Voice over IP: Risks, Threats, and Vulnerabilities

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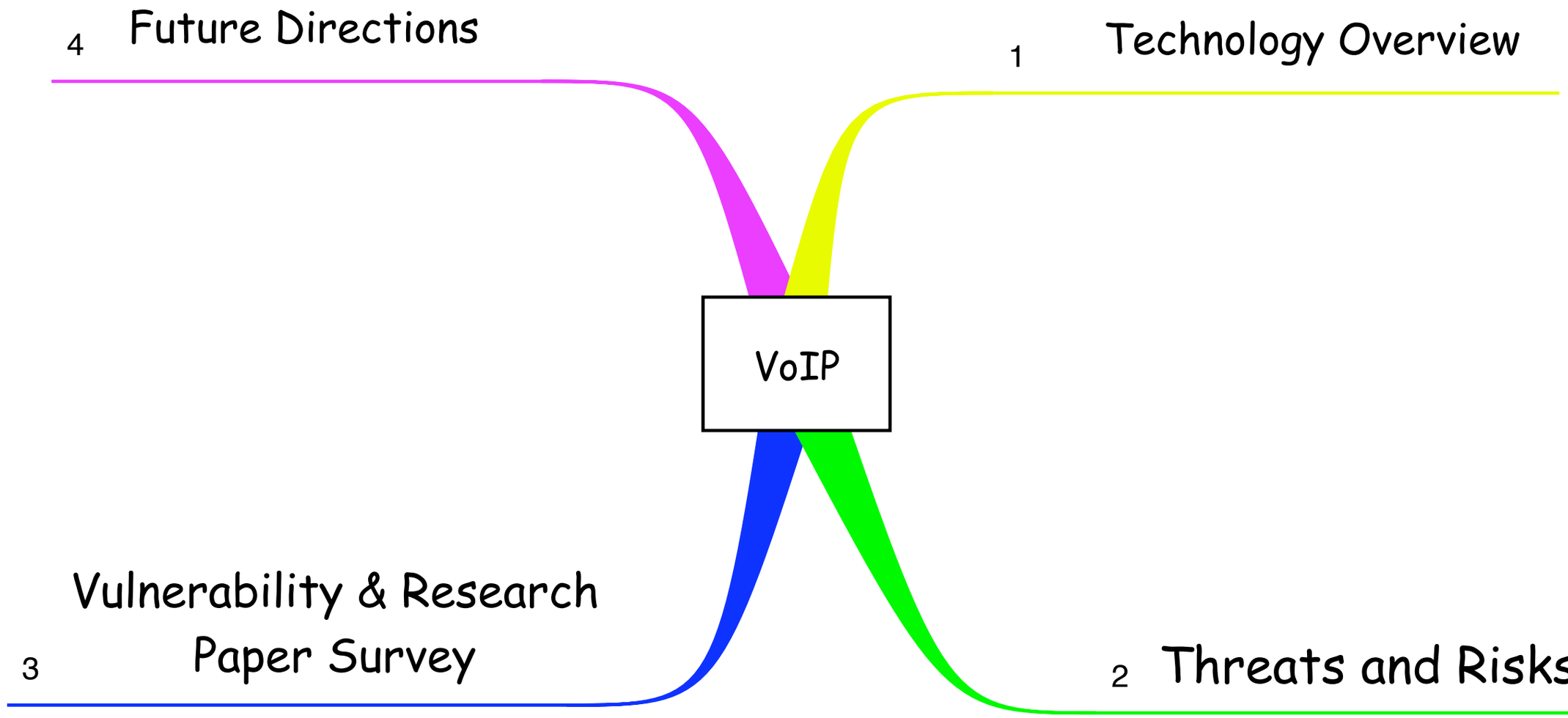
Why care about VoIP security?

- Increasing deployment and use
  - consumer, enterprise and government
- Highly complex system-of-systems
- Attractive target
  - carries sensitive data
  - provides critical services
  - immediate monetization

Why talk about it?

- Most research to date has focused on components
  - little to no “big picture” analysis of VoIP systems and infrastructures
  - emergent properties and nasty system interactions fall through the cracks
- Little understanding of how theoretical risks related to the real world
  - disconnect between what we worry about and what we are known to be vulnerable to
- Think about how we design future systems

What this talk is about



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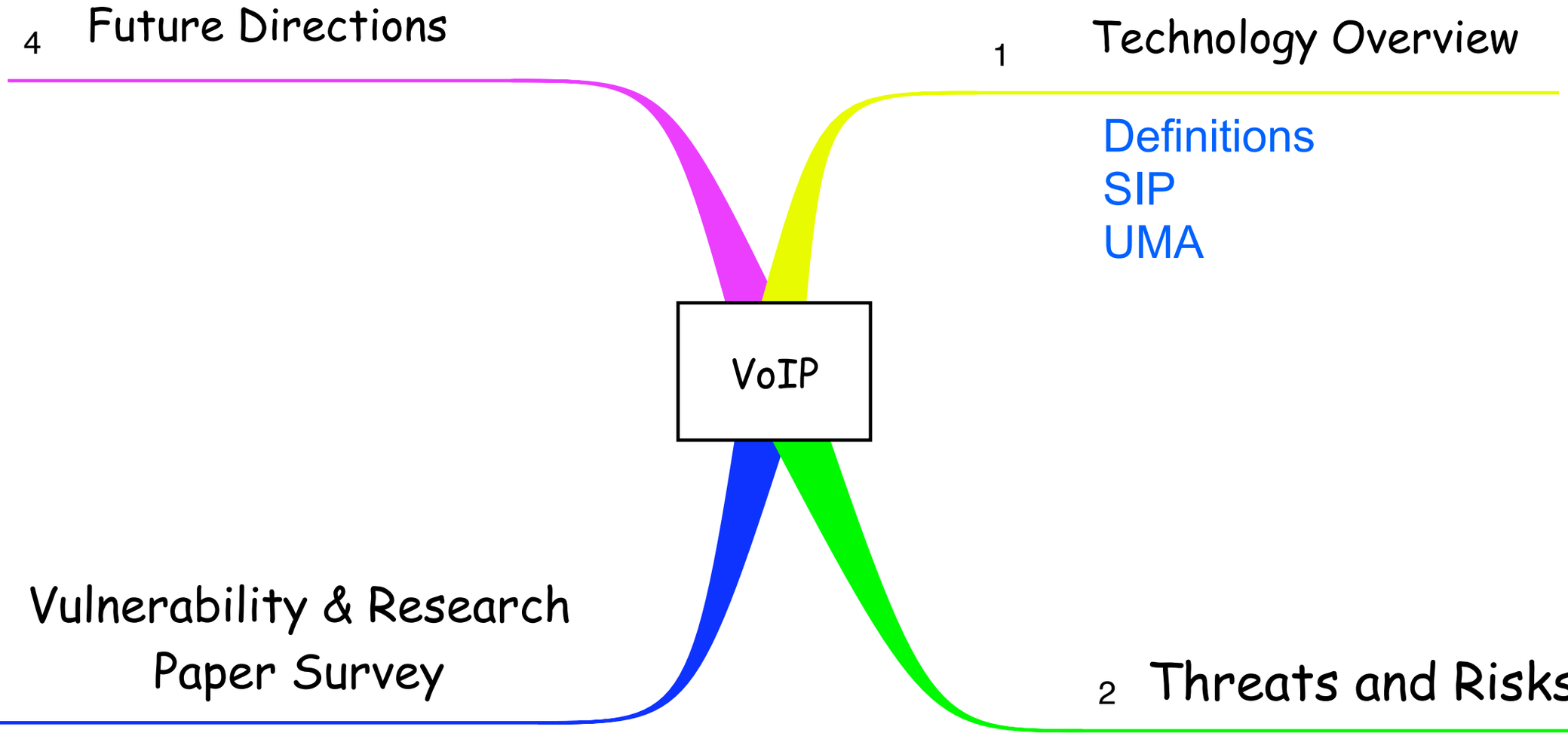

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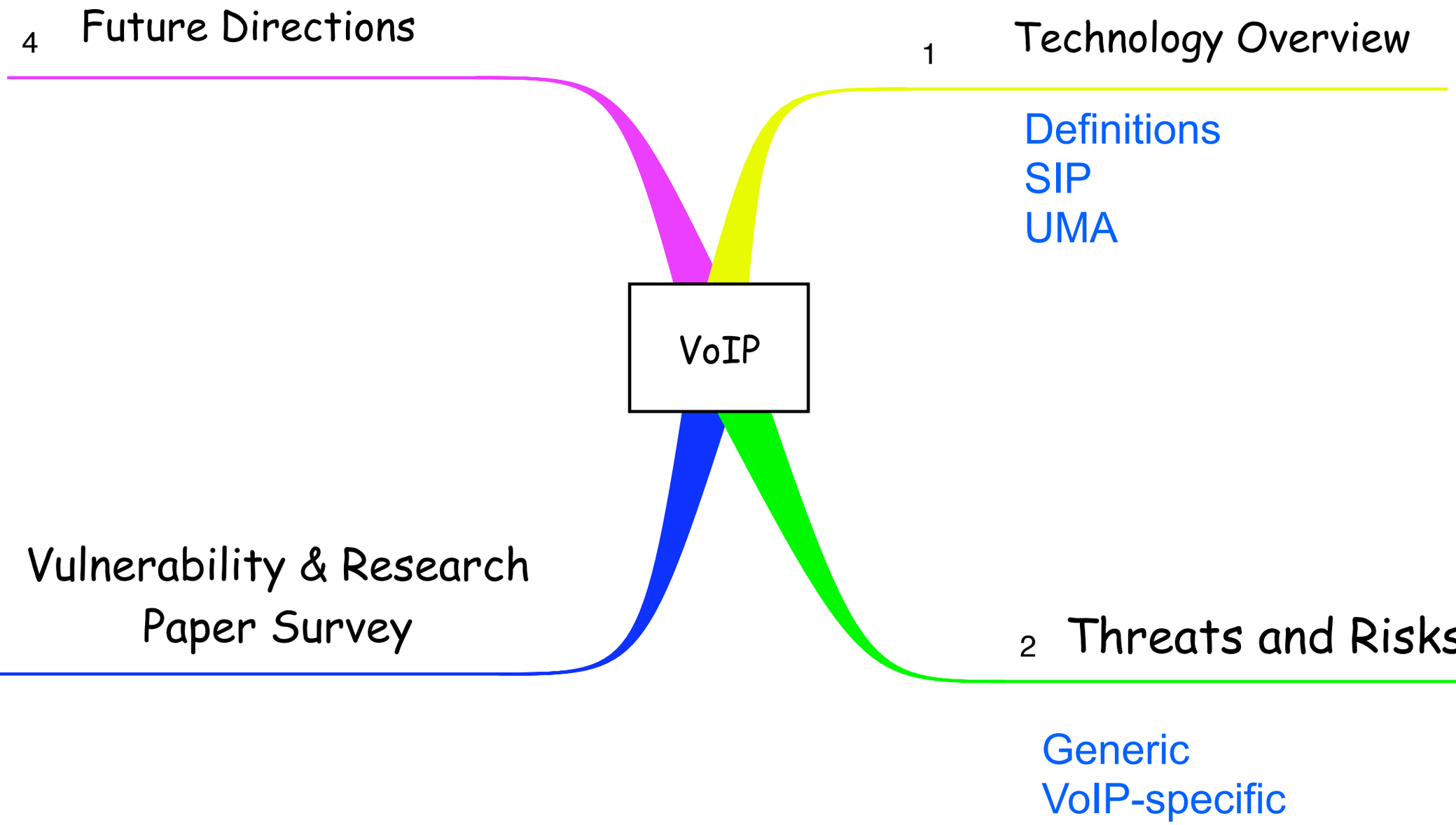

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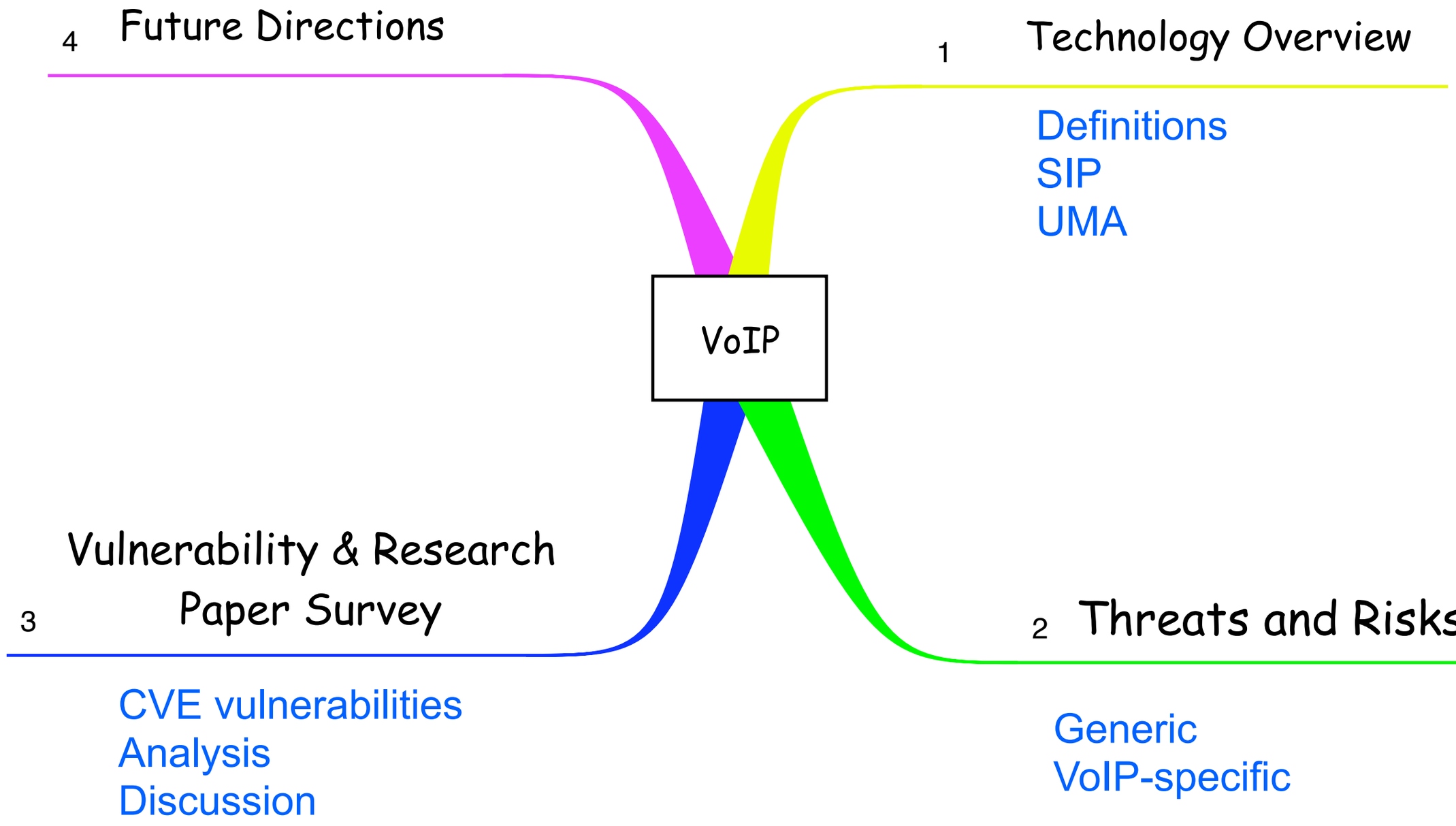

