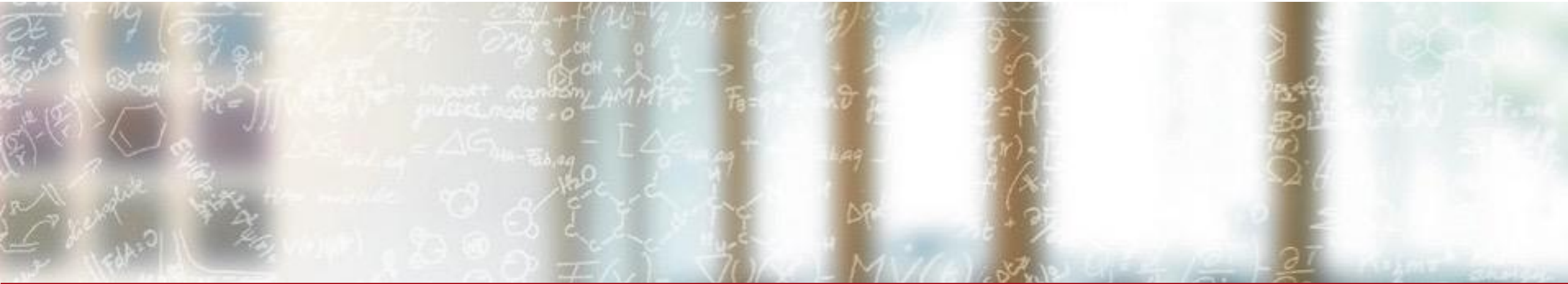




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Operationalizing Security in Dynamic HPC Infrastructures (Lessons from CSCS Alps)

17th Annual HPC-AI Swiss Conference, Locarno

Matteo Basso (ETH Zurich/CSCS)

April 23, 2026

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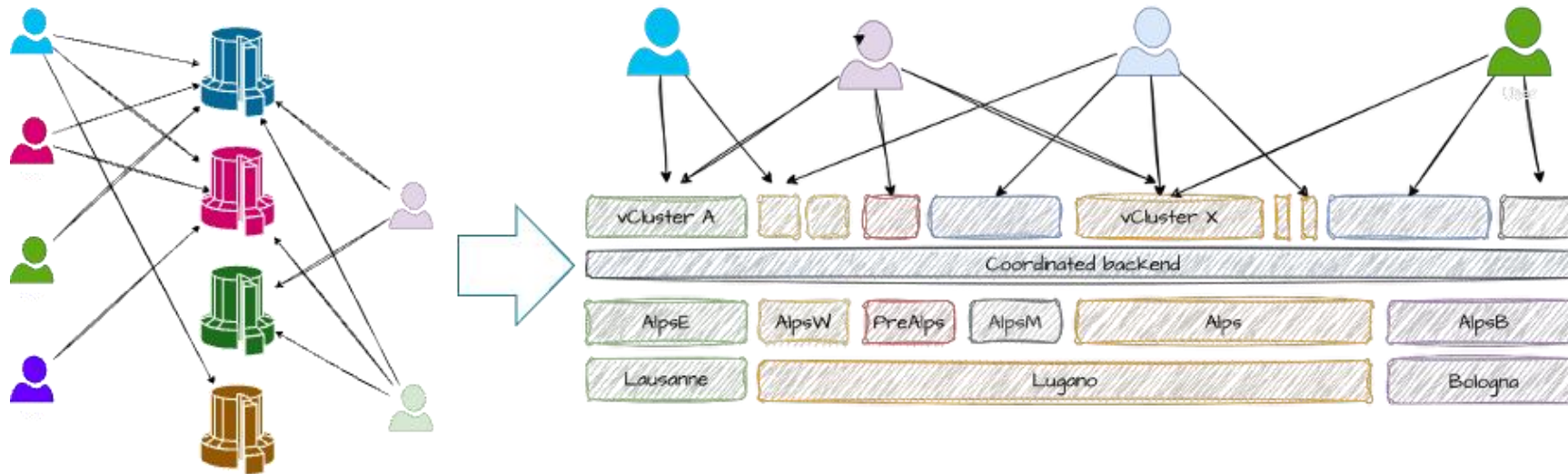
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Context & Motivation

Securing Software-Defined Alps HPC Infrastructure

- **The Shift:** From monolithic clusters to software-defined ecosystems
- **The Challenge:** Diverse tenants, automated pipelines, and evolving service stacks
- **The Requirement:** Security must be as "dynamic" and "versioned" as the infrastructure itself



HPC Security: Before vs. Now

Before

- Static jump hosts - single external boundary
- Monolithic OS image across all nodes
- One CVE surface - one patch cycle
- Simple threat model: SSH brute-force, credential stealing
- HIDS on jump hosts + perimeter firewall
- Centralized audit logging covered most scenarios



Now

- ⑩ Fleet of independently-configured vClusters
- ⑩ Each vCluster may contain different packages, users
- Each vCluster evolves differently, the CVE surface grows and fragments
- ⑩ IaC/laaS pipelines introduce a supply-chain risk
- ⑩ Multi-regulatory policies based on vCluster



Operational Reality & Constraints

- Performance First
 - Zero/minimal jitter on compute nodes; "Agent-light" preferred
- Scale vs. Team
 - Small security teams must manage large fleet
- Evidence-Based
 - Compliance (NIS2/CRA/ISO) requires queryable, live data & not manual reports



