Transparent Web Service Auditing via Network Provenance Functions

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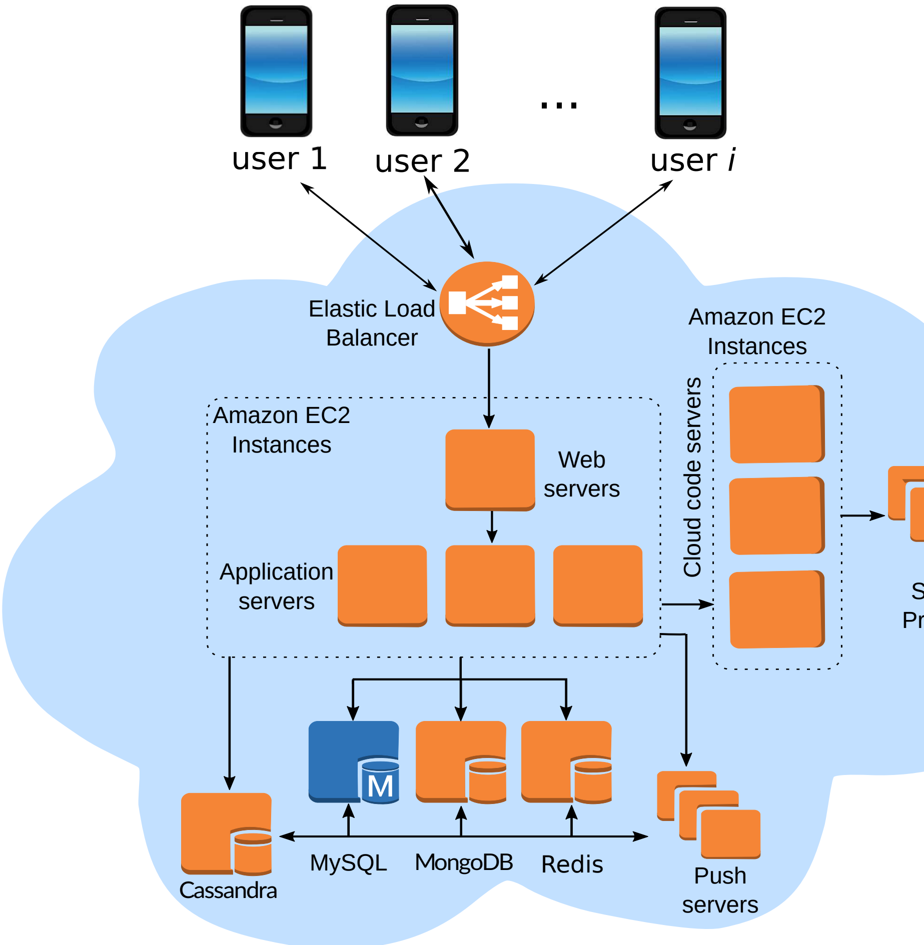
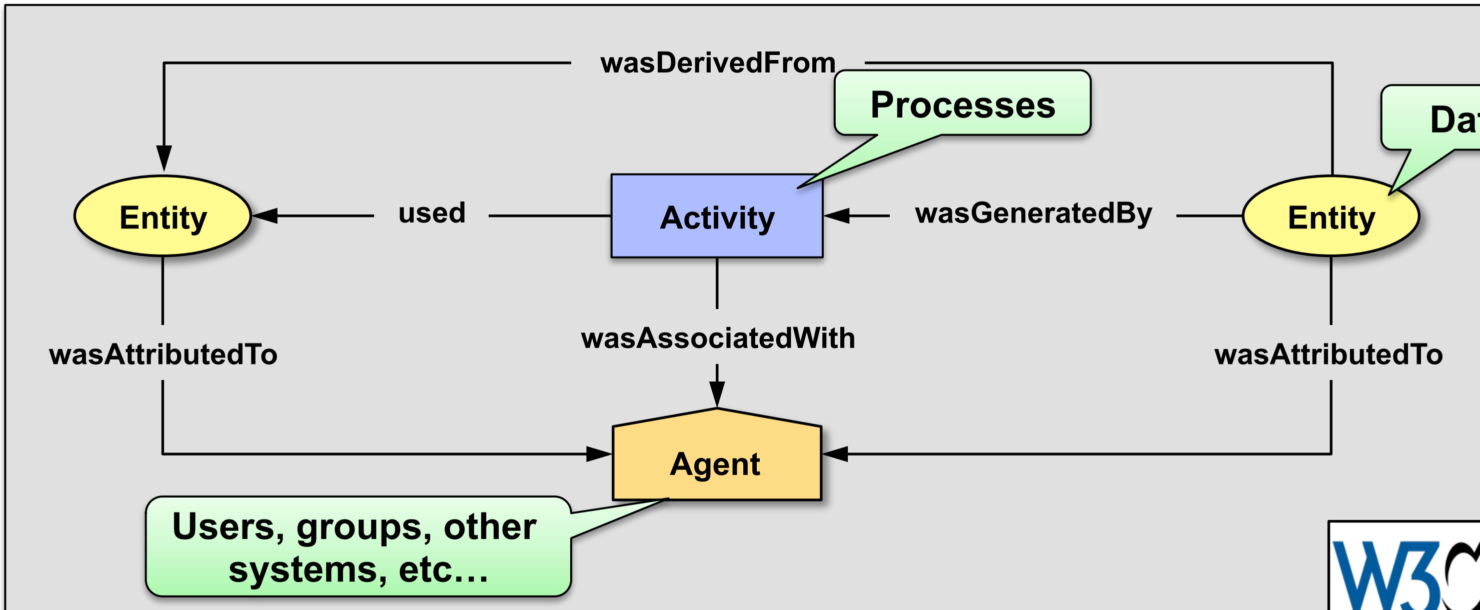
Motivation