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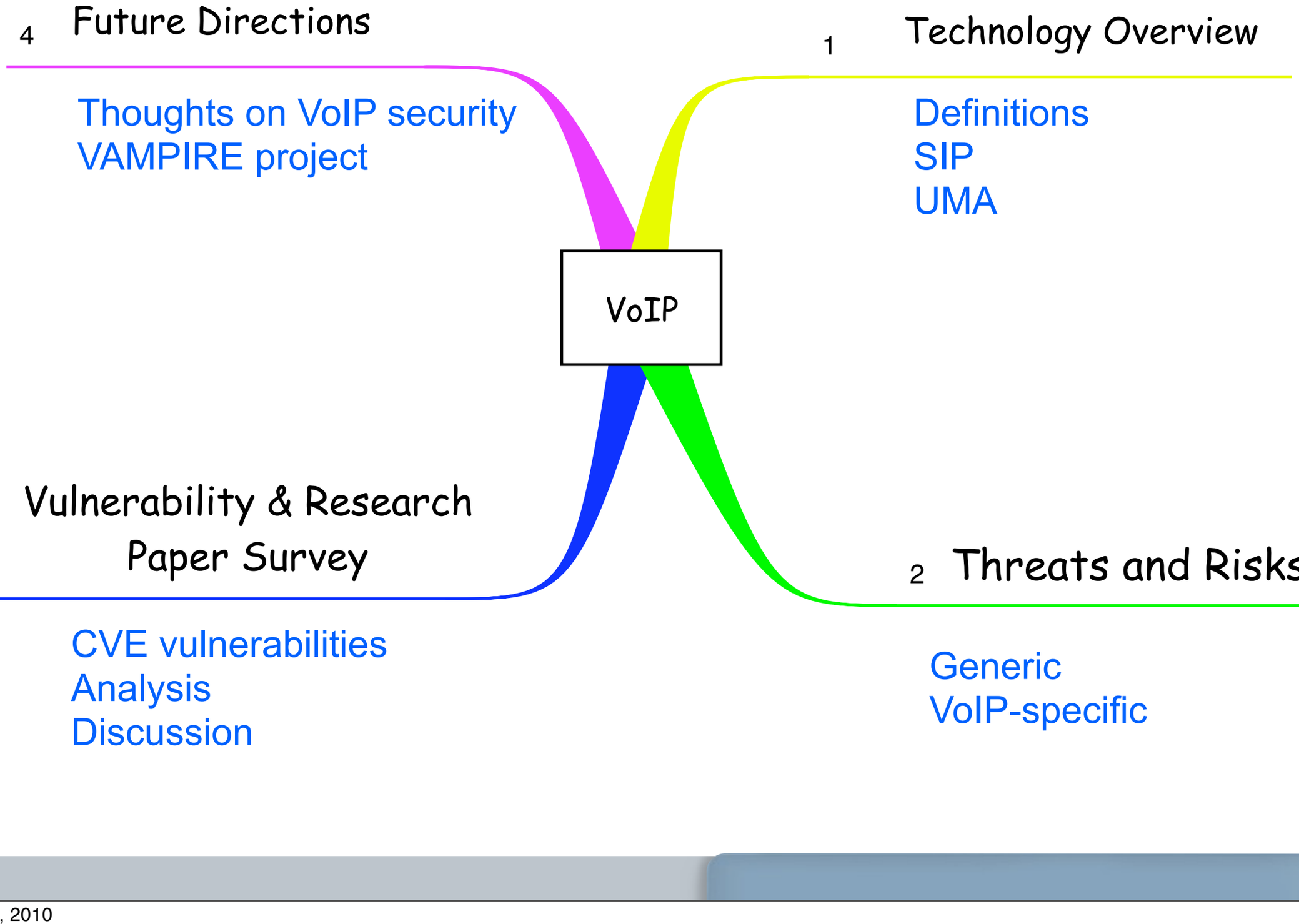


What is VoIP/IMS?

- Protocol(s) for voice communication over IP-based infrastructures
  - use of the Internet itself is dependent on operator

- Voice over IP: catch-all term

- IP Multimedia Subsystem: industry standard for IP-based multimedia communications
  - video, calendaring/scheduling, file-sharing, collaborative editing, ...

VoIP in the marketplace

- Basis for many products/services
  - commercial: Vonage, 3, T-Mobile/UMA, T-Mobile@Home, ...
  - free/semi-free: Skype, GTalk, MSN, Yahoo! IM, AIM, Gizmo, ...
- Both enterprise- and consumer-oriented
  - management simplification
  - cost reduction
- Various architectural models
  - centralized vs. P2P
  - open vs. closed

Components

- Signaling
  - responsible for call setup and management
  - architectural and operational components
    - principal/endpoint naming
    - IP mapping
    - proxying
    - billing
    - access control
    - device configuration/management
    - customer support
    - QoS
- Data transport
  - codecs, transport protocols (typically RTP), QoS, content security

IMS protocols

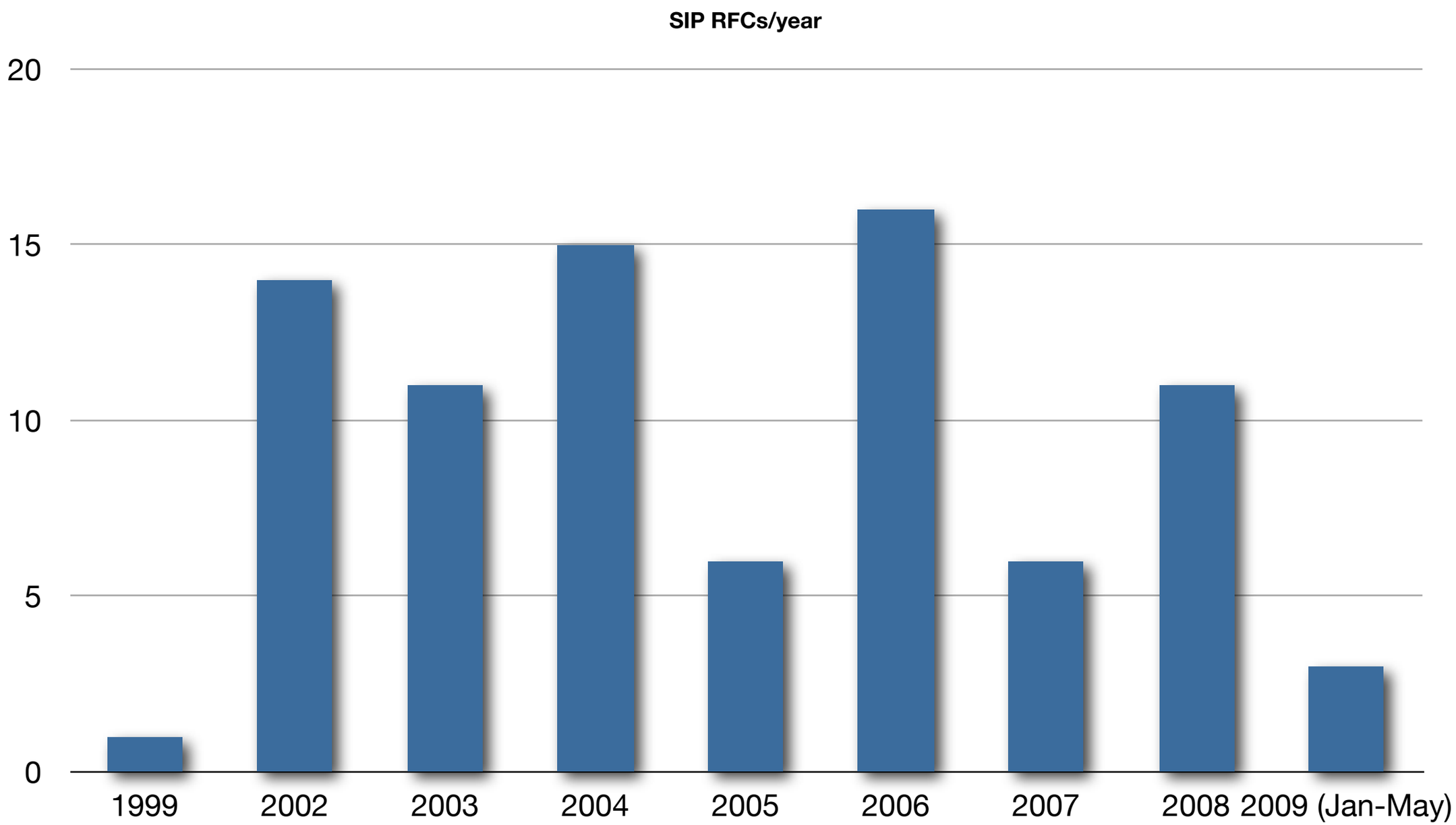
- Two predominant mechanisms
  - Session Initiation Protocol (SIP)
    - H.323 used in some environments
  - Unlicensed Mobile Access (UMA)

- Other popular mechanisms exist
  - Skype, Asterisk, GTalk/AIM ...

Session Initiation Protocol (SIP)

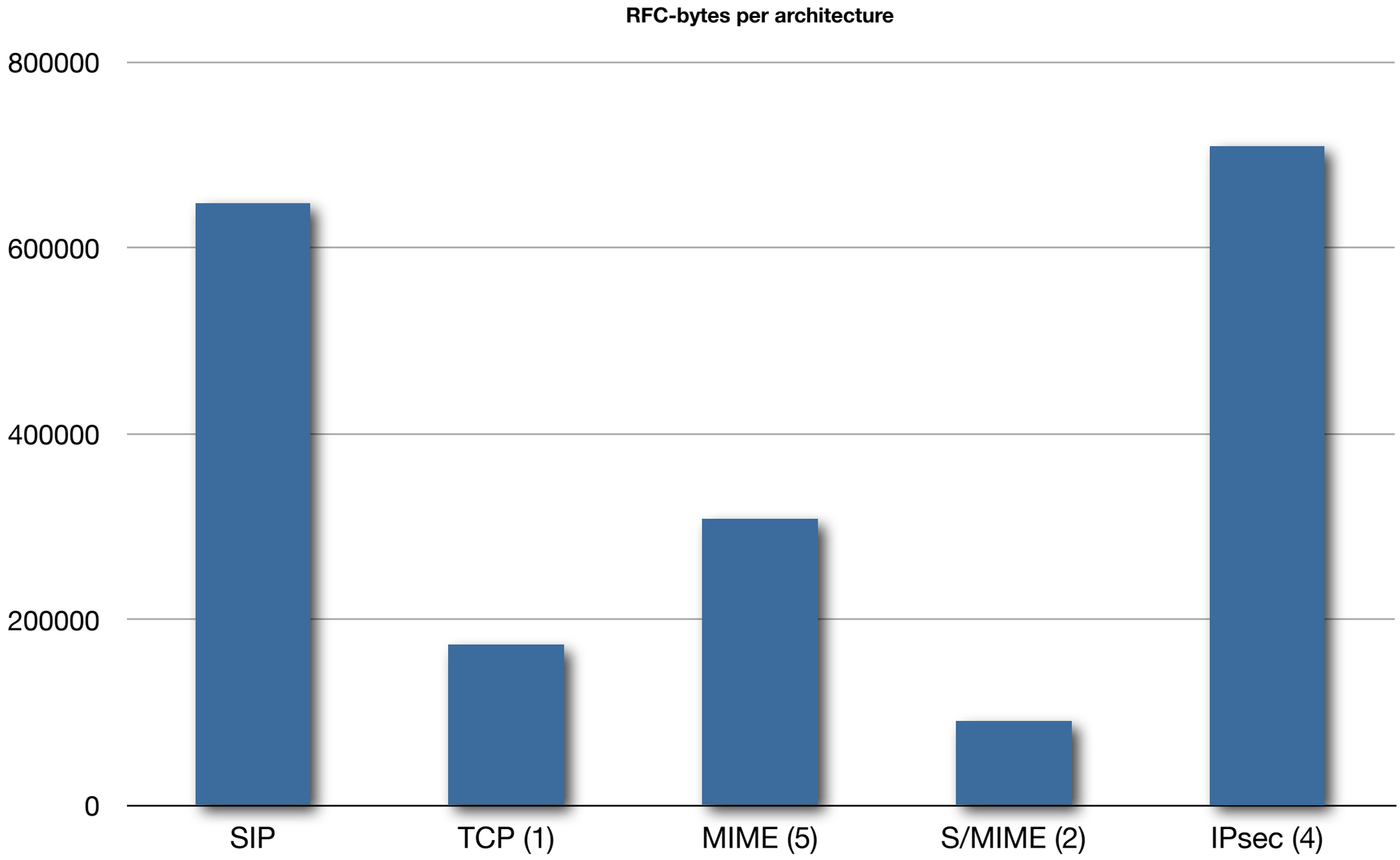
- Signaling protocol for IMS
  - similar to HTTP
    - text-based
    - request/response structure
    - uses HTTP Digest Authentication (adapted to SIP) for user authentication
  - unlike HTTP, it is stateful
    - highly complex FSM, source of numerous (most?) vulnerabilities