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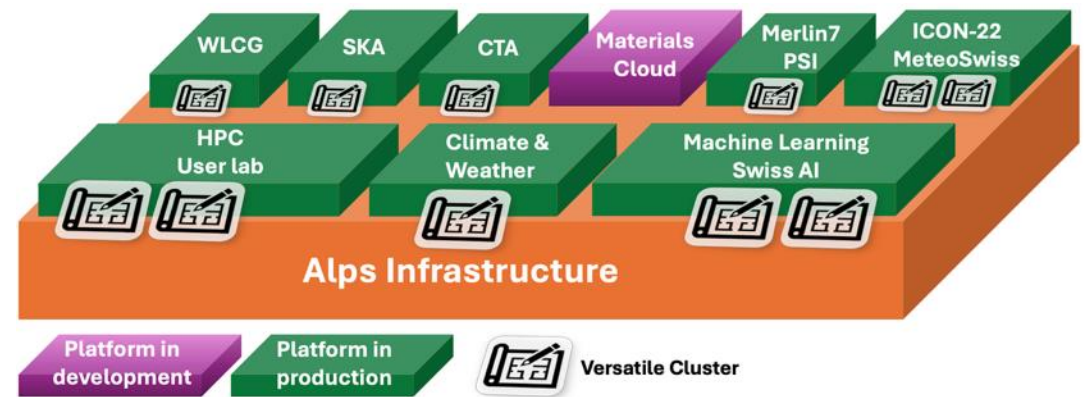
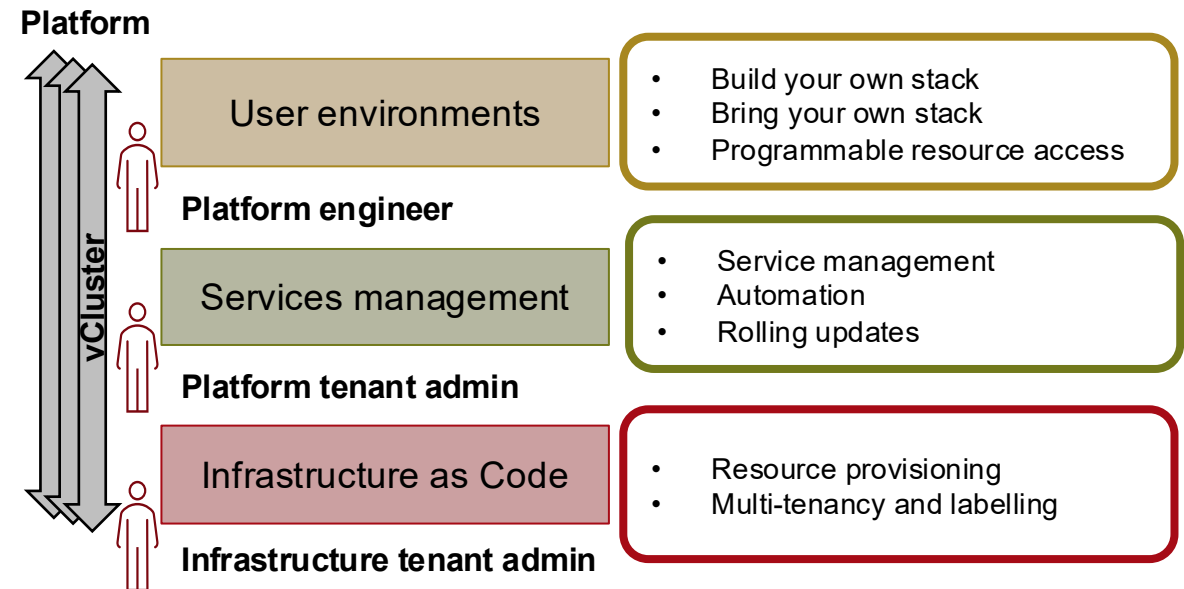
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Threat Model Shift & Architecture

CSCS Alps vCluster Model

- In CSCS Alps, vClusters provide tenant-specific clusters on shared bare-metal hardware
- A vCluster is a logical partition defined through code
- Each vCluster is instantiated from IaC/laaS pipelines specifying OS images, services, configuration, and access policies
- Base images are immutable and versioned: patches and updates create new versions
- vClusters share the same network fabric, with potential logical isolation between tenants
- They can be created & decommissioned on demand
- vCluster are evolving independently → Security must be designed to handle diversity and constant changes