- Typical cloud-based web application
  - Deployed in the cloud
  - Running services on different nodes
  - Complex interactions
- Attack occurs
  - How to track impact through application?
- Defenses often focus on network boundaries, not internal services



Data Provenance

Data provenance is the history of ownership/processing to guide authenticity



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Data provenance helps to answer:

- Where are all my data?
- Where did they come from?
- Are the data secure and trustworthy?
- How to recover after being attacked?

Goals

Complete

System must offer a complete description of requests that flow through the web service

Integrated

System must combine provenance from different software components into complete record

Widely Applicable

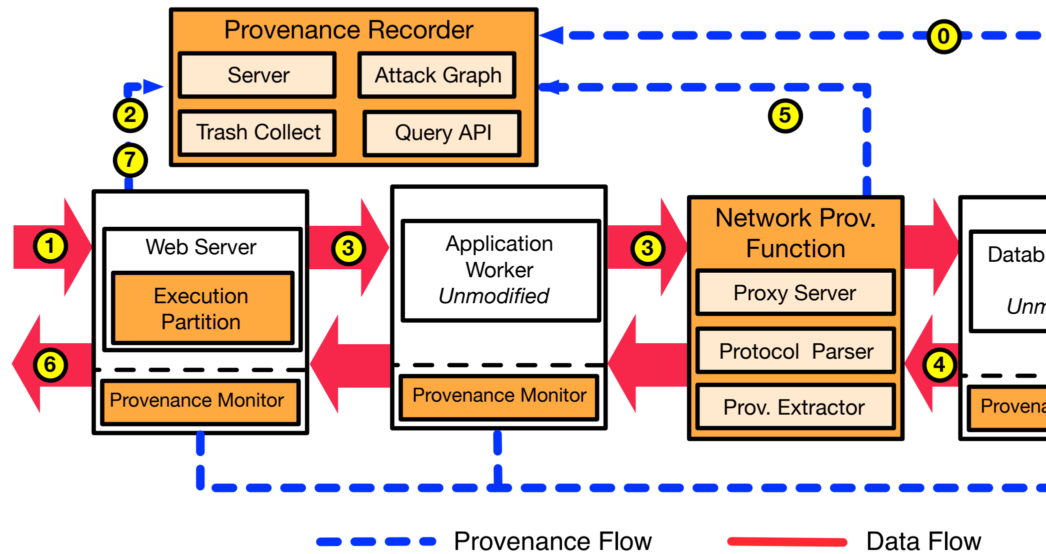
Should not be limited to a particular application, backend component, or architecture