SIP complexity

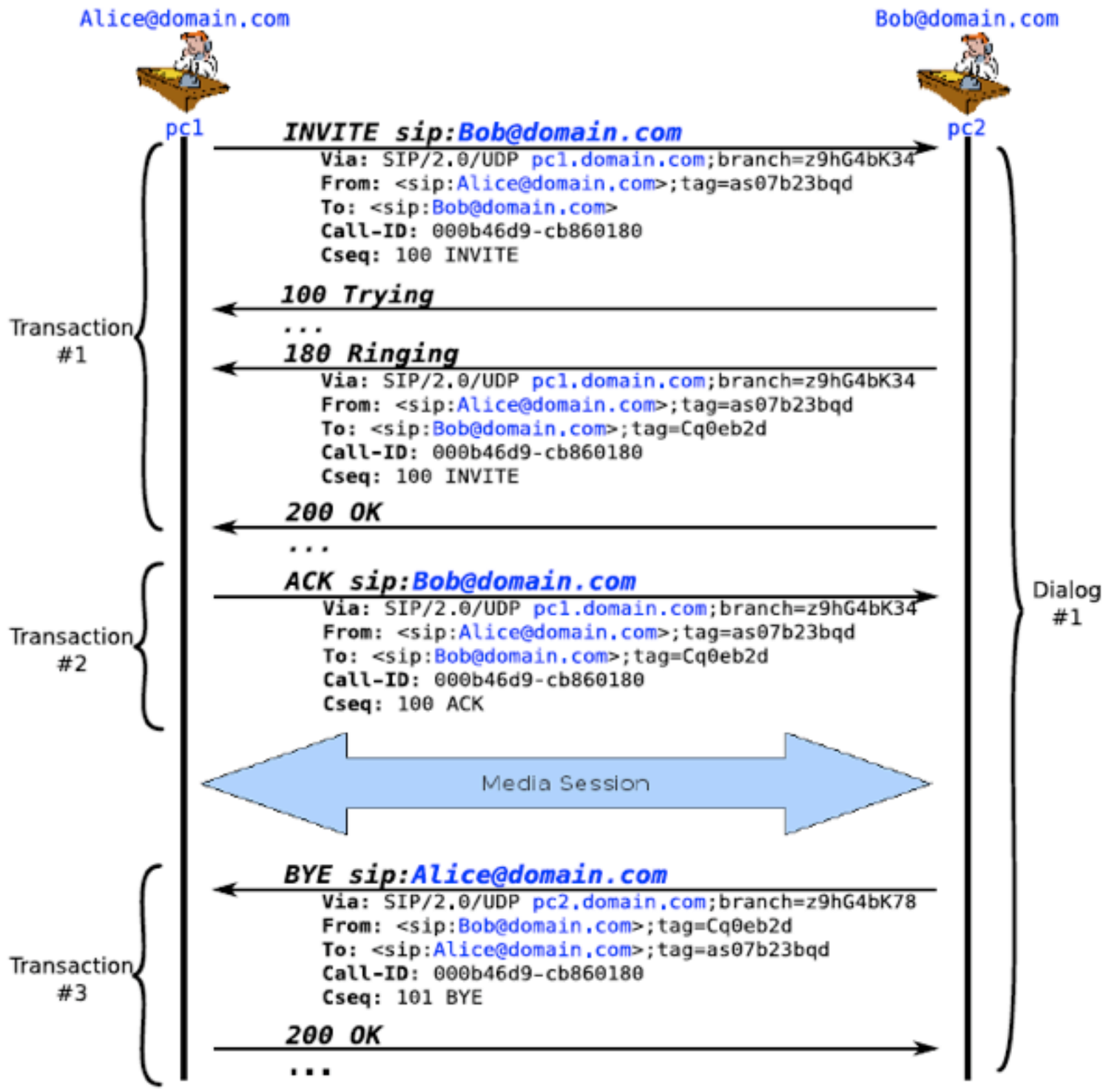


RFC 3261

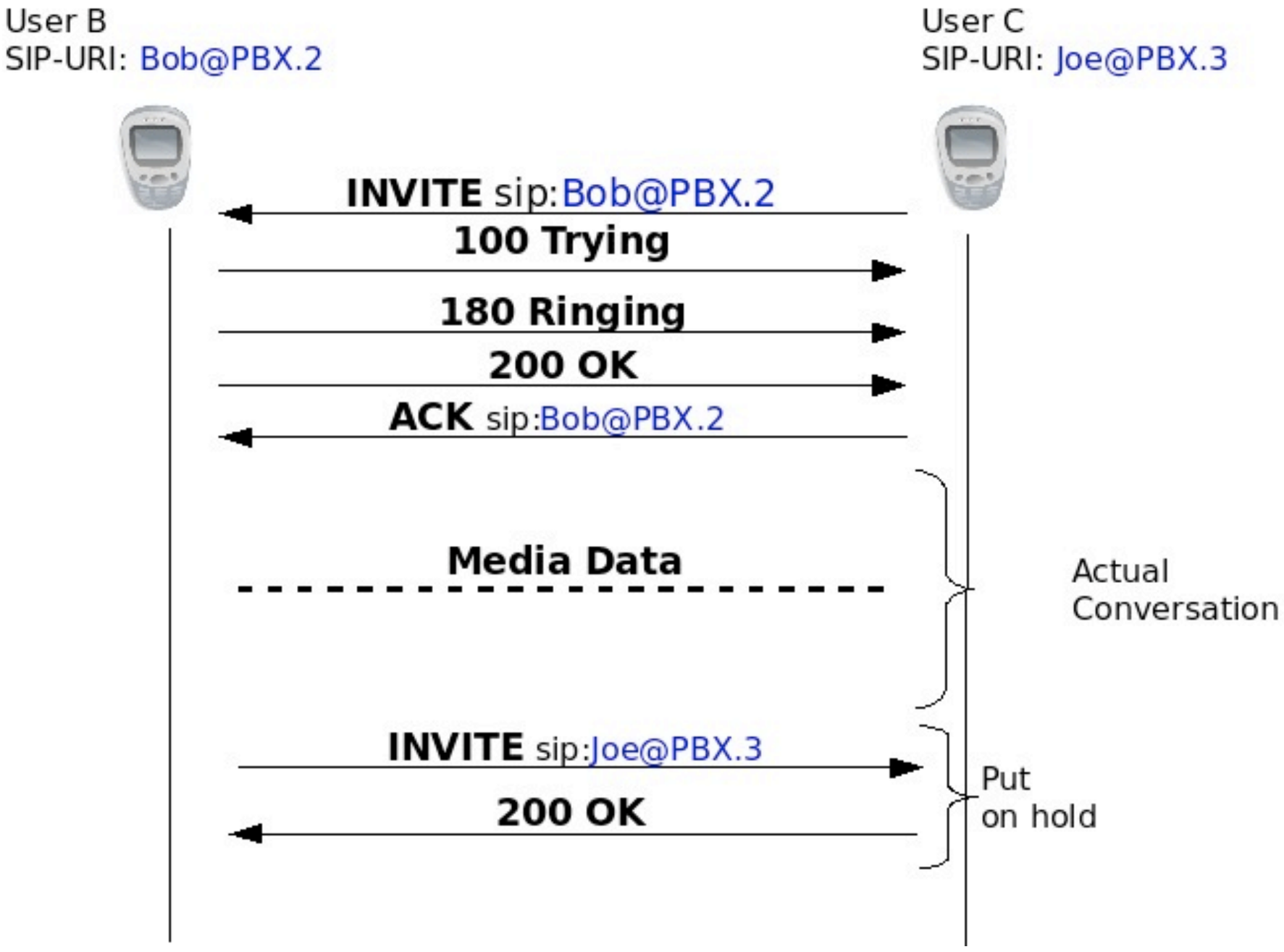
- Main SIP RFC is 2nd-largest ever (after “Internet Security Glossary”)