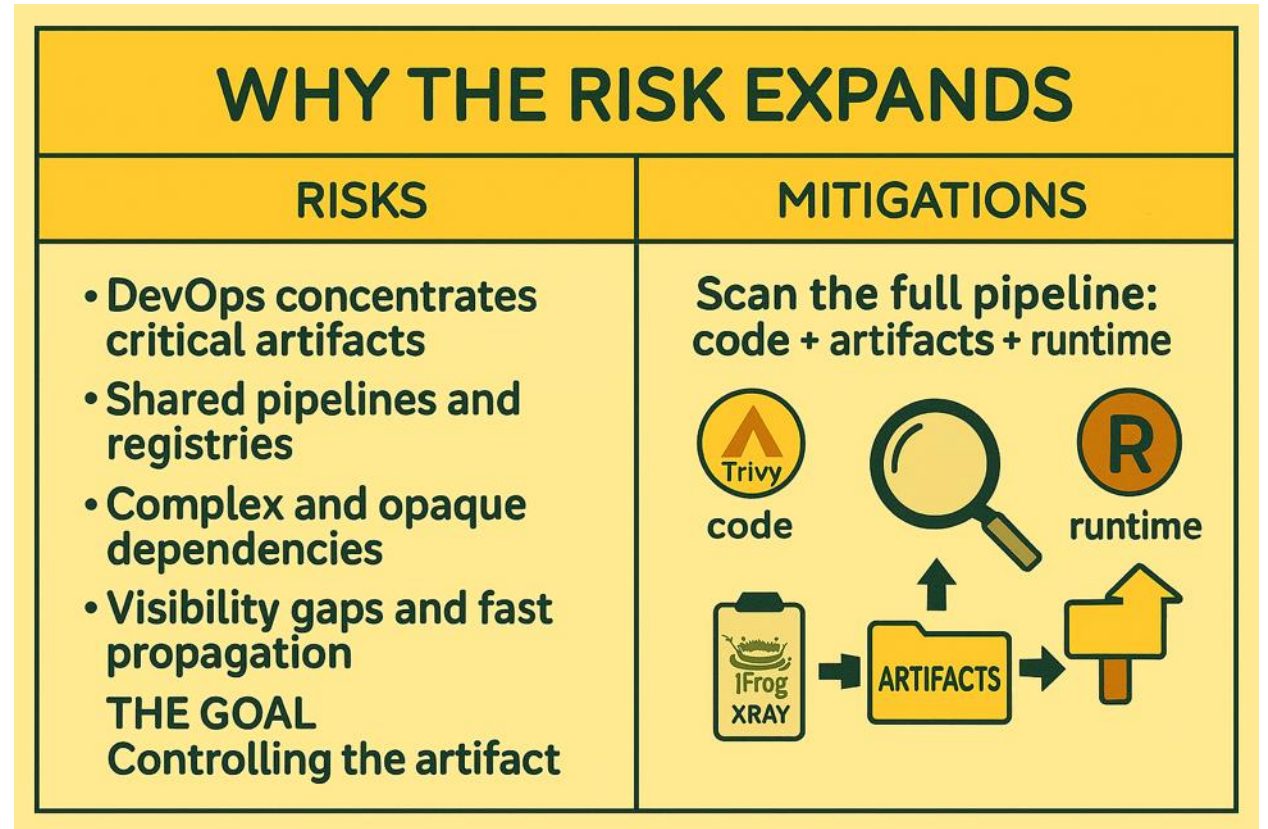
Security Impact of vClusters

- The security perimeter is split across many tenants
 - Independent OS, kernels, and packages create multiple concurrent CVE baselines
- Controls are no longer universal
 - IDS rules, FIM scopes, and benchmarks must be tuned per vCluster; one baseline can create noise or miss issues in another
- Access controls needs monitoring
 - When operations are delegated, access and actions must be auditable everywhere
- Security is no longer global, it becomes per-vCluster and continuously evolving