Threat Model

- **Attacker assumptions**
  - **Launch network attacks against applications and underlying infrastructure**
- **Goals**
  - **Command injection, e.g. SQL injection attacks against DB**
  - **Data exfiltration or injection**
  - **Gain foothold in system for further attacks, such as lateral movement**
- **Trust assumptions**
  - **Applications are vulnerable to compromise**
  - **At least one record of adversary access attempt is recorded before successful compromise**

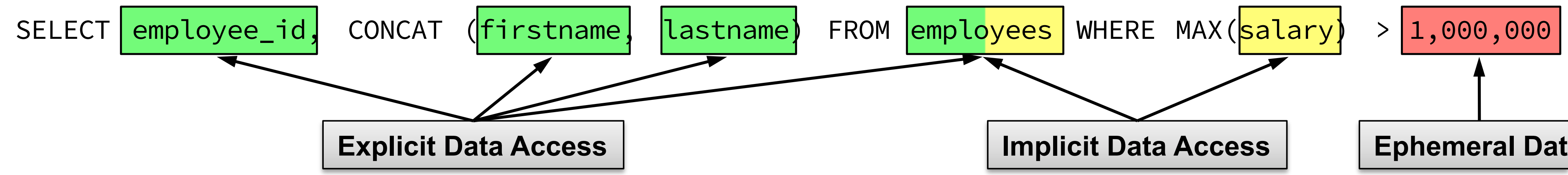
System Design

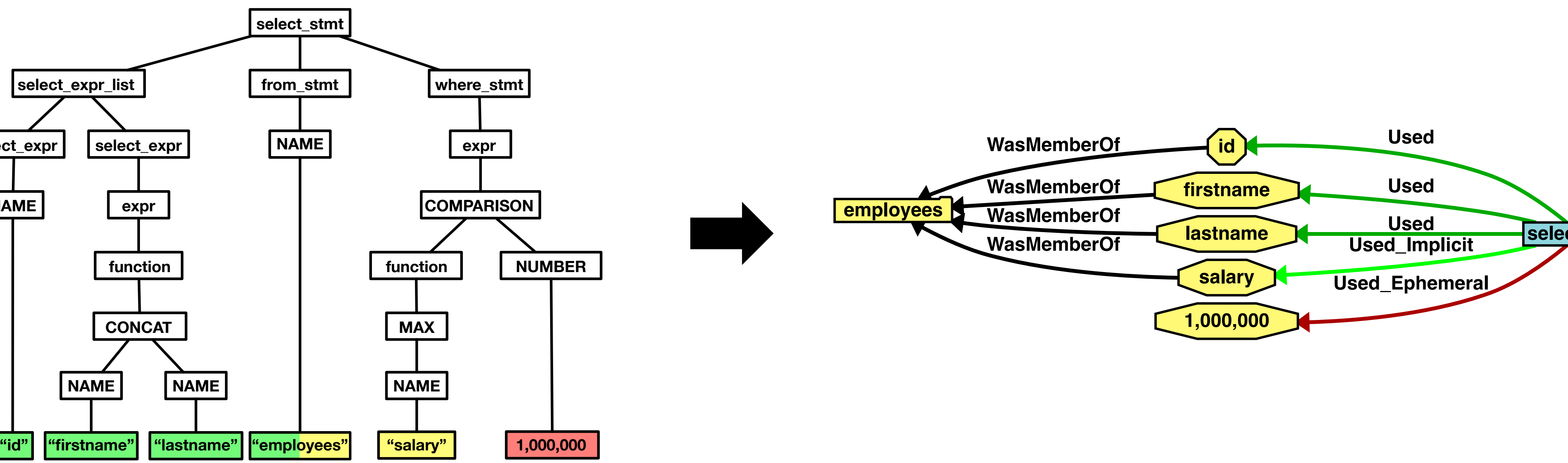
- Capturing provenance from system components
- Manual instrumentation
  – Add code to existing applications and backend infrastructure
- *Network Provenance Functions*
  – Proxy connections between components
  – Parse protocols to capture provenance
- Components
  – Provenance monitor
  – Execution partitioning
  – Network provenance functions
  – Provenance recorder