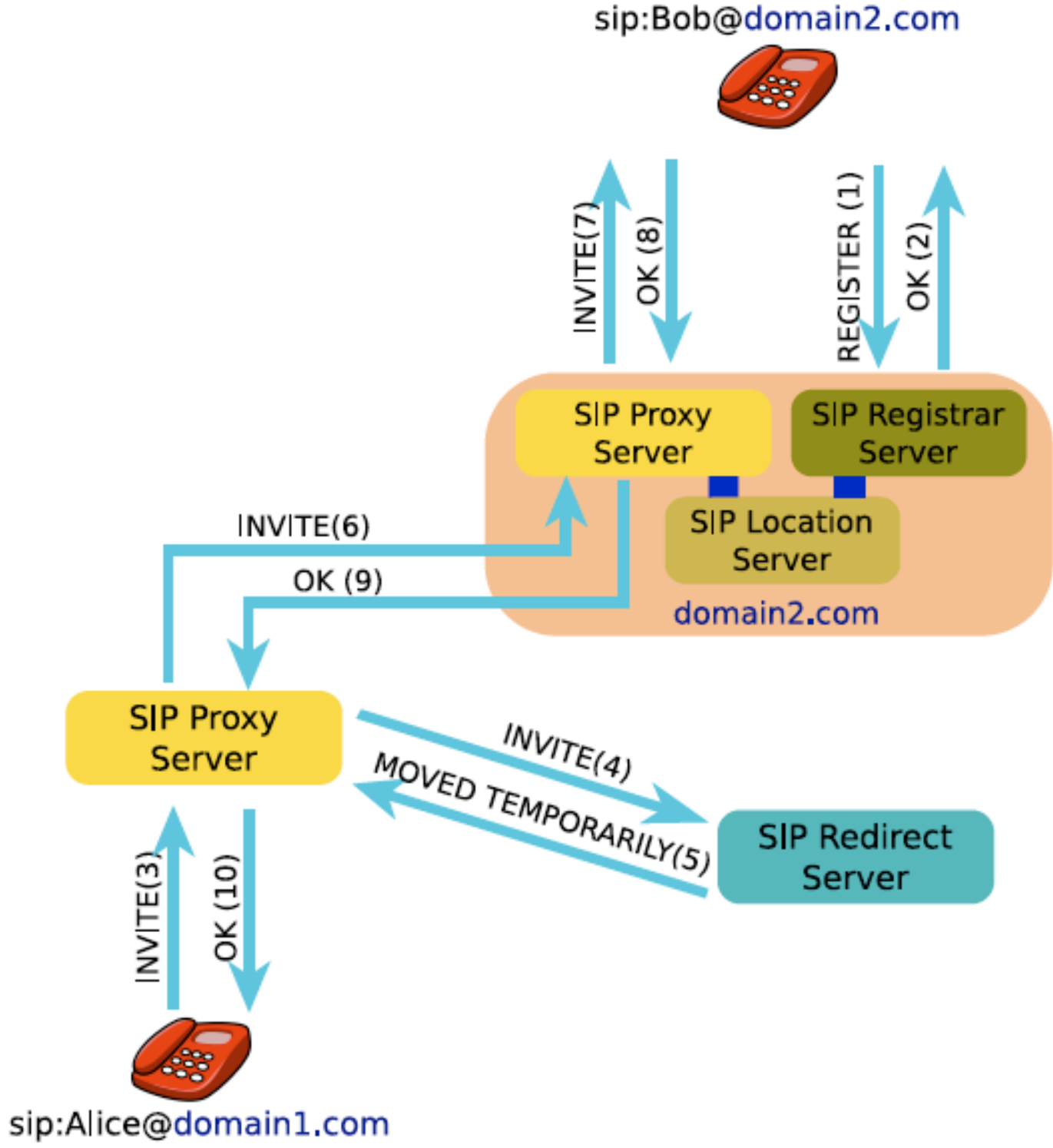
SIP exchange



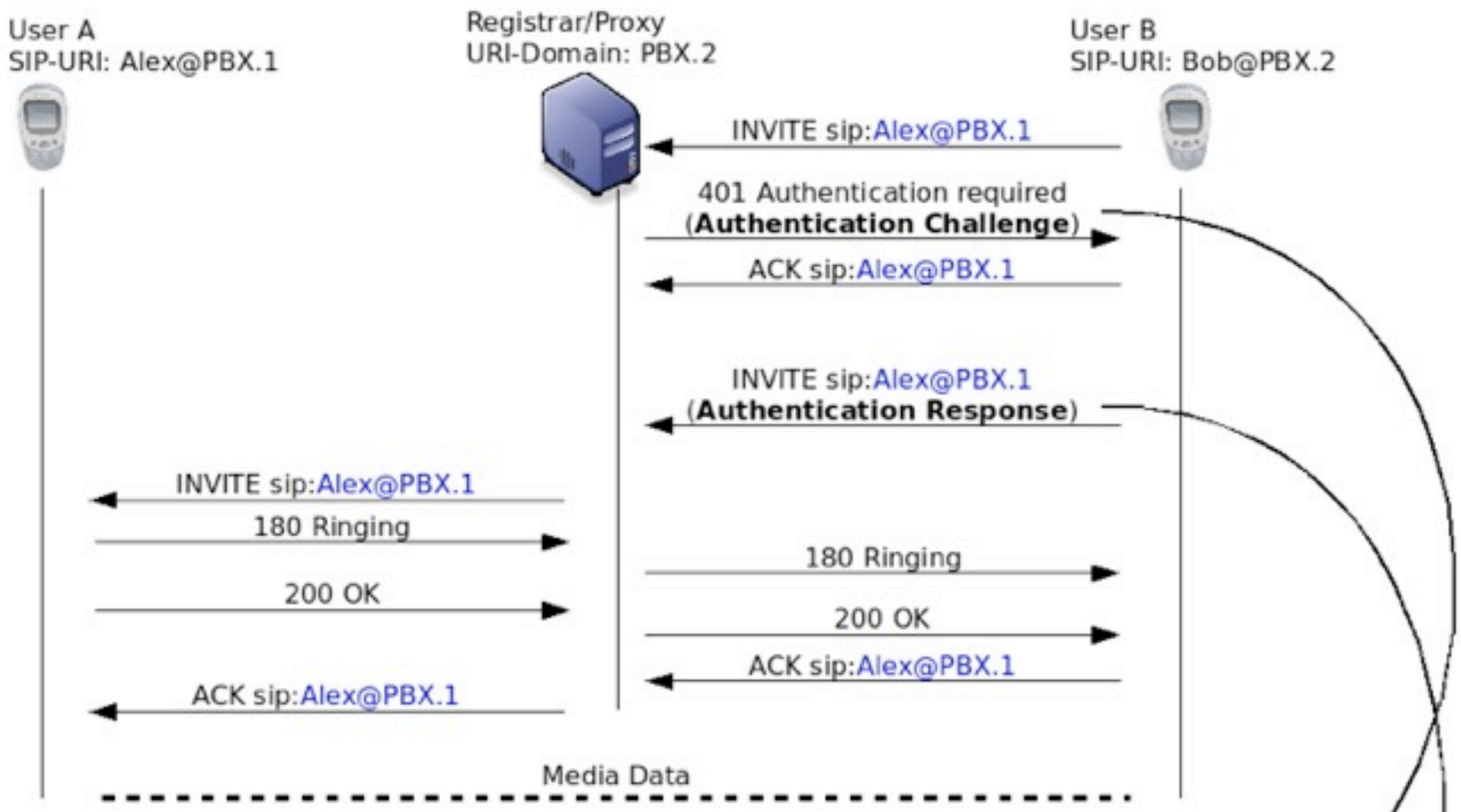
Call forwarding



SIP component interactions



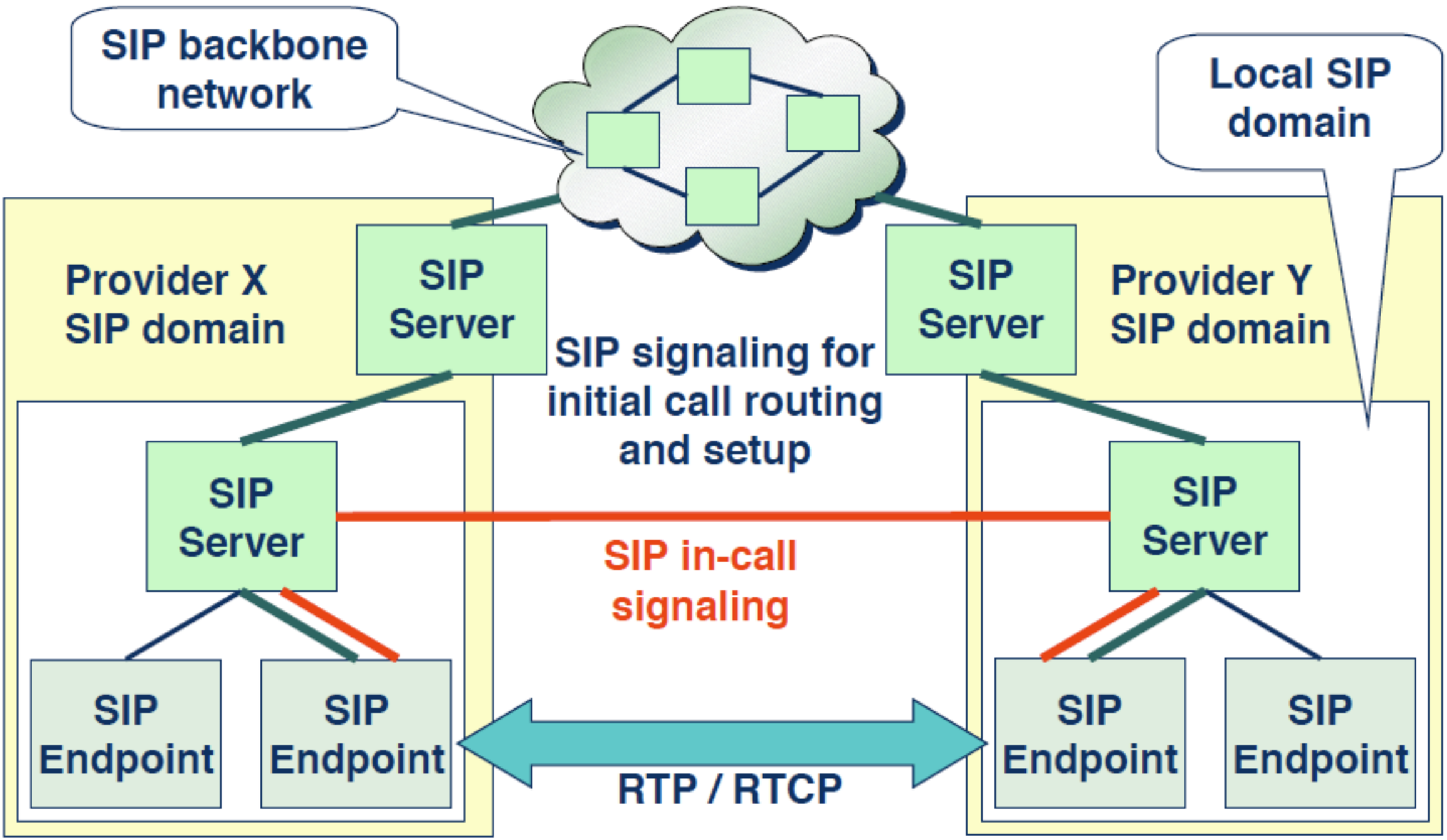
SIP authentication



Proxy-Authenticate: Digest algorithm=MD5,
realm="domain.org",
nonce="1d78fb72"

Proxy-Authorization: Digest username="Bob",
realm="domain.org",
uri="sip:Alex@PBX.1",
response="4cc8a1de5a60306c760",
nonce="1d78fb72", algorithm=MD5

SIP architecture



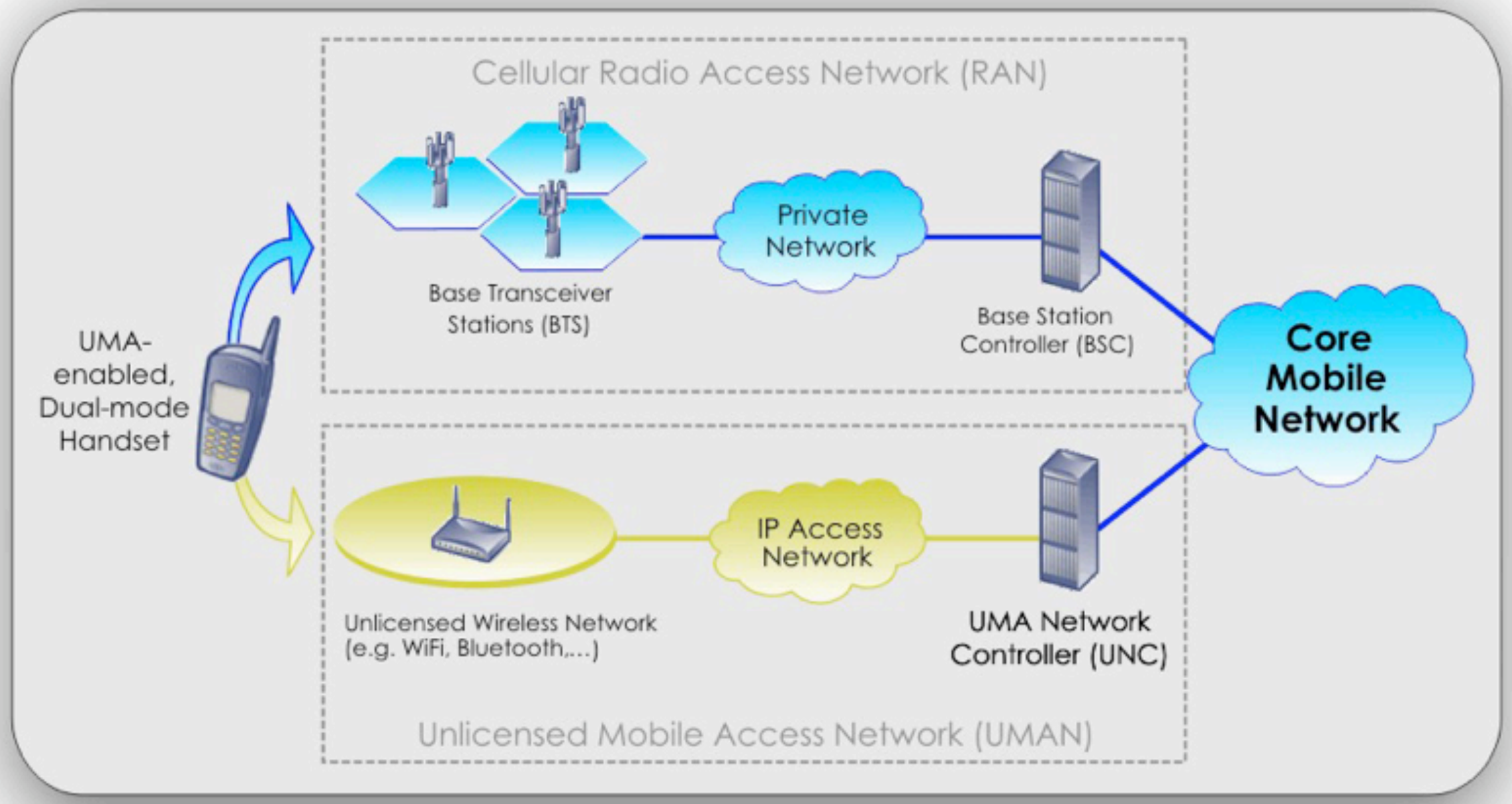
In reality...

- Much “hidden” shared infrastructure
  - DNS, web, NAT, TFTP, DHCP/PPPoE, Int/DiffServ, firewalls,...
- Emergent properties
  - example: web-based UI poisoning through SIP-field manipulation
- Real-time aspect makes problems harder
  - e.g., how can we filter voice spam based on content?

Unlicensed Mobile Access (UMA)

- Route GSM calls over the Internet (or a public network)
  - (usually) transparent handover between GSM and UMA
- Popular with cellphone providers
  - T-Mobile USA, Orange France, ...
- Benefits
  - reduce need to install expensive cell towers / upgrade capacity
  - reduce spectrum needs / utilization
  - improve “reception” in difficult locations
  - depending on billing, avoid roaming charges (think international!)
- Not to be confused with pico-/micro-/femto-cells

UMA deployment



Source: http://www.umatechnology.org/

UMA details

- Encapsulation of GSM/3G inside IP
  - complete frame, minus the on-the-air crypto
  - can transfer voice, IM and (in the future) video

- Typically, devices are WiFi-supporting cellphones
  - not strictly necessary, e.g., T-Mobile@Home in USA

- GSM frames are not natively protected
  - A5/2 is anyway weak (i.e., broken)

UMA security

- Handset-to-provider IPsec
  - strong crypto and integrity protection
  - key management (IKE, IKEv2) is a different story altogether
  - authentication done via EAP-SIM (based on shared secret)

- The key management protocol (IKE/IKEv2) is complex
  - perhaps “too big” to be trusted
  - more importantly, easy to misconfigure
    - not as big a problem in a tightly managed environment such as cellphones
    - but, UMA+smartphones smells trouble

- Provider needs to interface internal network with Internet
  - higher risk of compromise by external attackers
  - large numbers of potentially malicious insiders (i.e., legitimate users)

Threats in VoIP systems

- Everyone thinks of the traditional C/I/A threats
- Loss of communication confidentiality and privacy (C)
  - traffic analysis, content privacy

- Loss of communication integrity (I)
  - impersonation (inbound, outgoing calls), modification of content, falsification of call records

- Loss of communication availability (A)
  - accidental or intentional denial of service (DoS)

Unique VoIP characteristics

- Elaborate billing infrastructure in place
- Users are used to paying for telephony services
- Most charges are for relatively small amounts
- Large number of charges per billing cycle
  - unlikely that small unauthorized charge will be noticed or challenged
- Phone infrastructure is “trusted” by average user
  - perception carried over from PSTN
  - not grounded on facts or experience

VoIP-specific threats

- Theft of service
  - toll fraud
  - billing fraud
- Social engineering
  - phishing/spear-phishing made even easier
- Direct charge-back
  - immediate monetization

VoIP/IMS risk vectors

- Variety of risk vectors
  - some in common with other types of systems
    - software vulnerabilities
  - some are very specific to IMS
    - protocol vulnerabilities
  - some are common, but are amplified by some IMS feature
    - large-scale phishing through impersonation or call hijacking

Adversaries

- Who would launch attacks?
  - amateur blackhat
  - professional blackhat
  - fraudster
  - corporate competitor
  - national intelligence/espionage
    - recall 2006 wiretapping scandal in Greece
  - cyberwarfare
  - private investigator
  - ...

- Due to increased access (relative to PSTN), larger attack surface and larger number of potential attackers

Example of toll fraud attack

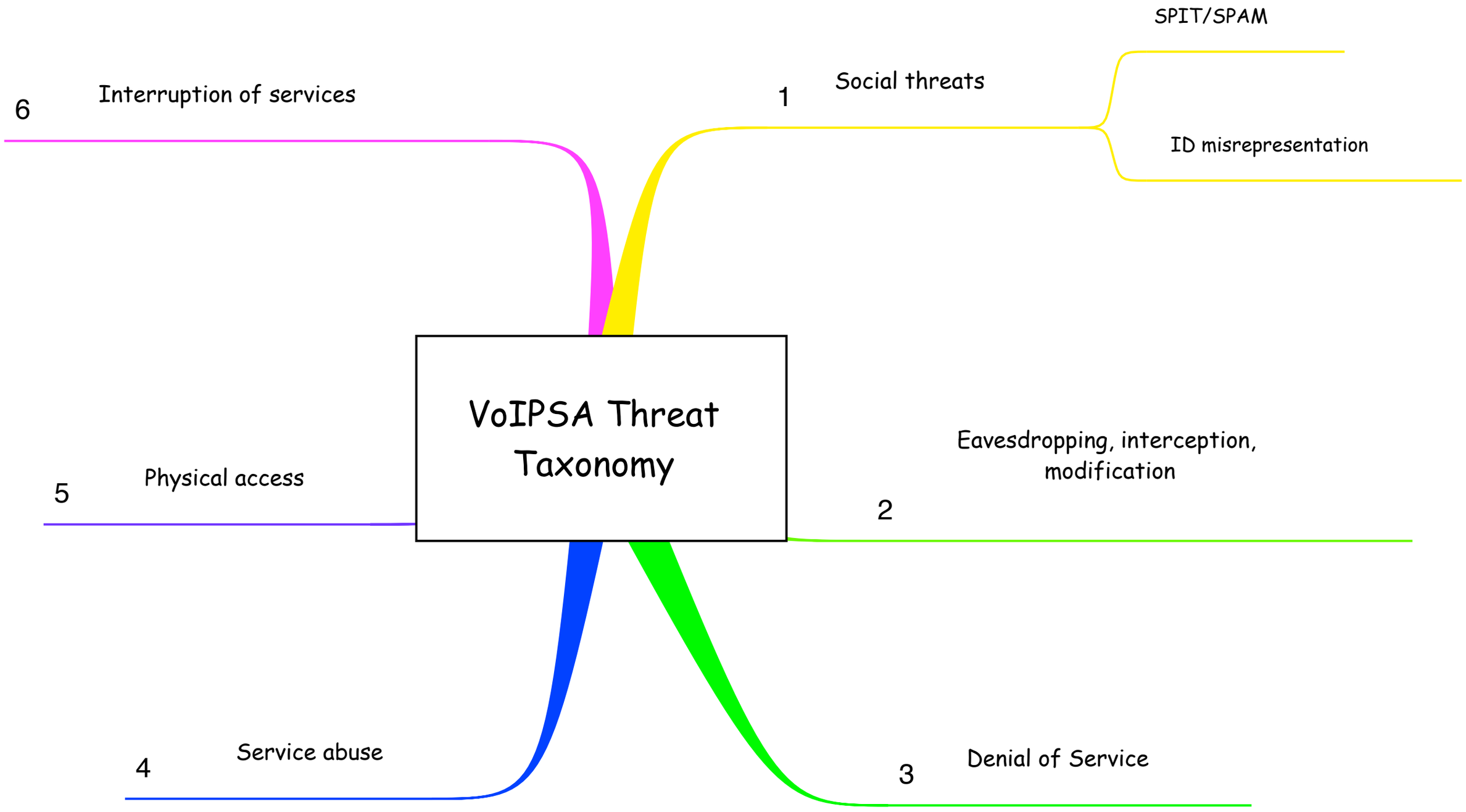
- Break into company PBX
  - use them to route calls of your customers
  - this has actually happened

http://www.theregister.co.uk/2006/06/08/voip_fraudsters_nabbed/
http://www.theregister.co.uk/2009/02/11/fugitive_voip_hacker_arrested/

"Federal authorities yesterday arrested a Miami man who they said made more than $1 million in a hacking scheme involving the resale of Internet telephone service."

