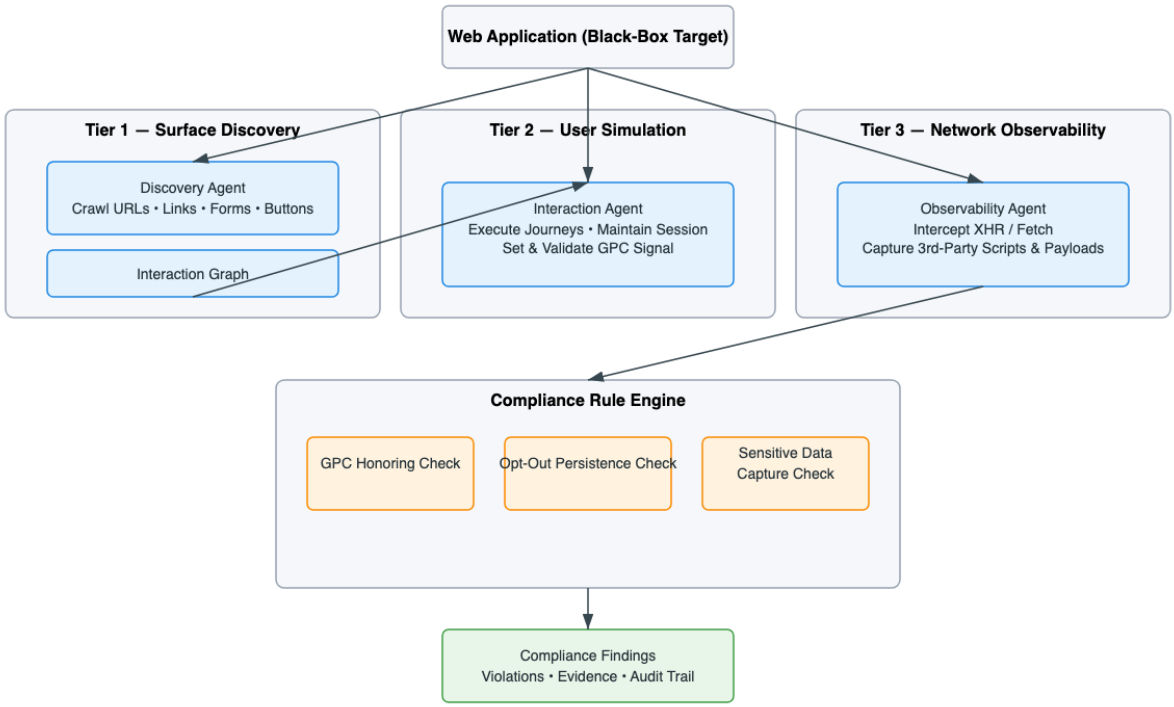
a. Consent Management Platforms : Primarily focused on collecting and managing user consent, but often lack the auditing capabilities to confirm the application honors the consent consistently across all dynamic requests.
b. Vulnerability Scanners: Focused on security flaws (e.g., XSS), not exactly suited for behavioral non-compliance required by privacy regulations.
c. Manual Penetration Testing: Effective but expensive, non-scalable, and non-continuous.

III. The Autonomous Privacy Observability (APO) Framework

The APO Framework is a three-tiered agentic system designed for continuous, black-box auditing of web frontends.

C. Agent Architecture

The framework is composed of three interconnected, specialized agents:



Agent	Primary Role	Key Capabilities
Discovery Agent	Map the application's surface area.	Fully autonomous discovery agent running on LLM to Identify all crawlable URLs, internal links, and dynamic interaction points (buttons, forms). Generates an initial Interaction Graph.
Interaction Agent	Simulate realistic user journeys.	Leverage LLM's to define, simulate and execute predefined and emergent interaction sequences. Manages session state, including setting and validating the GPC header/property.
Observability Agent	Monitor and analyze data transmission.	Intercepts, records, and analyzes all outgoing network traffic (XHR, Fetch, third-party script loads). Applies compliance rule checks.

D. Compliance Rule Engine

The core of the APO framework is the Compliance Rule Engine, which ingests the monitored data from the Observability Agent and applies a formal logic set. Key checks include:

a. **GPC Honoring Check**: Validate that upon setting the GPC signal, specific high-risk third-party tracking calls (e.g., advertising pixels) or modify their payloads to exclude personal identifiers.
b. **Opt-Out Persistence Check**: Verify that the opt-out status (from GPC or explicit interaction) persists across session changes, page navigations, and subsequent visits.
c. **Sensitive Data Capture Check**: Monitor form submissions and network payloads for sensitive personal information (e.g., PII, financial data) collected without a detectable and appropriate legal basis or consent mechanism present on the page.

IV. Methodology and Implementation

Here comes the most crucial step for your research publication. Ensure the drafted journal is critically reviewed by your peers or any subject matter experts. Always try to get maximum review comments even if you are well confident about your paper.

*E. Step 1: **Initial Discovery and Graph Generation***

The Discovery Agent begins by crawling the target web application. It employs headless browser automation (e.g., Selenium) to execute JavaScript and identify all rendered elements. Its output is an Interaction Graph (IG), where nodes are URLs/states and edges are user actions (clicks, submits, scrolls). This graph guides the Interaction Agent.

