Hardware Keystores for AI Agent Signing

A Zero-Trust MCP Enforcement Architecture

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Introduction

AI agents are moving from passive assistants to active operators. They now read documents, call tools, commit code, approve workflows, and trigger cryptographic actions on behalf of users.

- Signing is especially sensitive because a signature gives **authority** and **trust** to whatever the agent approves.
- Traditional keystore designs were built for deterministic applications, not **language-driven agents** interpreting open-ended tasks.
- This project redesigns signing as **a zero-trust workflow** where every cryptographic request is independently checked before the key is used.

The Threat

The main risk is the gap between what the user **intended** and what the agent eventually **tries to execute**, especially when the task involves external documents or messages.

- **Malicious instructions** can be **hidden inside content** the agent is expected to process, such as an email, contract, or fetched page.
- The agent may treat those instructions as part of the task and attempt to **sign a different payload** than the one authorized.
- The system therefore treats external content as untrusted and **verifies every tool** call against policy, context, and user intent.

Our Solution

We place a dedicated **MCP enforcement server** between the agent and the hardware keystore, so the agent can request signatures but cannot directly **reach the signing key**.

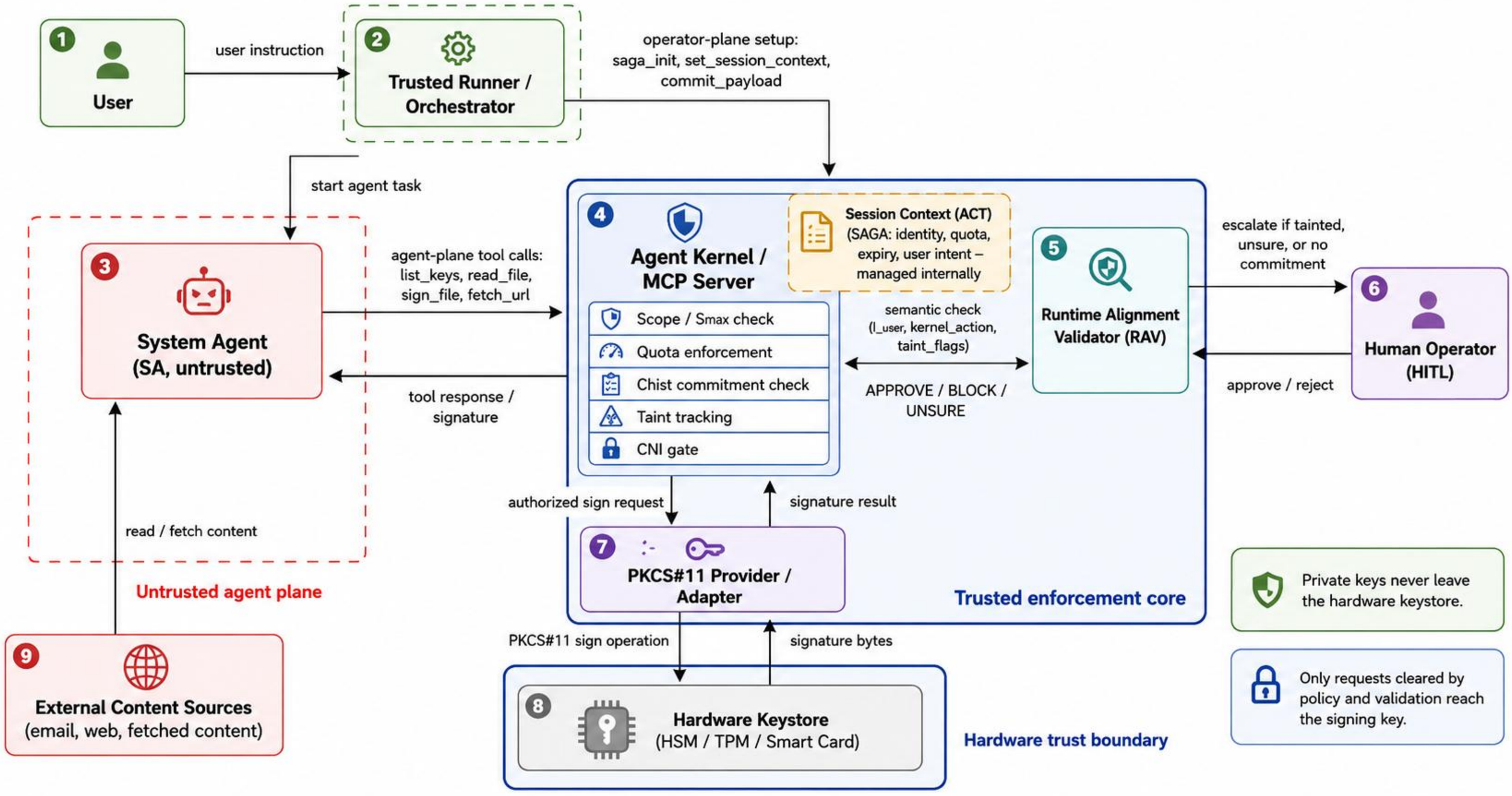
- The stack combines identity registration, short-lived cryptographic sessions, scope checks, quotas, payload commitments, and taint tracking.
- A Runtime Alignment Validator handles semantically ambiguous requests by comparing the requested **action** with the user's **intent.**
- Only requests cleared by the enforcement stack are forwarded to the hardware keystore through opaque key handles.

Hardware Key Protection

The main security guarantee is simple: the private key **never leaves** the hardware-backed keystore and is **never exposed** to the agent as a file, string, or memory object.

- The agent can ask for a signature, but it cannot read, copy, export, or transmit the underlying key material.
- Key exfiltration attacks are eliminated **architecturally**, rather than detected after the fact.
- The design follows the **PKCS#11 interface**, allowing the same enforcement logic to run with different hardware-backed keystore implementations.

System components and interactions in the zero-trust keystore architecture



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