Protocol Parsers: SQL

Need to determine what columns are accessed as part of a SQL query



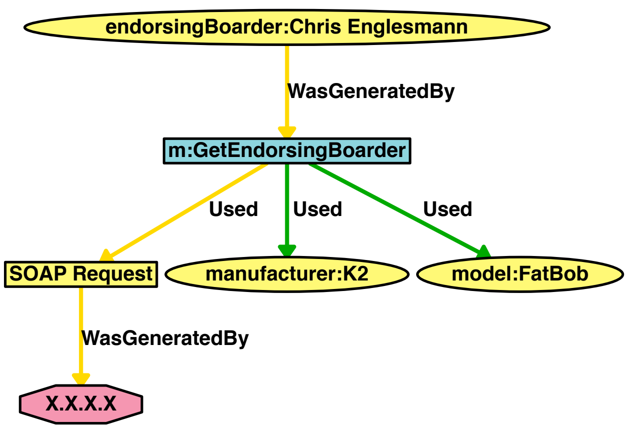


Protocol Parsers: Simple Object Access Protocol

- Simple Object Access Protocol (SOAP) enables remote procedure calls
- Requires web services description language (WSDL) file to parse messages
  – WSDL defines API for SOAP messages

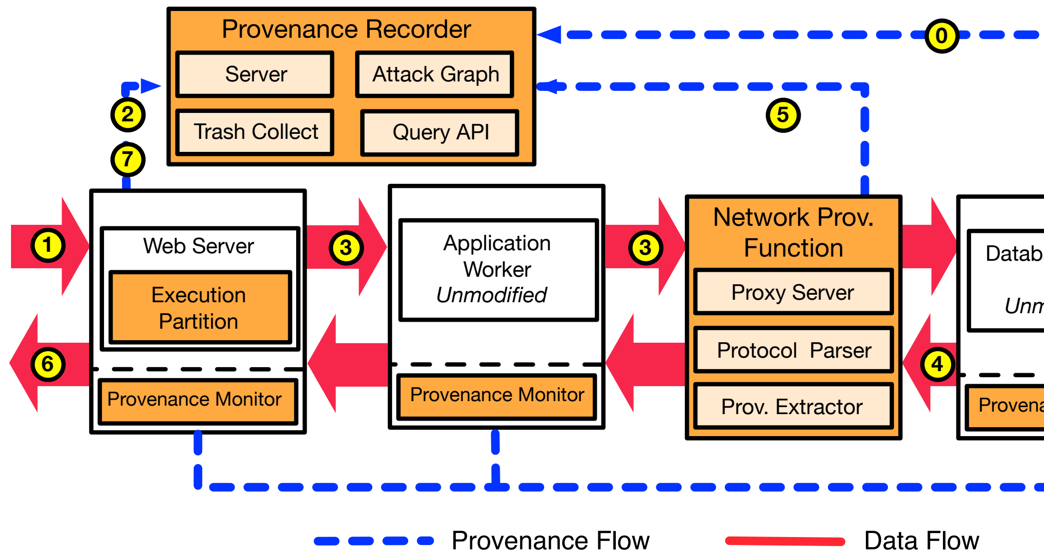
```
nvelope
OAP-ENV="http://schemas.xmlsoap.org/soap/envelope/"
V:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/">
NV:Body>
GetEndorsingBoarder xmlns:m="http://namespaces.snowboard-info.com">
 <manufacturer>K2</manufacturer>
 <model>Fatbob</model>
:GetEndorsingBoarder>
ENV:Body>
Envelope>
```

```
<SOAP-ENV:Envelope
    xmlns:SOAP-ENV="http://schemas.xmlsoap.org/soap/envelope/"
    SOAP-ENV:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/">
    <SOAP-ENV:Body>
        <m:GetEndorsingBoarderResponse xmlns:m="http://namespaces.snowboard
            <endorsingBoarder>Chris Englesmann</endorsingBoarder>
        </m:GetEndorsingBoarderResponse>
    </SOAP-ENV:Body>
</SOAP-ENV:Envelope>
```