"In all, more than 15 Internet phone companies, including the one in Newark, were left having to pay as much as $300,000 each in connection fees for routing the phone traffic to other carriers without receiving any revenue for the calls, prosecutors said."

VoIP Security Alliance taxonomy



VoIP vis. risks

- Confidentiality
  - in some protocols, attackers can easily eavesdrop
    - variety of available attack tools, e.g., VoMIT
    - particularly a problem with SIP/RTP
      - S-RTP defined, but largely unused
      - key management problem still unsolved (where's my PKI?)

- Integrity
  - software vulnerabilities
    - for example, as vulnerable to buffer overflows as any other piece of software
    - silver lining: even simple devices are generally designed for updateability
      - mixed blessing, update mechanism can be hijacked (usually based on TFTP!)

VoIP vis. risks

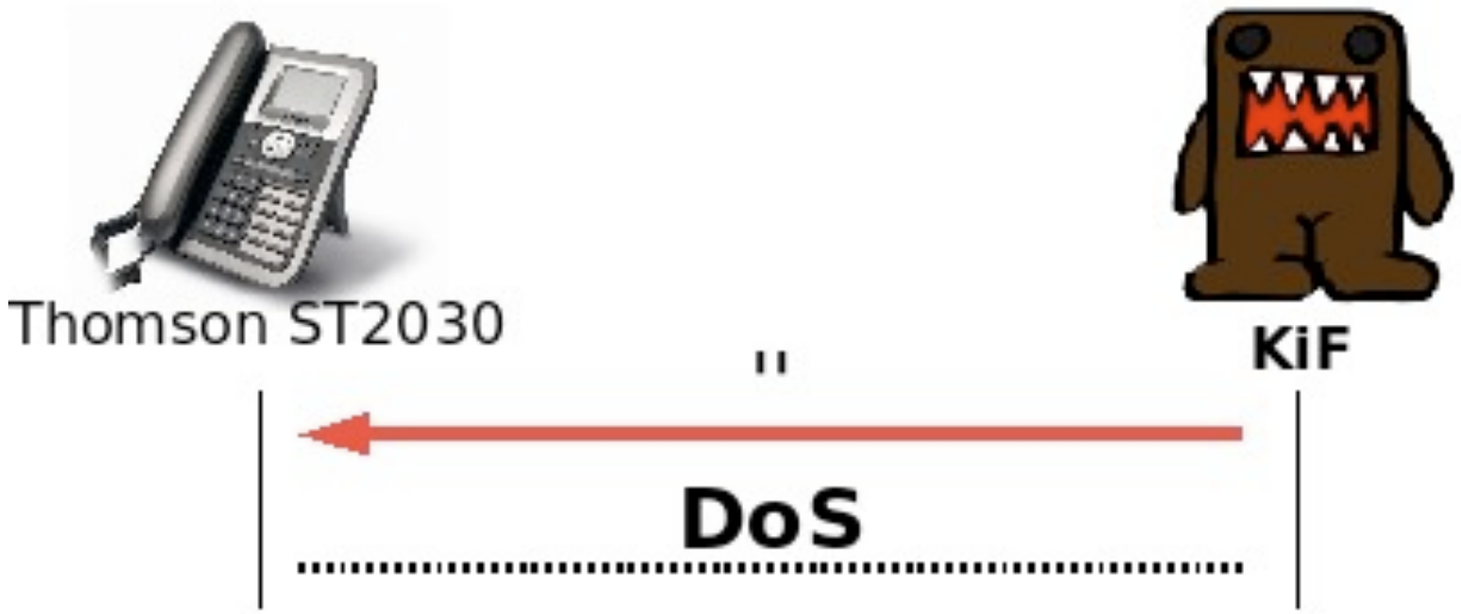
- Availability
  - susceptibility of equipment to denial of service
    - general network-borne DoS attacks, powerline, ...
  - how do you call someone to fix your problem?!

IMS-specific problems

- Architectural and protocol vulnerabilities
  - SIP device interactions (see following slides)
    - silent “snooping” via multipresence
    - fraud
      - bill bypassing
      - hijacking of someone else’s account/PBX
  - protocol-specific denial of service attacks
    - malformed messages
    - call routing games
  - separation between signaling/data transport can be leveraged
    - induce someone’s phone device to act as a DoS zombie
    - incriminate an IP address/person

Trivial protocol-specific DoS attack

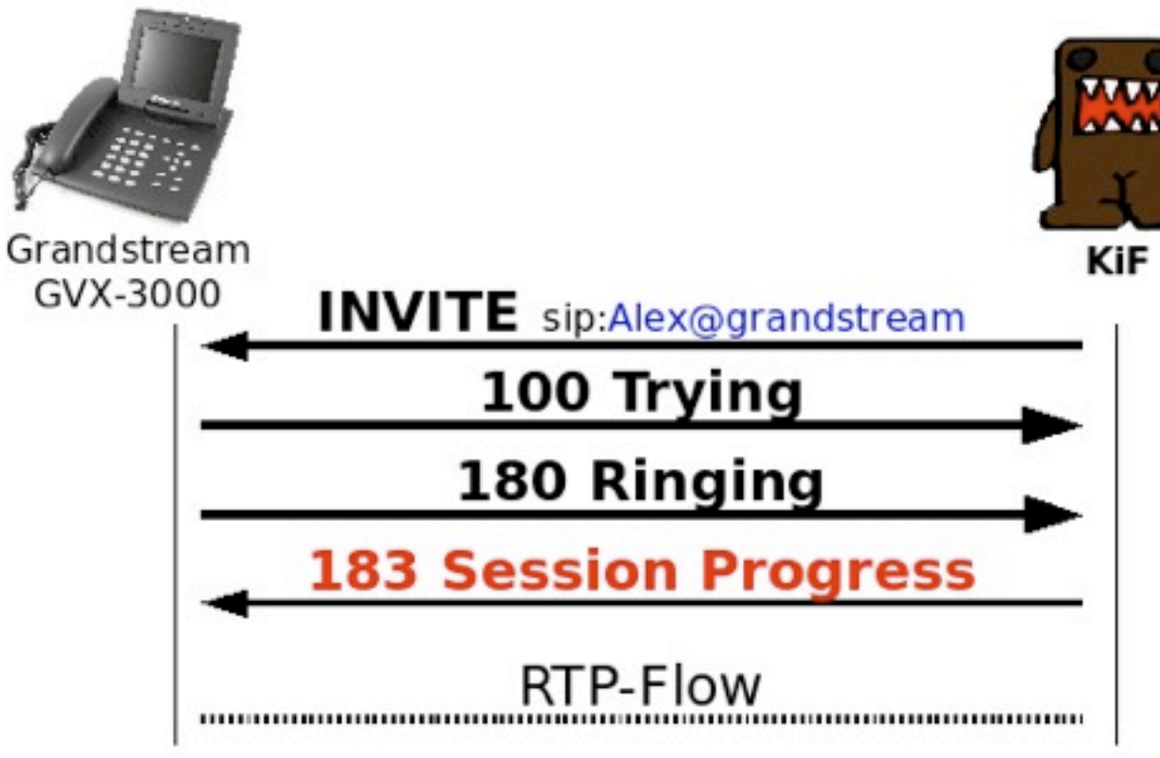
- Single packet “phone kill”



Vulnerability by KiF
CVE-2007-4753

Privacy attack

- Call someone, then report “call in progress” before ring
  - turns phone into eavesdropping device!



Vulnerability by KiF
CVE-2007-4498

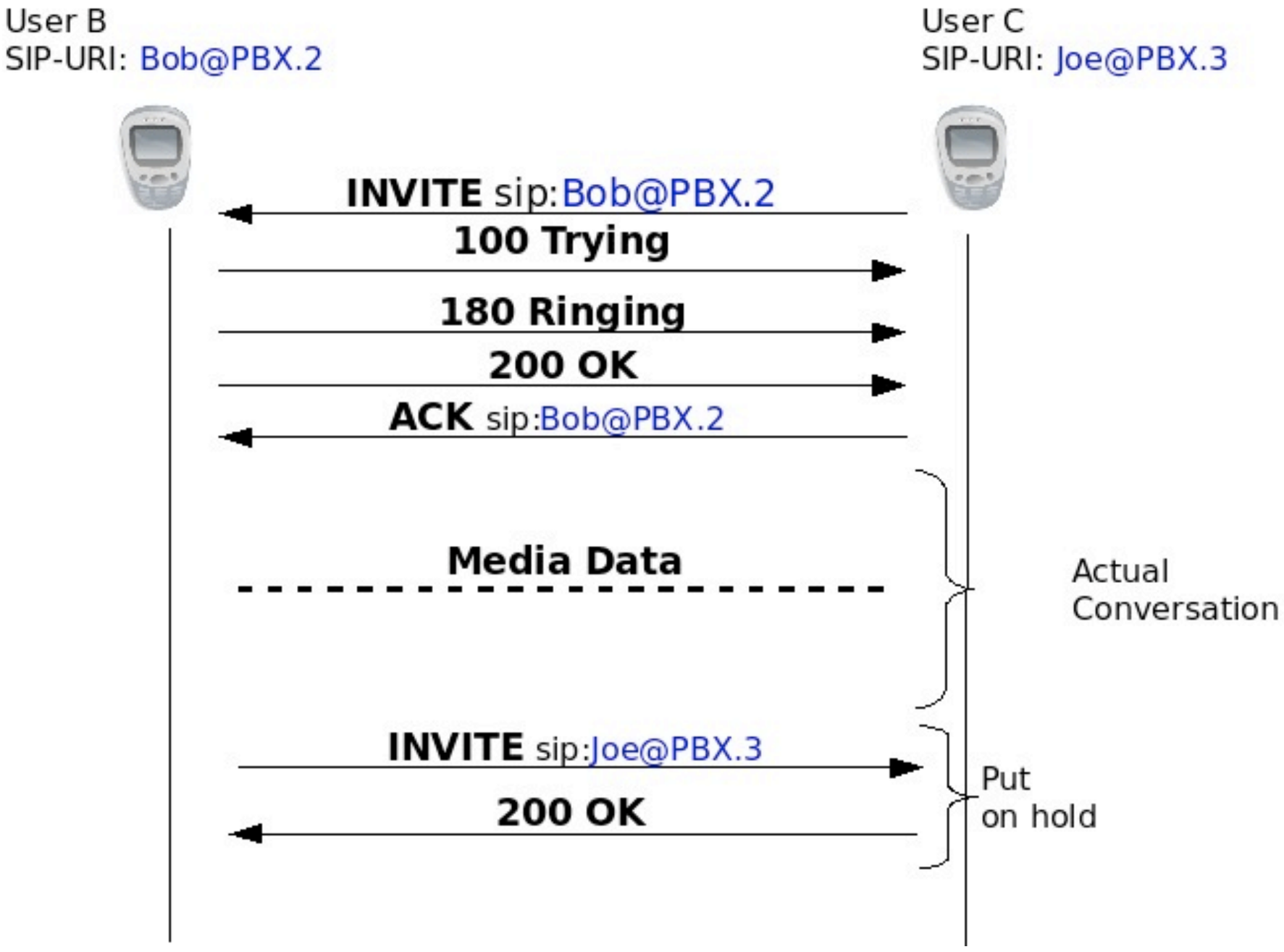
Billing avoidance and XSS attacks

- SQL injection that targets the PBX's billing records

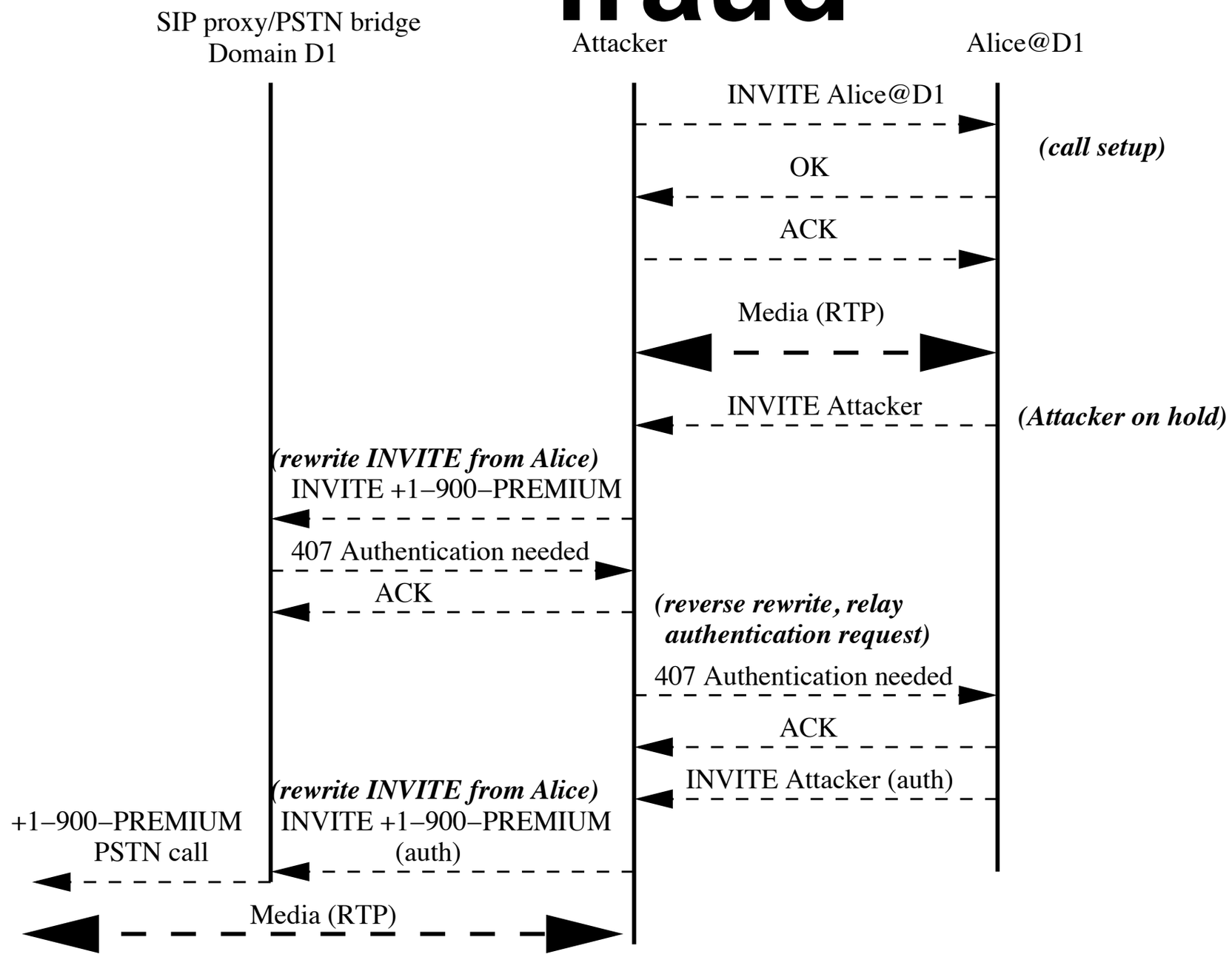
- SQL-enabled XSS attack that targets administrator or user viewing call logs with browser!