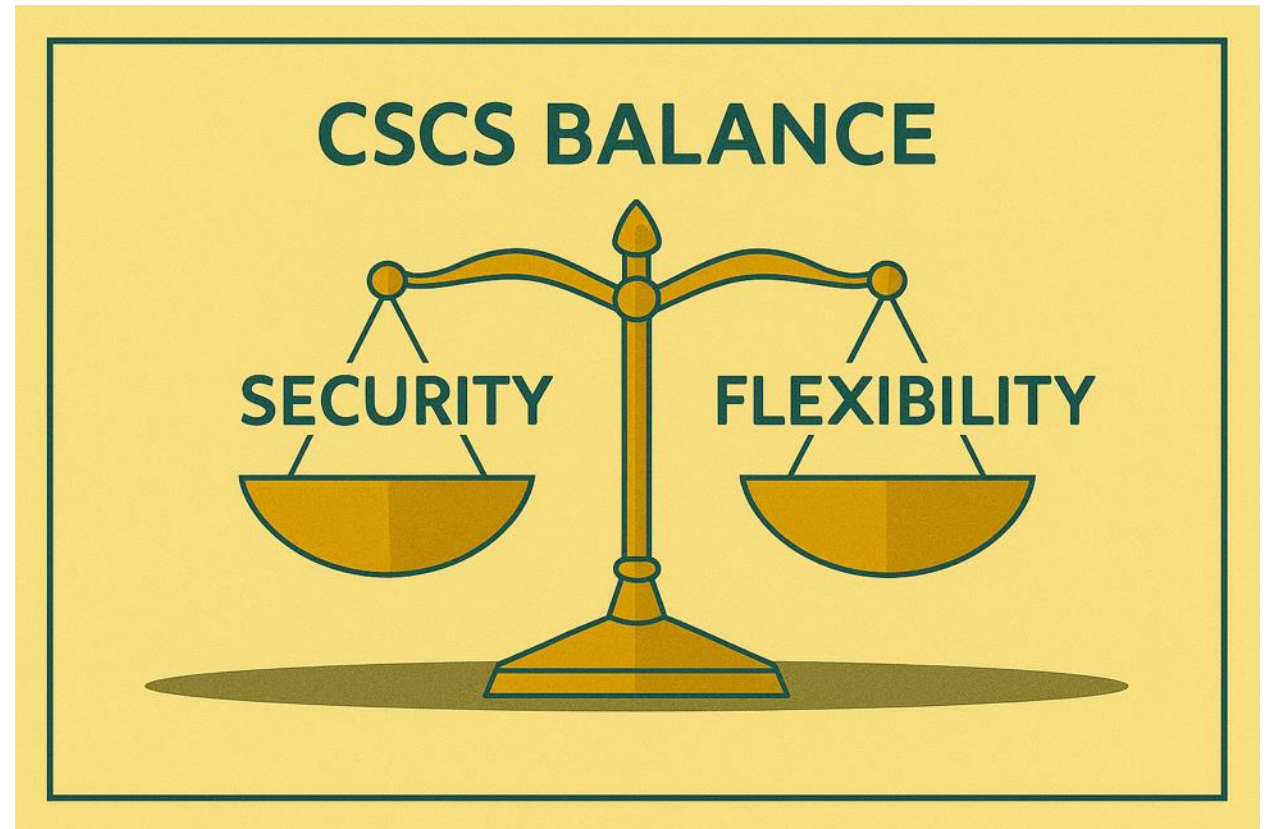
Supply-Chain Risk Blind Spot

- **The Goal:** Controlling the artifact before it hits the fabric



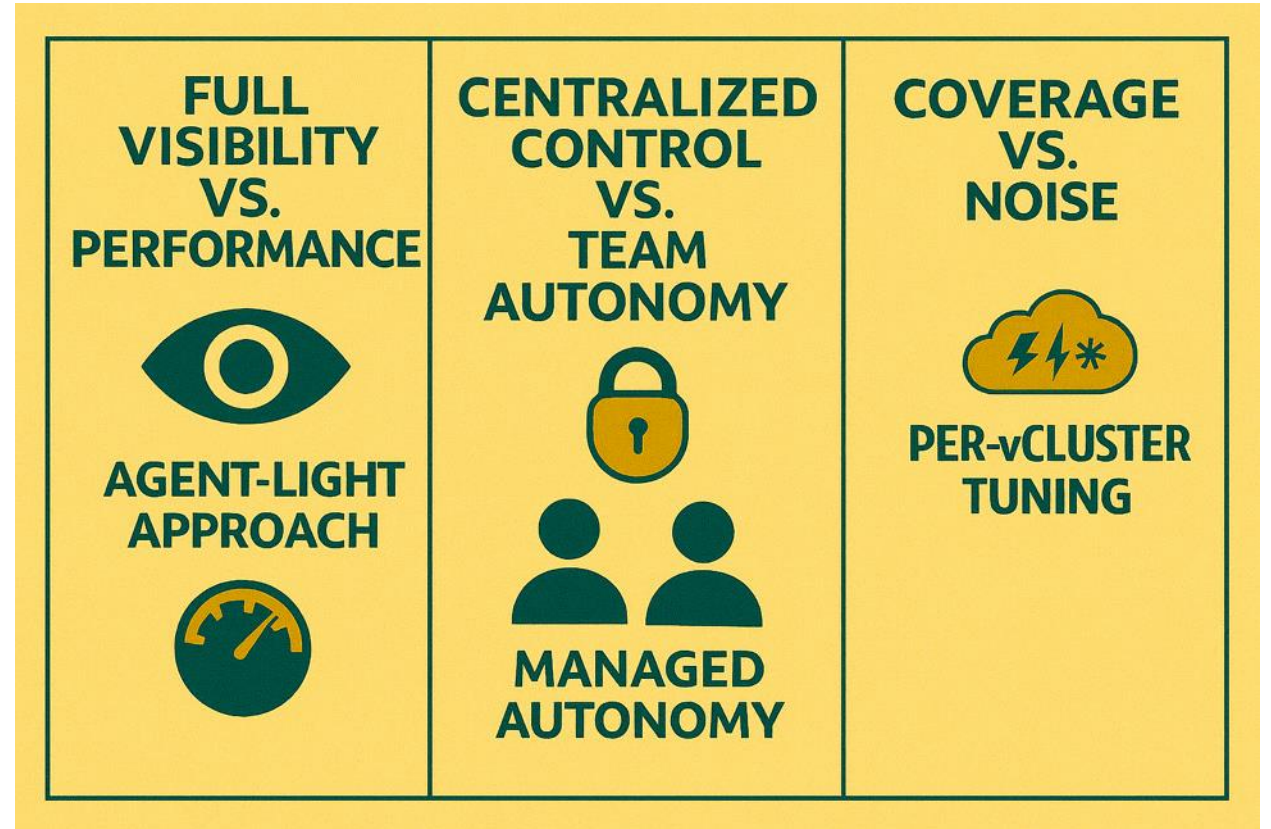
Security Must Scale Horizontally

- Automation & Standardization
 - vClusters, vServices, services, and tenants gets the rights security controls automatically
- Balance between security and flexibility
 - Team managing the vCluster run their own environments freely → Security team keeps visibility through shared tools
- Evidence comes for free
 - Security controls record what they do automatically, giving the evidence for compliance and incident response