Implementation

- Provenance monitor
  - Linux Provenance Modules (LPM) with Hi-Fi module enabled
- Execution partition
  - Modified Apache 2 web server
  - Added <5 lines of code
- Provenance recorder
  - C++ using SNAP graph library
- Network provenance function
  - Multithreaded TCP proxy in C
  - SQL parser using Bison



Evaluation Overview

- Physical host
  - 2.4 GHz Intel Xeon processors (2x4-cores)
  - 12 GB RAM
  - VMware Fusion
- Virtual machines
  - CentOS 6.5
  - 2 vCPUs
  - 4 GB RAM
- Measurements
  - End-to-end latency
  - Microbenchmarks
  - Case Studies

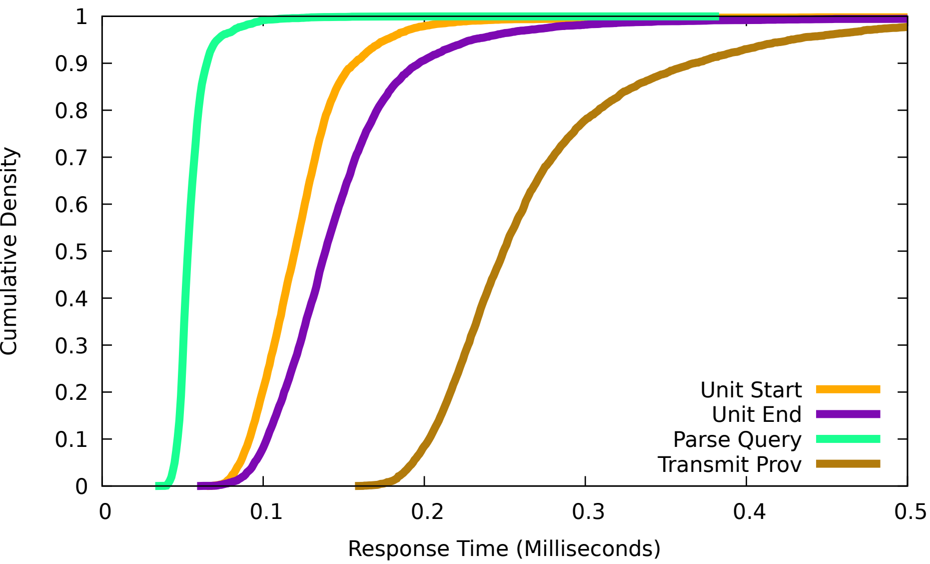
End-to-End Delay