Vulnerability by KiF
CVE-2007-54881

Reminder: call forwarding



Protocol games: toll fraud



draft-state-sip-relay-attack

Hybrid threats

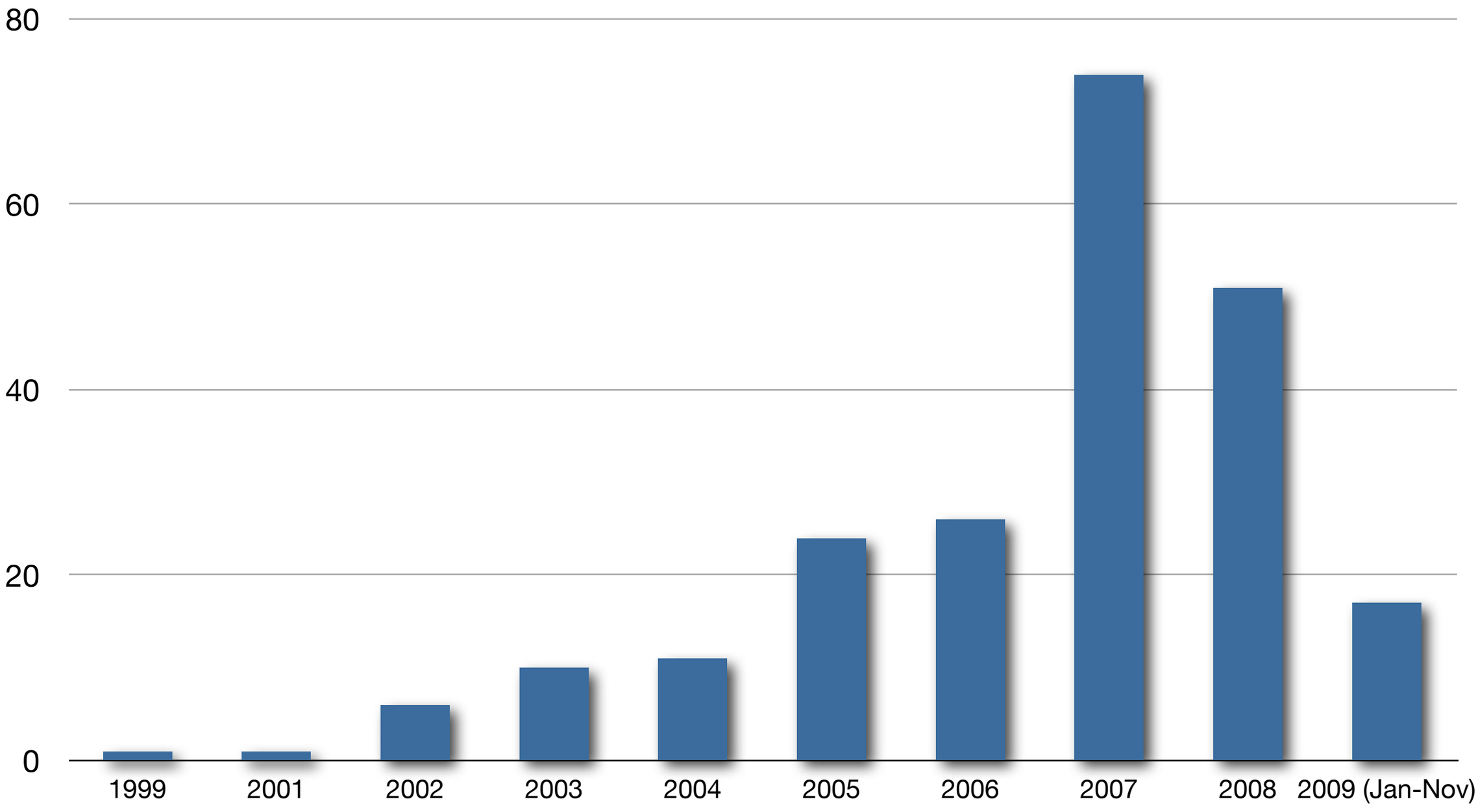
- Generic threats made easy/enabled by IMS architecture
  - more realistic phishing/spear-phishing
    - common attack: call by “bank officer” asking for personal information
      - remember: CallerID easy (trivial) to spoof
    - (somewhat) more complicated attack: compromise SIP signaling to catch the “callback” from customer to the bank!
      - compromise of company SIP-PBX or end-device
      - router- and routing-based attacks
      - DNS poisoning

- Configuration problems
  - many options, many devices: easy to misconfigure

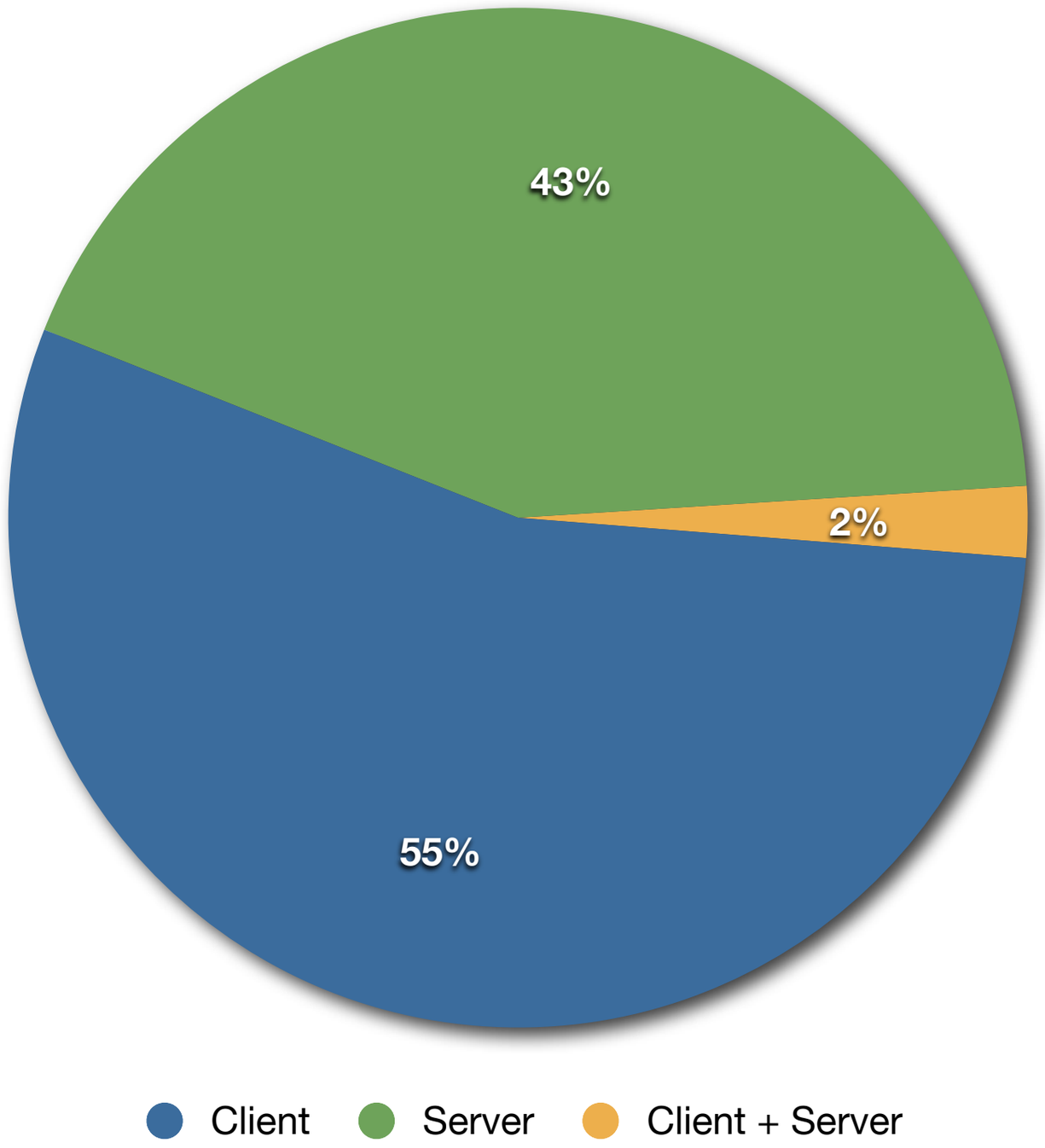
Vulnerability Survey

- Looked at 221 publicly disclosed vulnerabilities on VoIP & SIP
  - listed at the Common Vulnerabilities and Exposured (CVE) database
    - http://cve.mitre.org/
- Classified them according to three criteria
  - VoIPSA taxonomy
  - Confidentiality/Integrity/Availability (CIA) violation
  - Implementation/Configuration/Protocol vulnerability