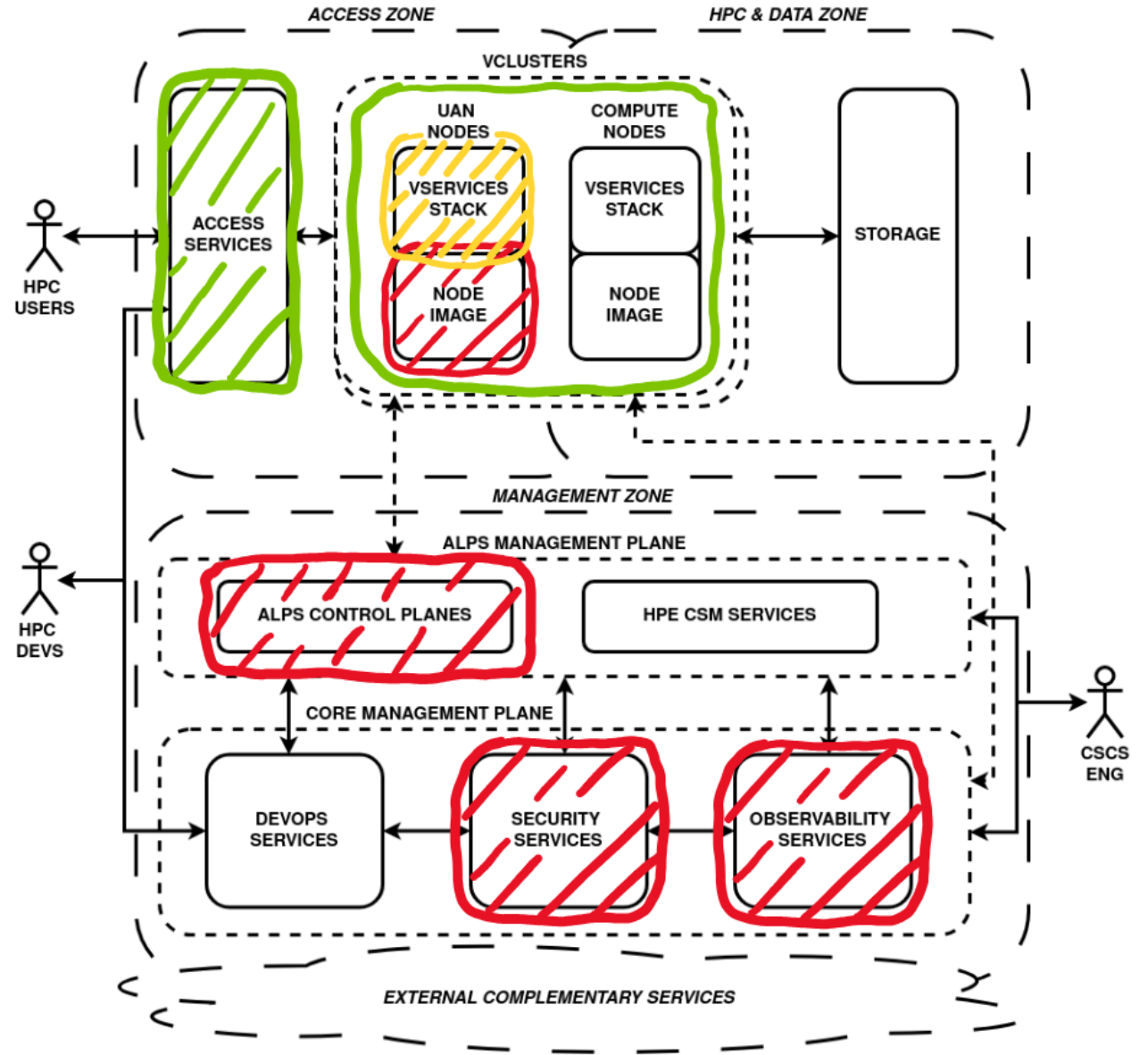
Architectural Principles

- Full visibility vs. Performance
 - we chose agent-light approach
- Centralized controls vs. Team autonomy
 - we chose managed autonomy
- Coverage vs. Noise
 - we chose per-vCluster tuning



Security Architecture Overview

- Security vService
- SIEM Platform
- Vulnerability Management
- Compliance Validation





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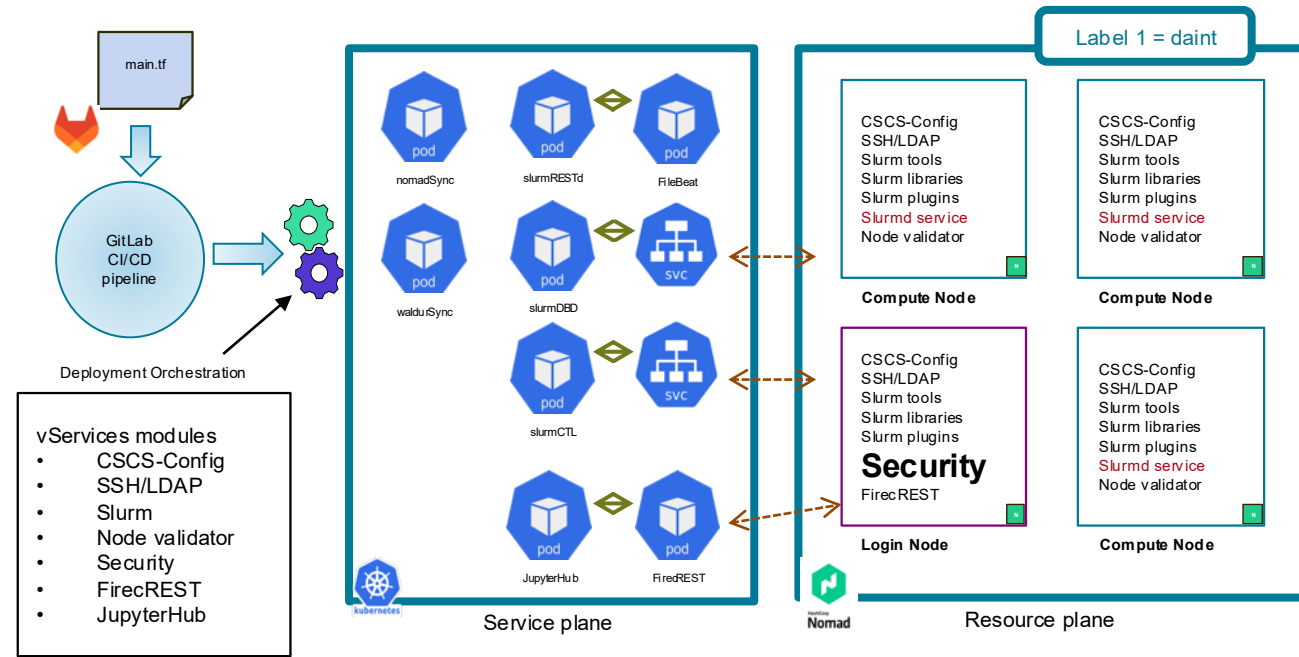
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Implementation

Security vService

- Versioned IaC security bootstrap
 - A reusable deployment unit that automates security setup across vClusters
- Complete monitoring at provisioning
 - Wazuh & Tenable.SC agents installed
- Rapid critical patch pipeline
 - 0-Day patches pushed as temporary solution
- Easily reproducible (eg. Ansible Playbook)
- Handles ~11 vClusters / ~30 login nodes (production scale)