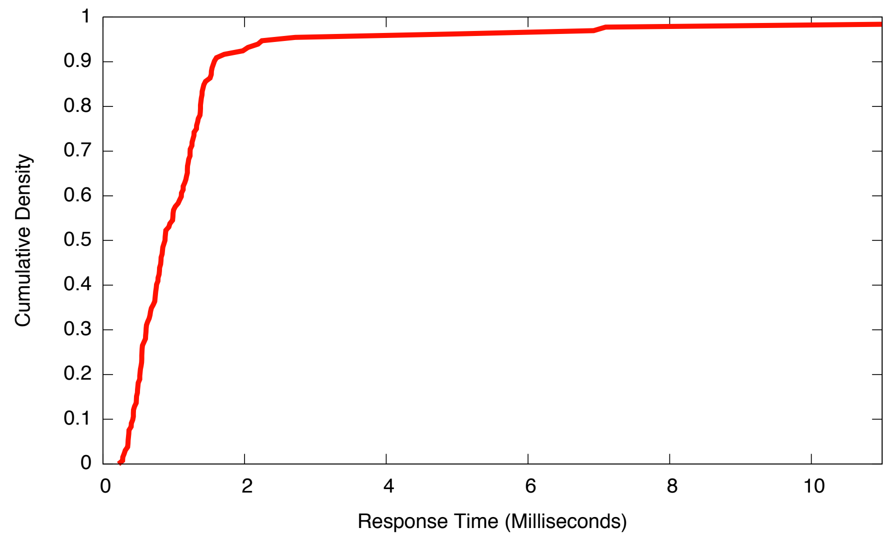
- **Need to ensure that NPFs don't make system unusable**

Benchmark	Total Queries	Database Size (GB)	Average Time (ms) w/o NPF	Average Time (ms) with NPF	Percent Overhead
Dell DVD Store	6451	10	10.7	11.7	9.3
RUBiS	6430	1	6.5	7.2	11.2
WikiBench	6581	3	6.3	7.0	11.6

- **Average overhead is ~11%, or at most 1ms per connection**

Microbenchmarks

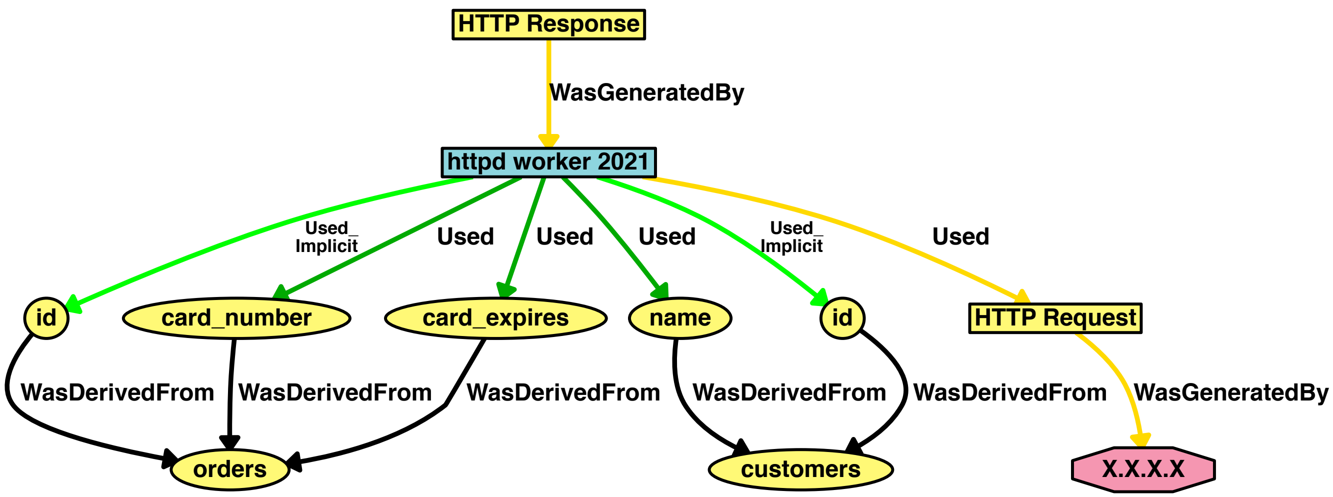




- Capture performance
  - Parse query: 0.053ms on average
  - Transmit provenance: 0.318ms on average
- Query performance
  - 1.23ms on average
  - 7ms in the worst case
  - 0.5ms to build provenance graphs