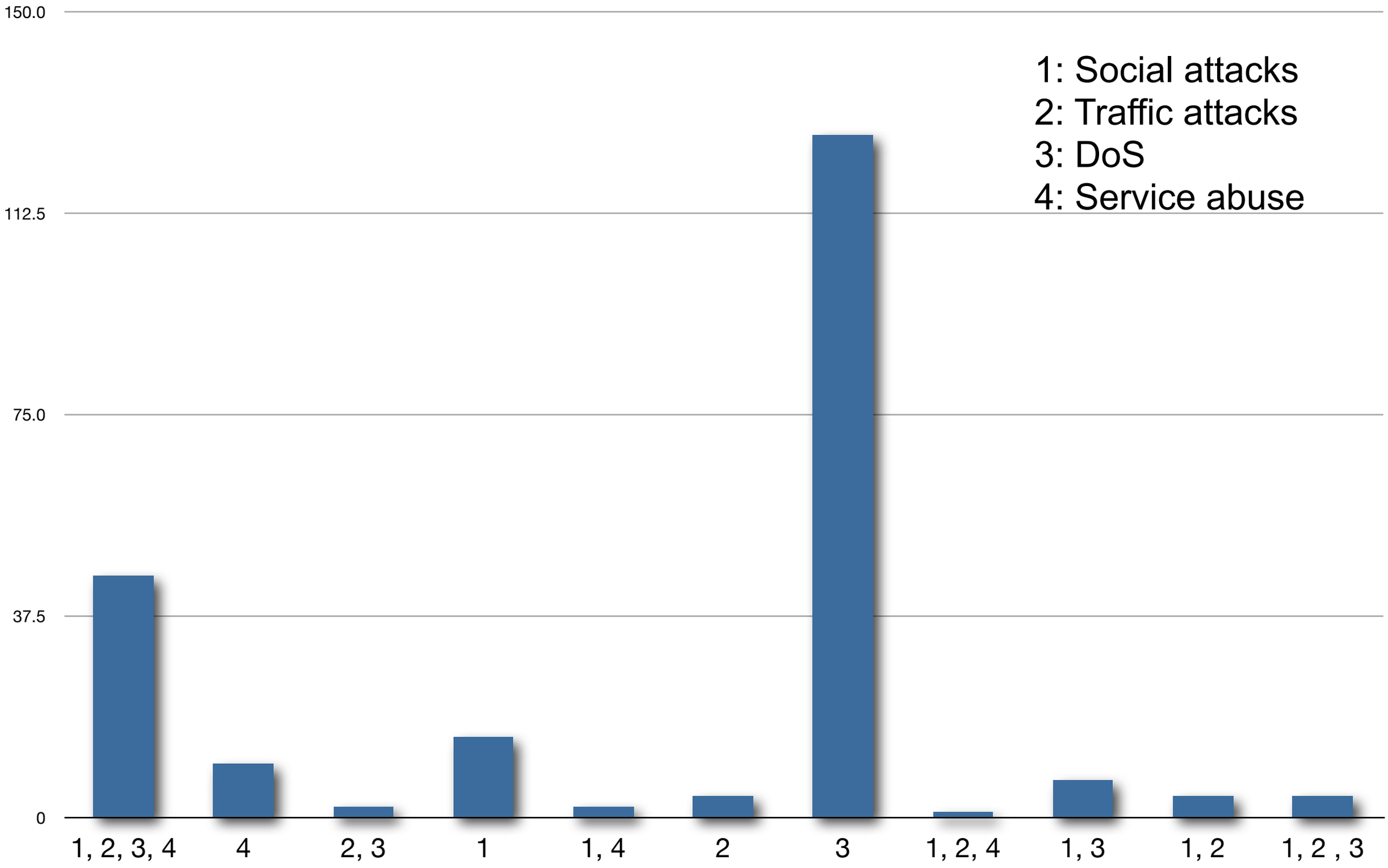
Vulnerabilities/year



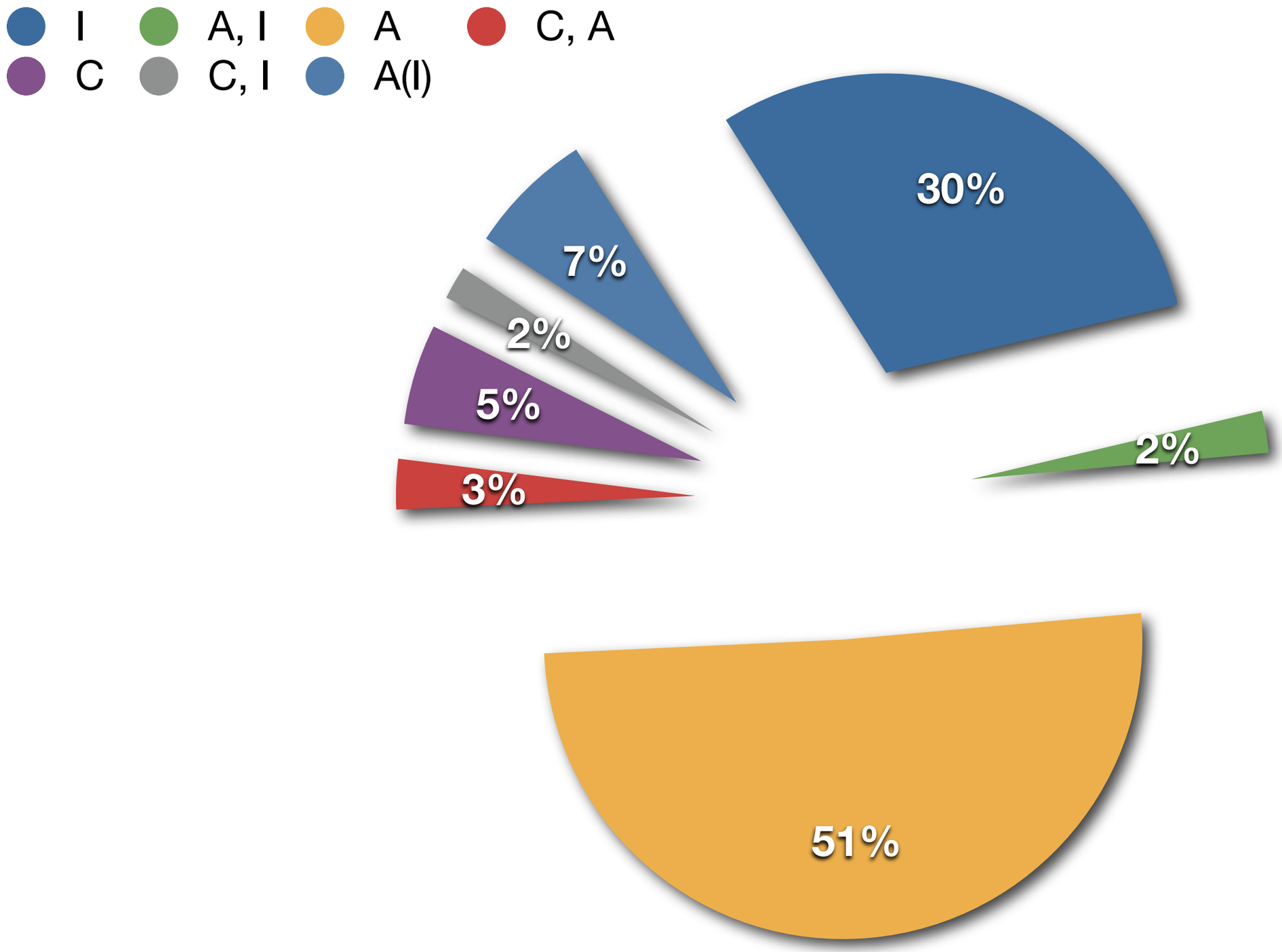
Client vs. Server



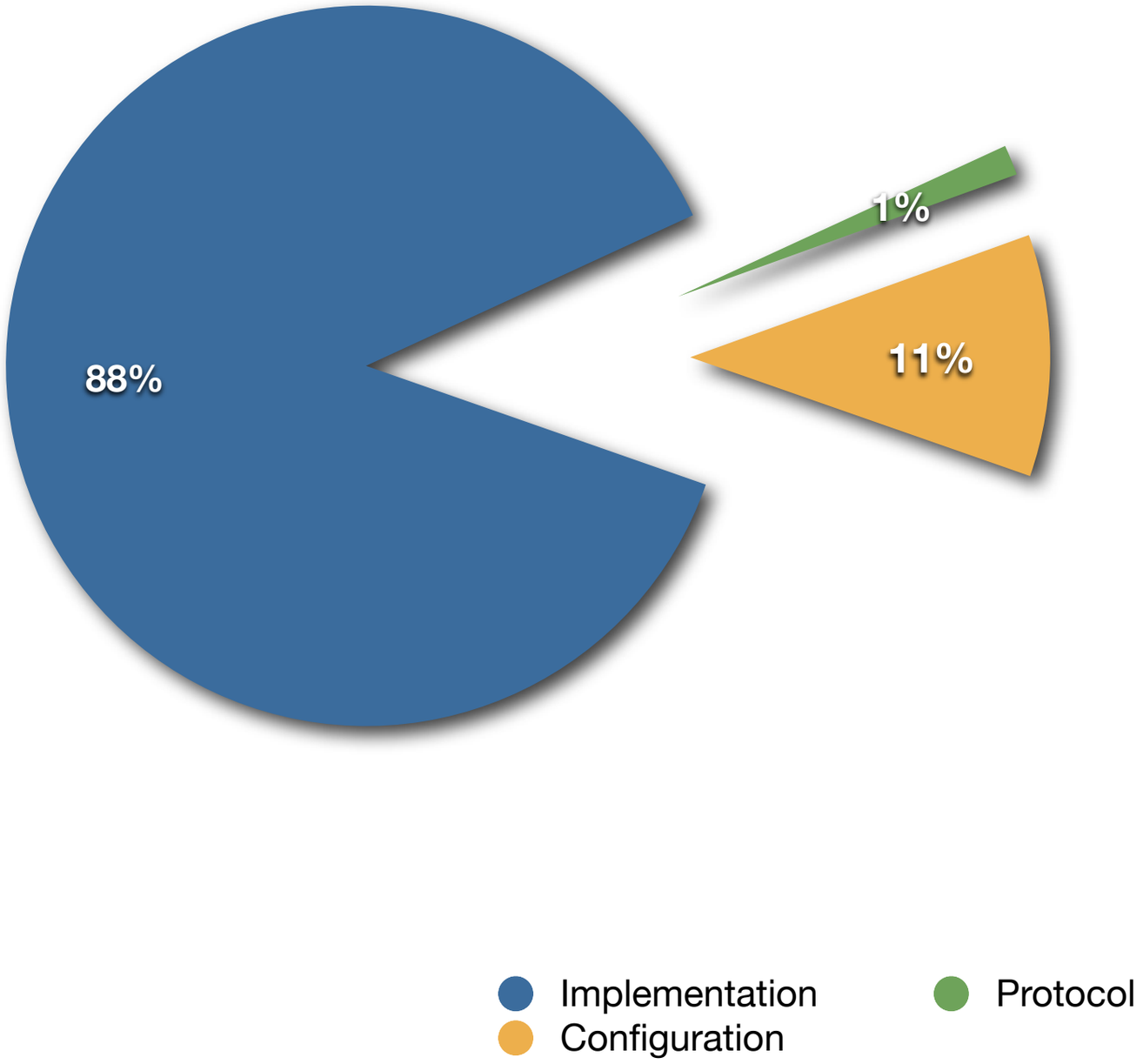
VoIPSA classification



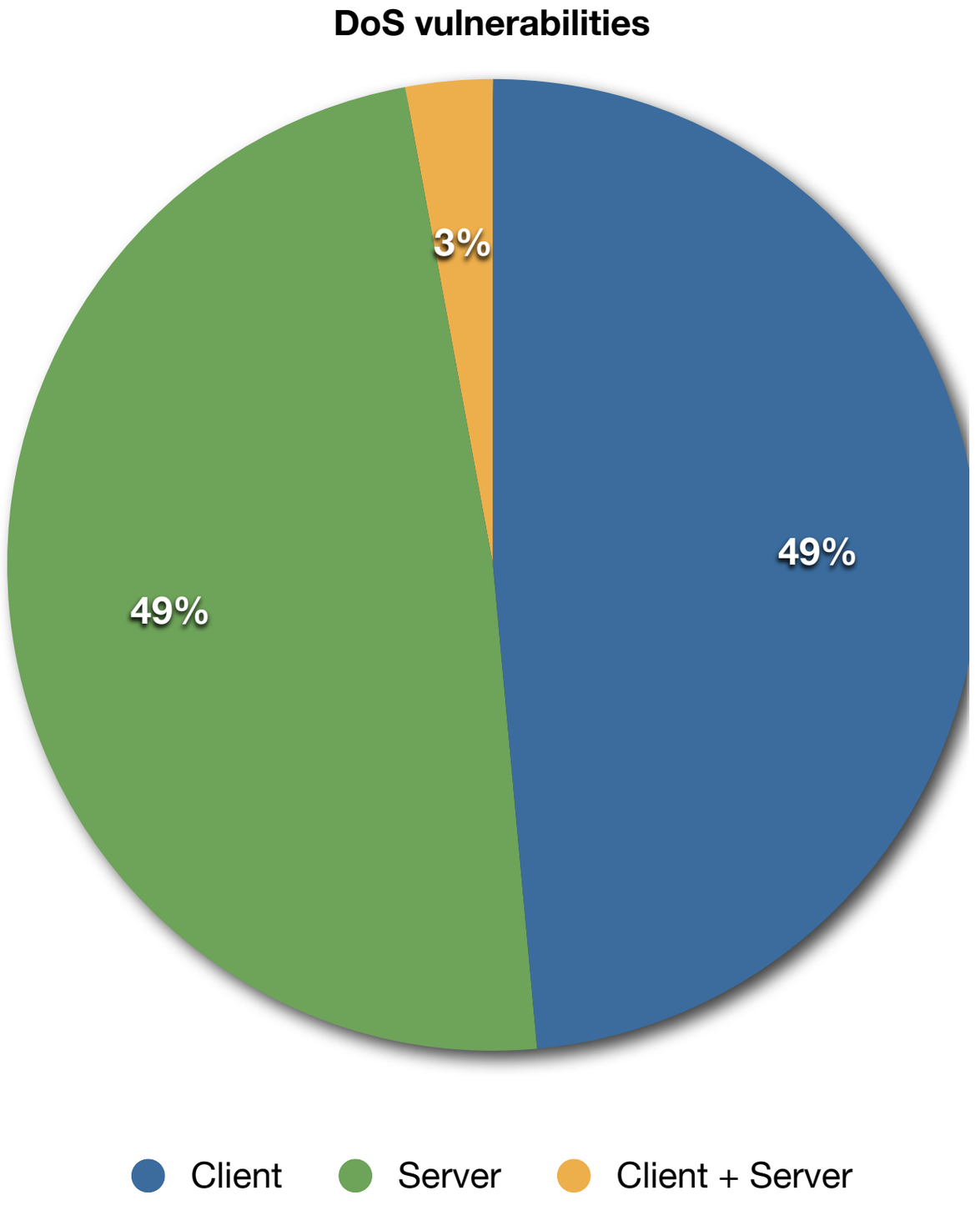
CIA classification



ICP classification



DoS breakdown



Other insights

- Only 3 out of 221 vulnerabilities could be mitigated by the user
  - all others required action by the manufacturer
- 55+ out of 221 vulnerabilities involved cross-protocol interaction bugs
  - most commonly (19/55) through HTTP/web server on device
- 10+ bugs involved default passwords or bad/no authentication
- 3 systems had remotely accessible debuggers running
- 8 vulnerabilities on VoIP-handling component of firewalls or security appliances

Thoughts

- We worry about loss of confidentiality
  - data shows that primary threat is about availability
- Implementations are particularly weak
  - rife with buffer overflows, XSS, CSRF, and other code-injection vulnerabilities
  - lessons for protocol designers?
- Weak default configurations
  - debuggers, unauthenticated privileged access, etc.
  - probably tip of the iceberg on site-specific configuration-based vulnerabilities

Thoughts (2)

- Protocol-level ambiguities and vulnerabilities exist despite many eyes scrutinizing the specifications

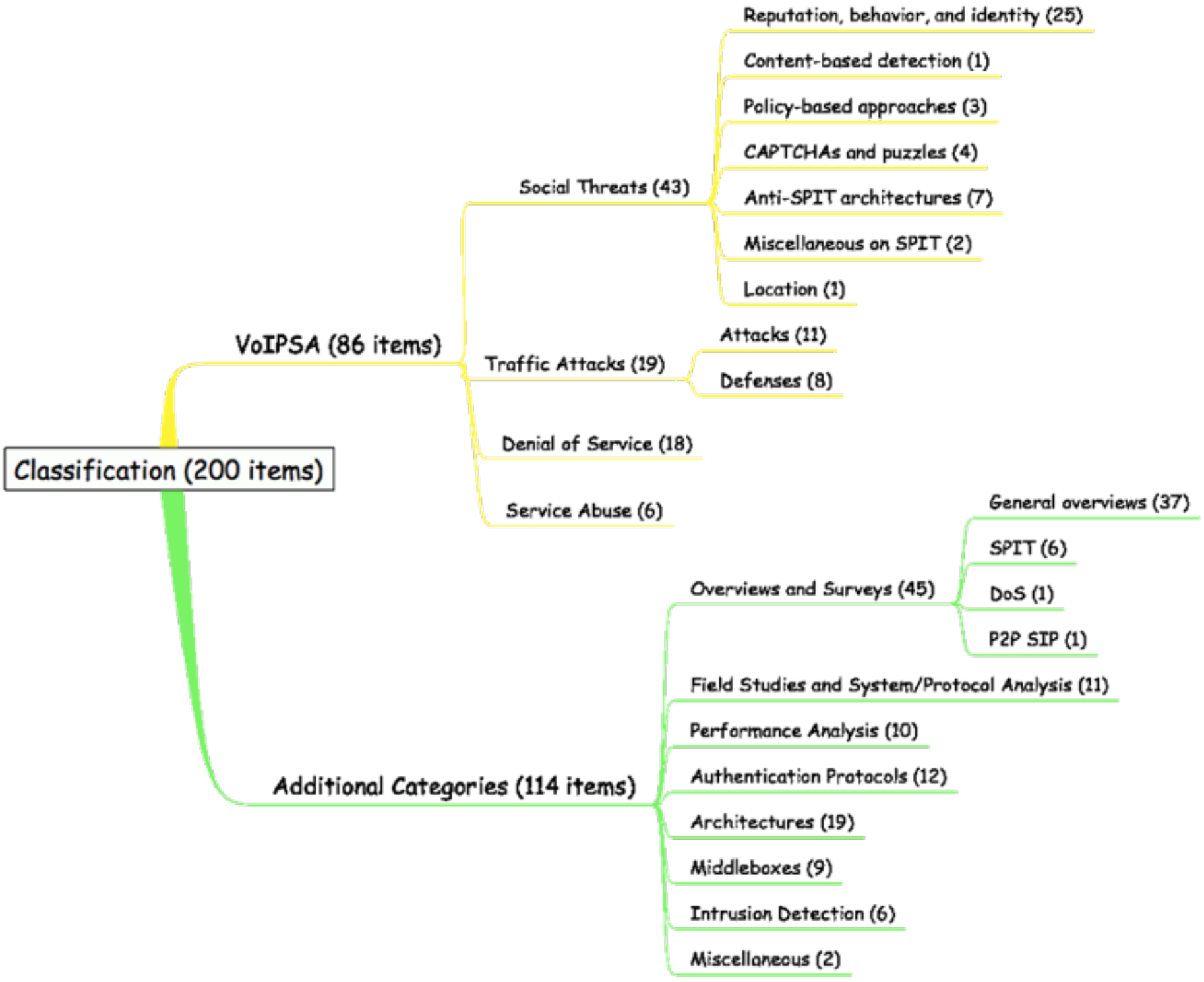
- Large number of cross-protocol vulnerabilities
  - how do we address such problems?