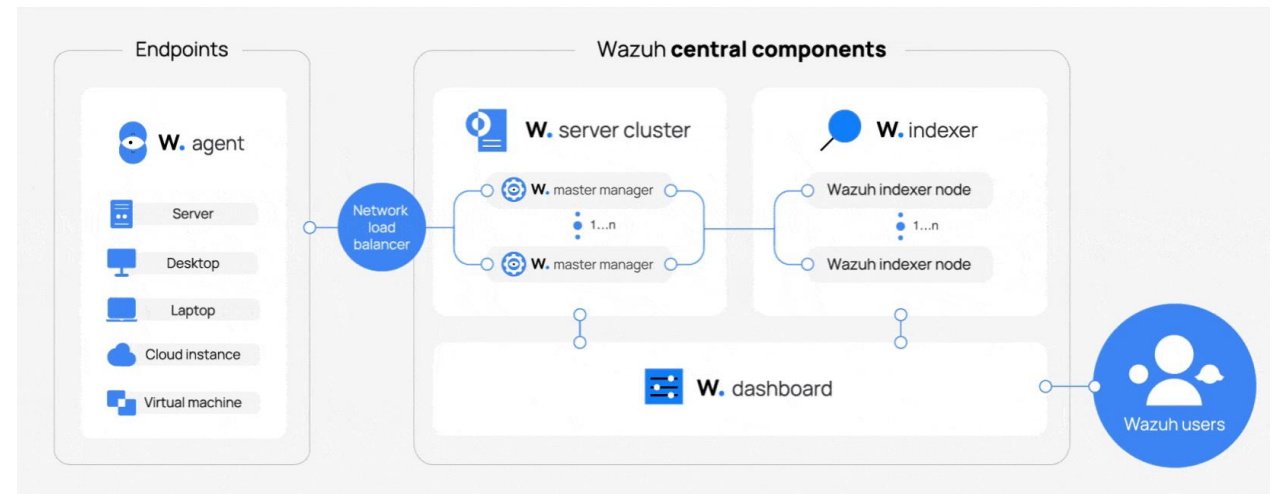


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2 - name: Install Tenable agent for x86_64
3   include_tasks: tenable-agent-x86.yml
4   when: ansible_architecture == "x86_64"
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6 - name: Install Wazuh agent for x86_64
7   include_tasks: wazuh-agent-x86.yml
8   when: ansible_architecture == "x86_64"
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10 - name: Install Wazuh agent for
11   include_tasks: wazuh-agent-a
12   when: ansible_architecture =
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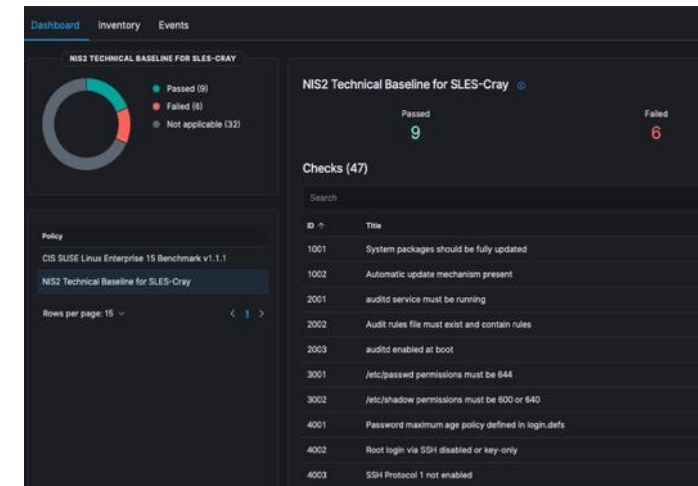
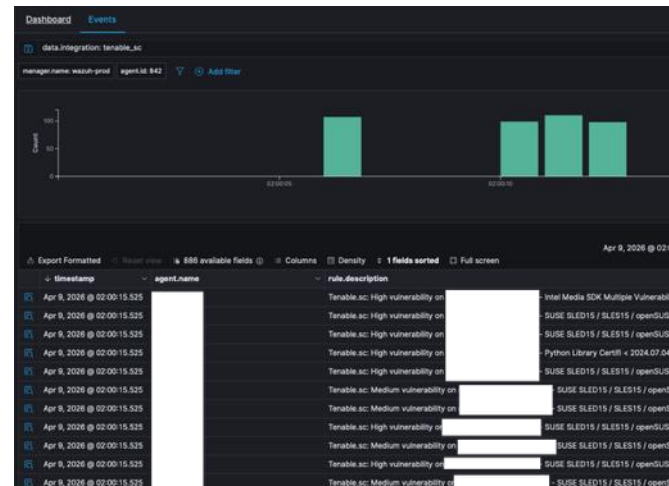
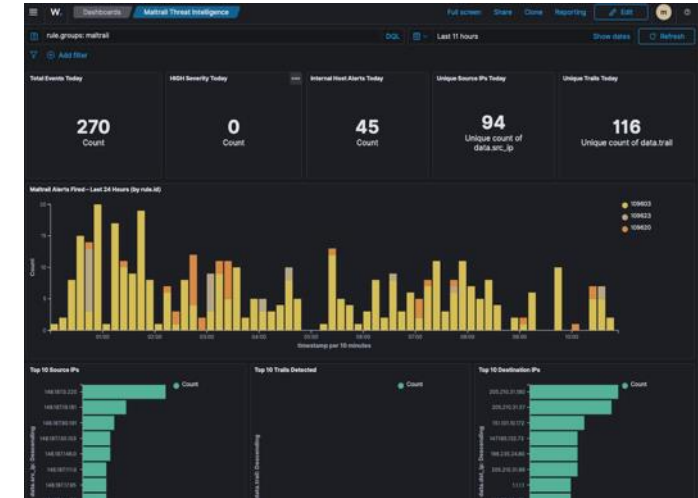
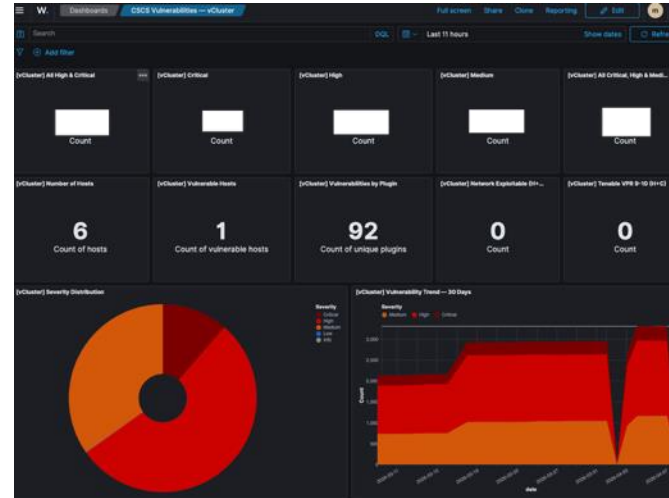
SIEM – Why Wazuh?