Case Study: SQL Injection Attack

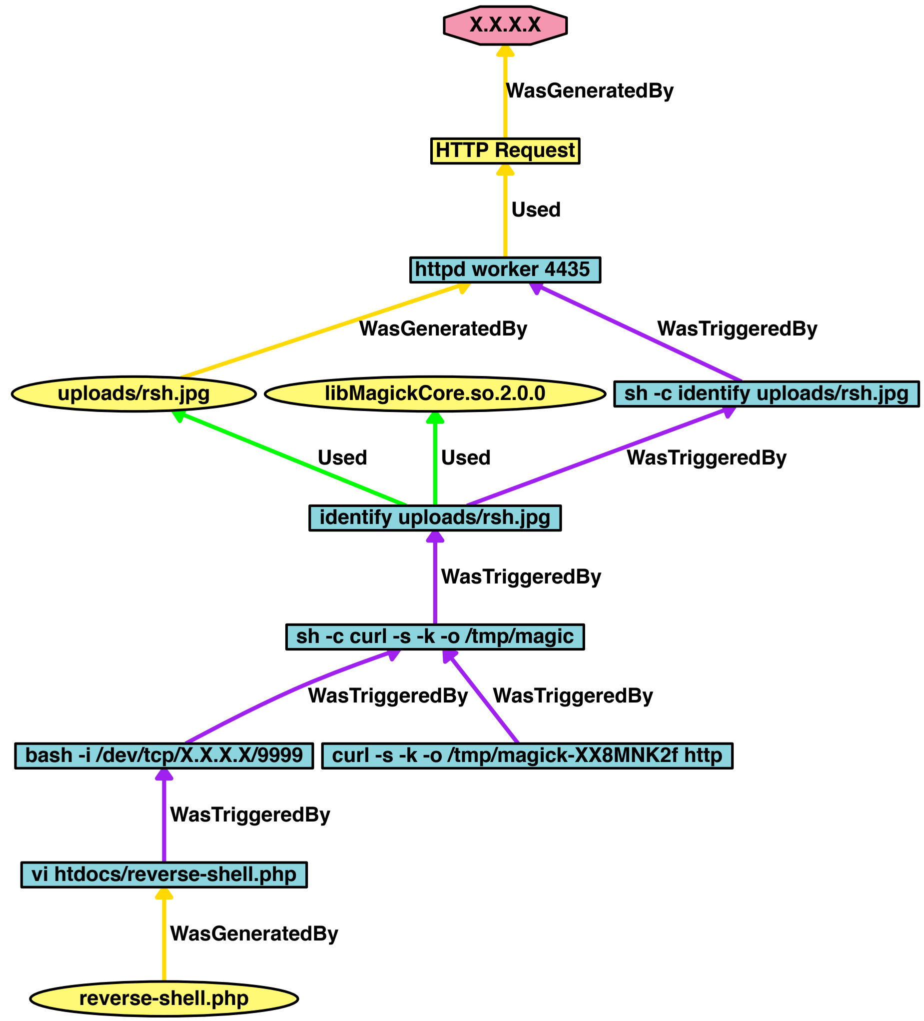
- Web application vulnerable to SQL injection (SQLi) attack
  - Attackers often obfuscate queries to evade protections in applications
- Fully tracking path of attack needs to consider many aspects of the system
  - Network context, bypassed application logic, and database accesses
- Existing audit solutions ill-suited to this task
- With NPF, admins create succinct policies about data crossing network boundaries



Case Study: ImageTragick

- mageTragick: arbitrary code execution
- Layer NPF with whole-system provenance to track reverse shell through ImageTragick
  - Evaluation uses Linux Provenance Modules to track files created on system, e.g. reverse-shell.php
- Attacker uploads file that created everse shell on system
- mageMagick runs identify on file, executing code to create reverse shell

```
 graphic-context
box 0 0 640 480
e over 0,0 0,0 'https://127.0.0.1/x.php?x=`
h -i >& /dev/tcp/aaa.bbb.ccc.ddd/9999 0>&1`'
graphic-context
```



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Summary

- Web applications continue to exhibit vulnerabilities and a need for fine-grained auditing capabilities
- Network provenance functions provide application developers with mechanisms to monitor and protect sensitive web services
  - Minimally invasive
  - Low overhead
  - Widely applicable

Questions?