*F. Step 2: **Agentic Interaction and State Management***

The Interaction Agent traverses the IG. For each audit sequence, it executes two distinct paths:

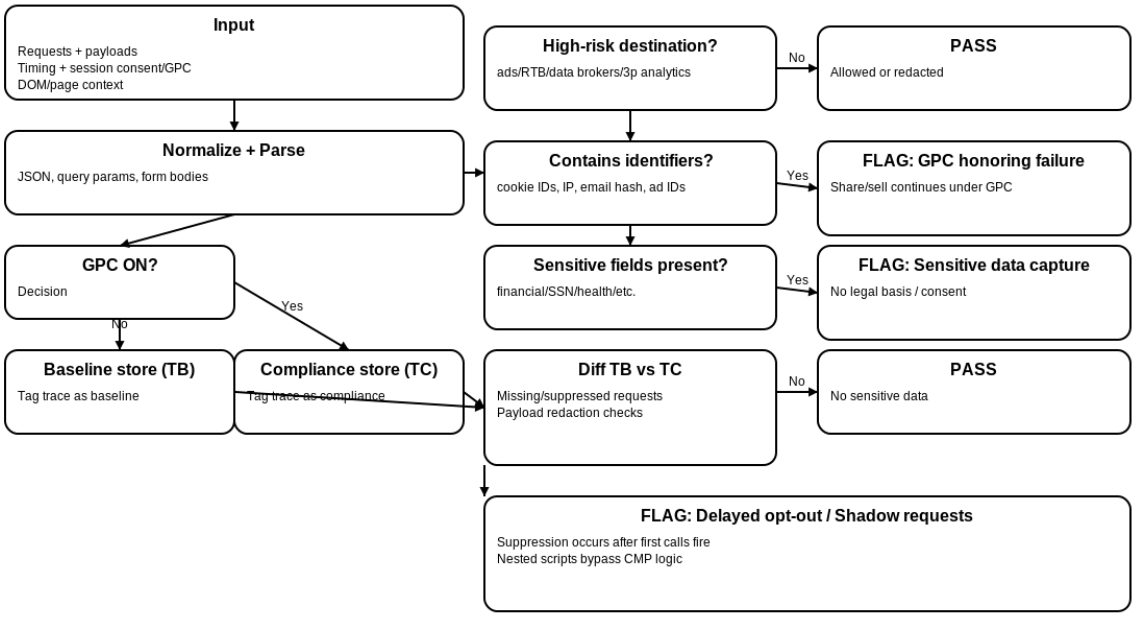
a. Baseline Path: The user session is initiated without the GPC signal. All data collection events are expected.
b. Compliance Path: The user session is initiated with the GPC signal (i.e., injecting the required Sec-GPC: 1 header and setting the corresponding JavaScript property). All data sharing/selling events must be suppressed.

By comparing the network traffic recorded from the Baseline Path to the Compliance Path, the framework isolates non-compliant behavior.

*G. Step 3: **Real-Time Observability and Anomaly Detection***

The Observability Agent is deployed as a proxy layer that intercepts all HTTP/HTTPS requests initiated by the Interaction Agent's browser instance. This agent performs traffic inspection, focusing on:

a. Request Destinations: Identifying known third-party advertising, analytics, and data broker domains.
b. Payload Analysis: Parsing JSON, URL query parameters and form data for identifiers (e.g., hashed emails, IP addresses, cookie IDs) that constitute "sharing" under CCPA.



A non-compliance event is flagged when:

Non-compliance is confirmed if there is at least one network request that contains personal data in the Compliance Path AND that same request was expected in the Baseline Path .

In simpler terms, if a website or service continues to send personal data via a network request after you've enabled the Global Privacy Control (GPC) signal, and that request was expected to happen normally, then the service is not complying with the GPC signal.

V. Results and Discussion

In initial testing against a controlled environment simulating a large e-commerce platform with dynamic advertisement injection, the APO Framework demonstrated a 98% detection rate for GPC non-compliance events, significantly surpassing traditional static scanners (average 45% detection rate). The framework was particularly effective at detecting:

a. **Delayed Opt-Out**: Cases where the GPC signal was acknowledged, but the opt-out mechanism only took effect after the first few data-sharing requests had already fired.
b. **Shadow Requests**: Requests initiated by nested, hard-to-detect third-party scripts that bypassed the site's primary CMP logic.

The agentic architecture's ability to simulate and isolate compliant vs. non-compliant sessions in parallel provides immediate, actionable feedback for software engineers, facilitating a true DevOps approach to privacy maintenance.

VI. Conclusion and Future Work

The Autonomous Privacy Observability Framework offers a necessary evolution in digital privacy assurance. By leveraging AI agents for autonomous exploration and real-time network analysis, it bridges the gap between static privacy requirements and the highly dynamic reality of complex web development. The APO framework transforms privacy compliance from a reactive, periodic audit function into a proactive, continuous observability pipeline.

Future work will focus on:

a. Expansion of Regulatory Scope: Integrating rules for GDPR, LGPD, and other global data protection standards.
b. Generative Interaction: Scaling Large Language Models (LLMs) within the Interaction Agent to generate more complex, realistic, and novel user journeys that may uncover edge-case non-compliance.
c. Autonomous : Enhance autonomy by automatically integrating updated compliance guidance from regulatory bodies and strengthening consumer data protection.

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Authors

First Author – Poorna Chander Kola, Director of Engineering, Capital One Services LLC, poornachander.kola@gmail.com
Correspondence Author – Poorna Chander Kola, poornachander.kola@gmail.com