- One lightweight agent
 - One lightweight agent does it all, overhead and operational complexity low.
 - Agent overhead: ~1-2% CPU (observed)
- HPC-Friendly detection
 - OSSEC based, but flexible enough to avoid HPC false positive and allow custom rules.
- Scalable backend
 - OpenSearch lets us search and slice the data flexibly
- OpenSource and highly configurable



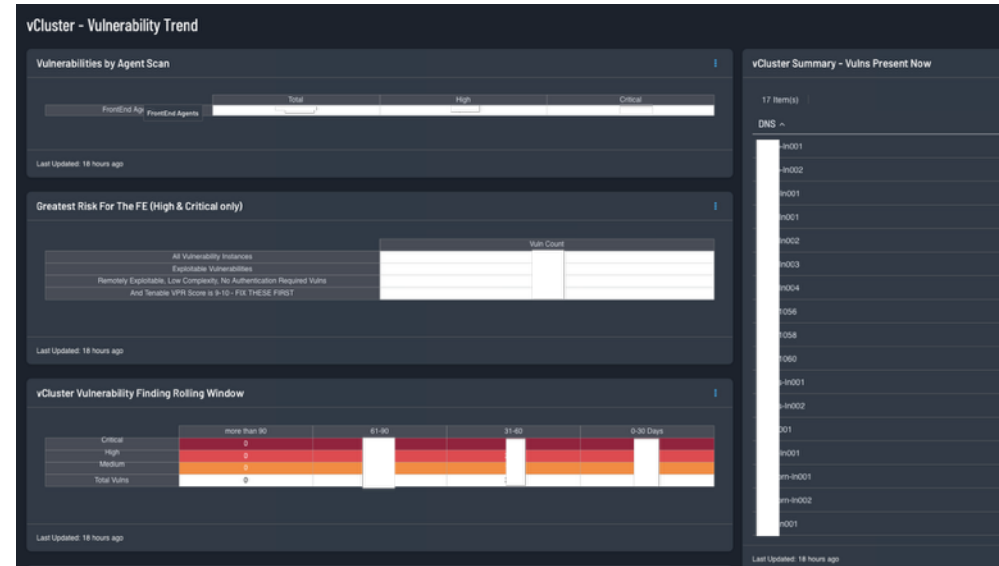
SIEM In Practice

- Central Event Aggregation/Correlation
 - Wazuh agent events from UAN
 - Ingestion from other tools
- Detection & Response
 - SSH Brute-force
 - FIM and anomalous processes
 - MITRE ATT&CK
- Ownership routing
 - Notifications can go to the team
 - Dedicated dashboards
- Tailored configuration per vCluster
- Ad-hoc compliance checks
 - e.g. NIS2, HIPAA



Vulnerability Management

- Know what you have, then fix it
 - Tenable.SC gives authoritative view of each vCluster, tracks issues over time
- Static & Runtime Vulnerability Checks
- SIEM integration and ingestion
 - API ingestion enriches SIEM, new correlation



```
#-----  
def send_to_wazuh_socket(agent_id, agent_name, agent_ip, event: dict):  
    """  
    Inject event directly into the Wazuh queue attributed to a specific agent.  
    The manager will process it as if it came from that agent.  
    Wazuh queue format:  
    1:[agent_id] (agent_name) agent_ip->location:message  
    """  
    try:  
        msg = json.dumps(event)  
        header = f"1:[{agent_id}] ({agent_name}) {agent_ip}->tenable_sc:"  
        full = f"{header}{msg}"  
  
        sock = socket.socket(socket.AF_UNIX, socket.SOCK_DGRAM)  
        sock.connect(WAZUH_SOCKET)  
        sock.send(full.encode("utf-8"))  
        sock.close()  
        return True  
    except Exception as e:  
        logging.warning(f"Socket send failed for {agent_name} ({agent_ip}): {e}")  
        return False
```

The screenshot shows the 'Vulnerability Summary' dashboard. It includes a search bar, filters for 'DNS Name', 'Address', 'Plugin Name', and 'Severity', and a table of 205 results. The table columns are 'Plugin ID' and 'Name'. The results list various security updates for SUSE SLED15 / SLES15 / openSUSE 15.

| Plugin ID | Name |
|-----------|--|
| 197702 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : perl (SUSE-SU-2024:1762-1) |
| 201905 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : krb5 (SUSE-SU-2024:2302-1) |
| 202250 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : libvpx (SUSE-SU-2024:2409-1) |
| 206566 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : bubblewrap and flatpak (SUSE-SU-2024:3104-1) |
| 213064 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : libaom, libyuv (SUSE-SU-2024:4333-1) |
| 242865 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : MozillaFirefox, MozillaFirefox-branding-SLE (SUSE-SU-2024:4333-1) |
| 243535 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : sqlite3 (SUSE-SU-2025:02672-1) |
| 301289 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : mozilla-nss (SUSE-SU-2026:0813-1) |
| 301809 | SUSE SLED15 / SLES15 Security Update : ImageMagick (SUSE-SU-2026:0853-1) |
| 271844 | SUSE SLES15 Security Update : xen (SUSE-SU-2025:3797-1) |
| 271802 | SUSE SLED15 / SLES15 / openSUSE 15 Security Update : mozilla-nss (SUSE-SU-2025:3804-1) |

Compliance as Code - ReFrame

- Baseline as executable tests
 - Continuous compliance with ReFrame¹
- Standard & Custom requirements
 - The test library covers standards and custom controls, each tagged by severity scope
 - ANSSI bp-028 enhanced, STIG DoD, custom
- Validation in the workflow
 - Check early, validate changes, prove compliance when needed

ETH Data Classification Level: **CONFIDENTIAL**

System Health Check

System: **nid00XXXX**

Summary [Check Results](#) [Disclaimer](#)

Security Tests Profile

| | | | | |
|-----------|------|----------------|-------------------------------|------------------------|
| nid00XXXX | root | 215.3 s | 4.10.0- dev.0+8858b80 5 | 2026-01-09 11:06:37 |
| Hostname | User | Execution Time | Reframe Version | Execution Date |

Test Execution Summary

| | | | | |
|-------------|-----------|--------------|--------------|--------------|
| 965 100% | 0 0.0% | 454 47.0% | 164 17.0% | 347 36.0% |
| Total | Aborted | Failure | Skipped | Success |

1. Victor Holanda Rusu et. al. 2025, doi:10.1145/3757348.3757351

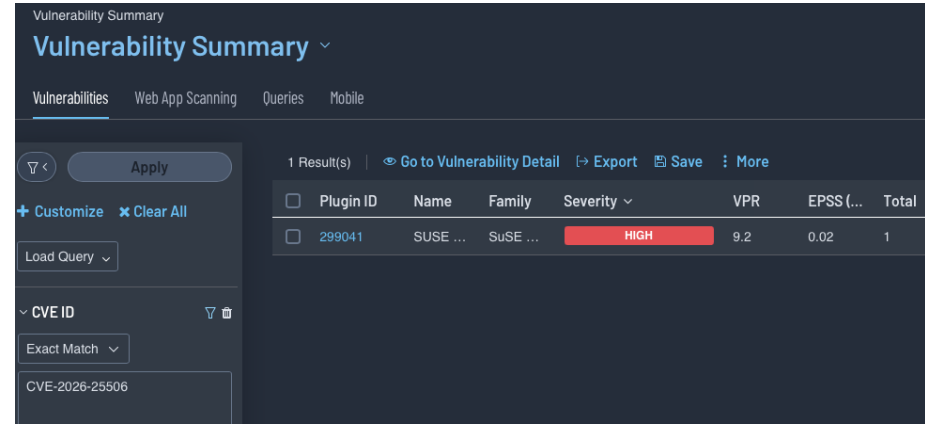
Compliance Alignment

- Swiss Information Security Act : real time reporting with the SIEM
- NIS2 & Cyber Resilience Act : monitoring and supply chain
- ISO/IEC 27001 process alignment

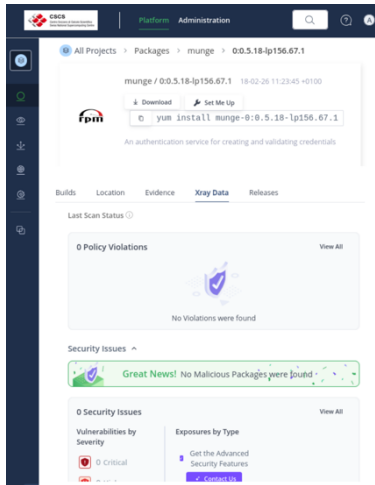
In Practice: Munge Vulnerability Workflow



SIEM/Wazuh – Detection



Vuln Manag/Tenable.SC Check



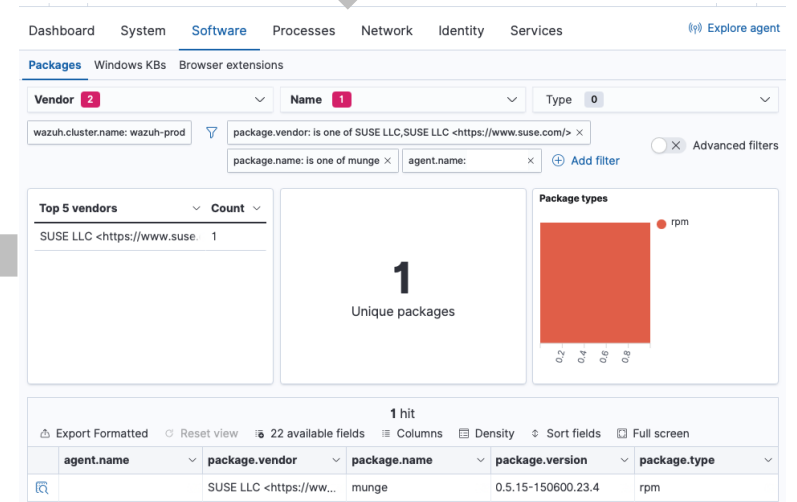
Jfrog Xray

```

# pkgs_to_update = ["vim", "curl", "openssl"] --> update vim, curl
pkgs_to_update: [ "munge" ]

- name: Updating critical packages with 0-days
  community.general.zypper:
    name: "{{ pkgs_to_update }}"
    state: latest
    extra_args: "--from jfrog-opensuse-15.5"
    when: pkgs_to_update is defined and pkgs_to_update | length > 0
    
```

Security vService 0-Day Pipeline



SIEM/Wazuh IT Hygiene Dashboard



CSCS

Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

ETH zürich

Conclusion

Key Takeaways

- Security vService
- SIEM Platform
- Vulnerability Management
- HPC-aware Tools
- In software-defined HPC, security becomes part of the control plane, not an external layer

Future Work & Vision

- Evidence-Based Compliance
 - Formalize operational metrics to make audits fully queryable and verifiable in real-time
- Upstream Security
 - Move controls into developer env; unify SBOM, CI/CD, and artifact signing pipelines
- Deep Integration
 - Extend SIEM correlation to K8S control planes, storage, and network telemetry
- Continuously Security Integration
 - Consolidate reporting in Grafana
 - Integrate MarmotGraph
 - RAG-driven security insights
 - eBPF integration in vService

Q&A

- Any question?

CSM?

- Collecting audit logs and analyzing them
- Difficult to have it now into the architecture
- Moving to ochami? Ready and working on it