Research Paper Survey

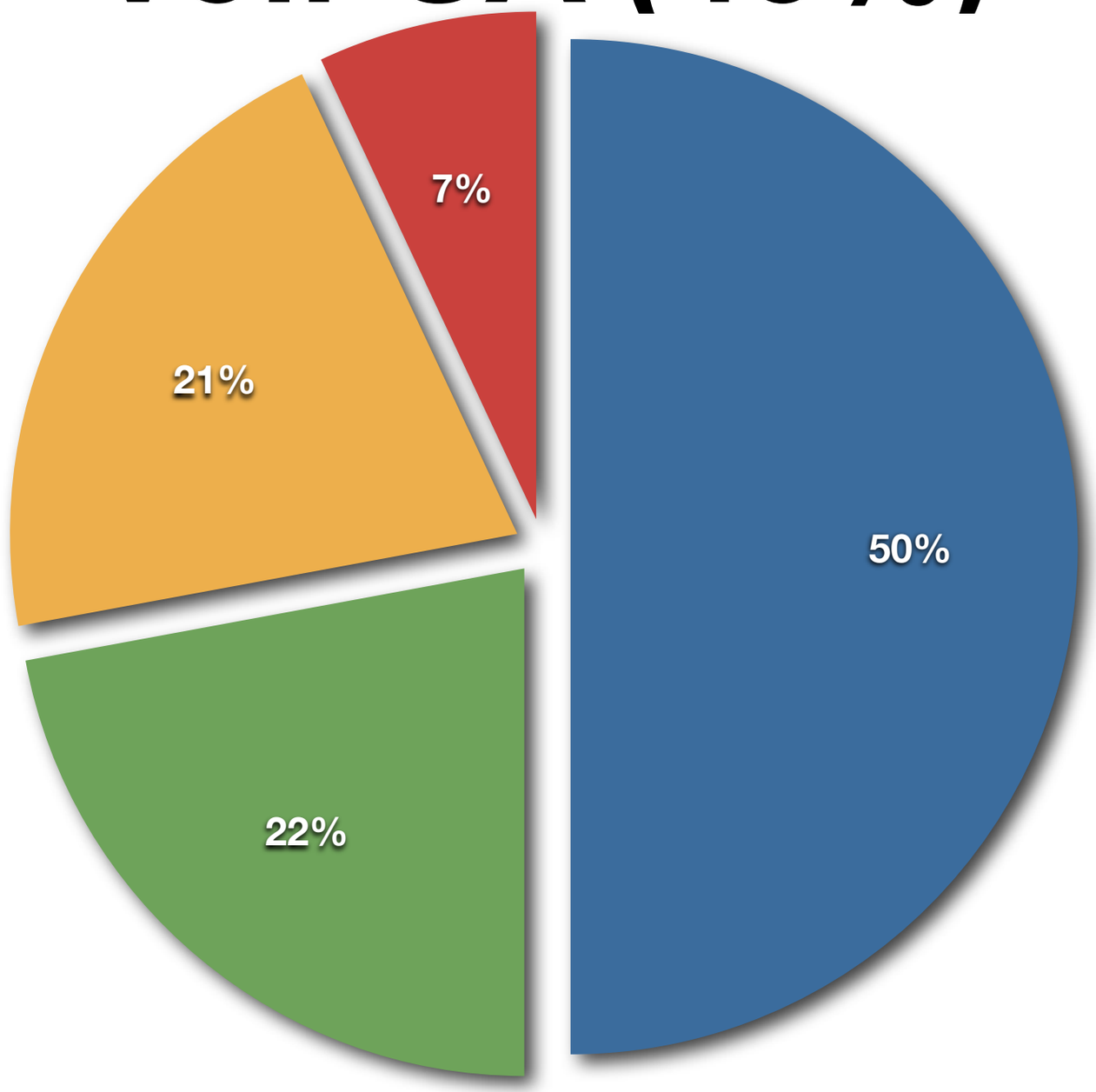
- What do we, as researchers, focus on?
  - Does it relate to the vulnerabilities that are reported?

- Conducted survey of 200 research papers
  - Conference, journals, workshops, plus a few white papers
  - Started from some known seeds, then recursively followed citations to relevant work, looked at prior/following years in same venue, used search engines
  - Group of papers forms a closure under cross-referencing
  - Paper in the ICISS proceedings is short version; longer version to appear in 2010

Paper classification

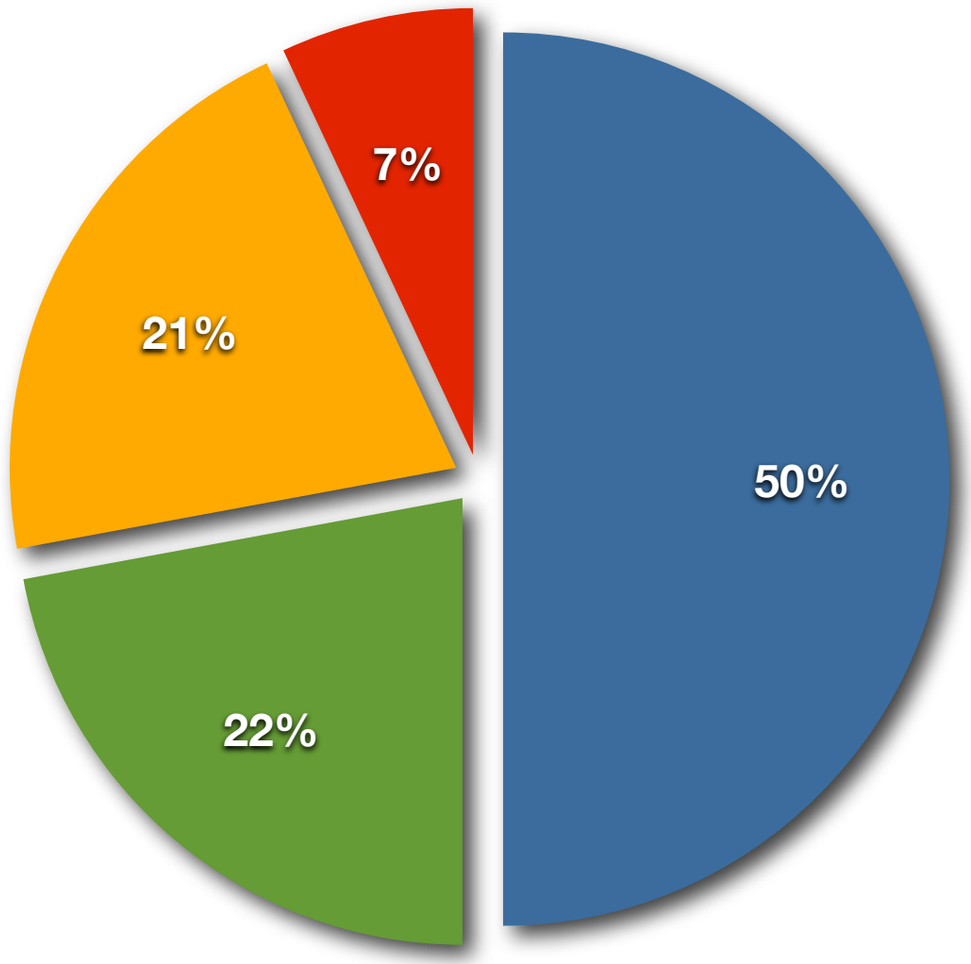


Paper classification per VoIPSA (43%)

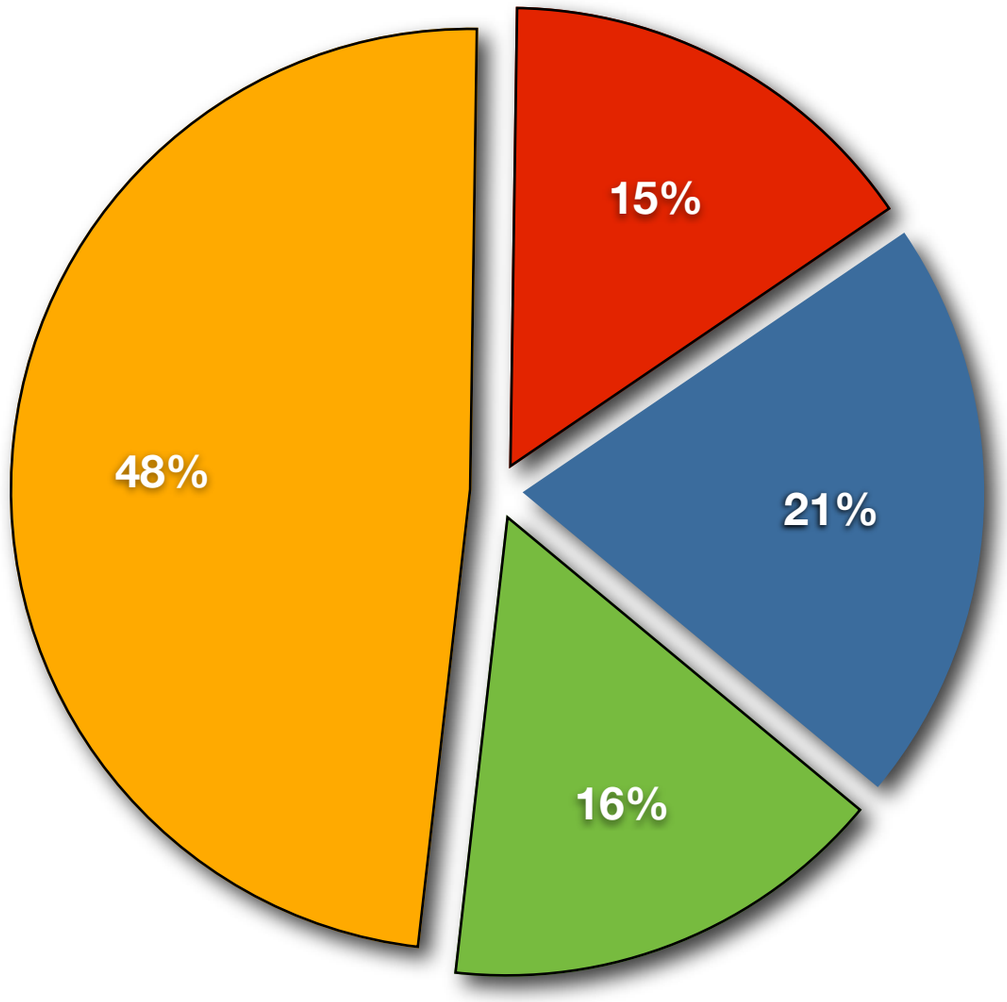


Comparison with Vulnerabilities

Research Papers

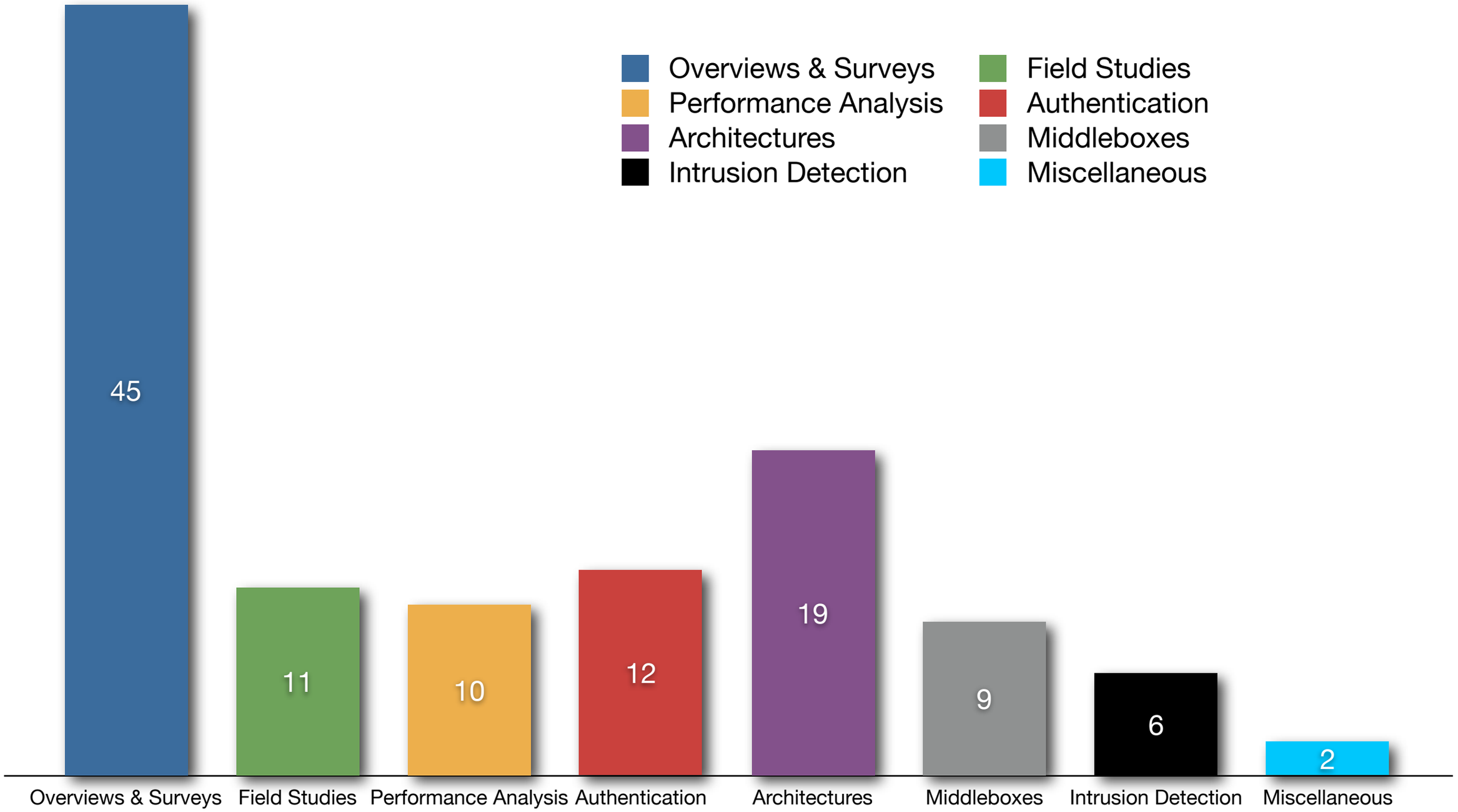


CVE Vulnerabilities



Social Threats (1)
Traffic Attacks (2)
Denial of Service (3)
Service Abuse (4)

Non-VoIPSA papers (57%)



Lessons

- A lot of work goes into SPIT prevention
  - We have not seen much of that in practice
    - the lesson of email SPAM well-learned?
  - But, SPIT isn't all there is to social threats!
    - not much else is being done, in terms of research

- Some work on service abuse is being done
  - Unsurprising, since abuse translates to $$$ lost
  - Statistics-only view can be misleading, however...

- Research severely under-investigates DoS vulnerabilities
  - Note that these are not the same as network DoS (flooding) attacks
  - Particularly worrisome given the vulnerability of both clients and servers
    - how do we do fault tolerance for a VoIP handset?

Big Caveat

- Both surveys represent “static” and abstract views

- We don’t really know what is happening in practice
  - What are the bad guys doing wrt VoIP devices/services, and how?
  - How successful are they?
  - Do they target VoIP service providers, enterprises, consumers, ... ?

- To know the significance of both the reported vulnerabilities and the research being done, we need to know the answers to these questions!

VAMPIRE project

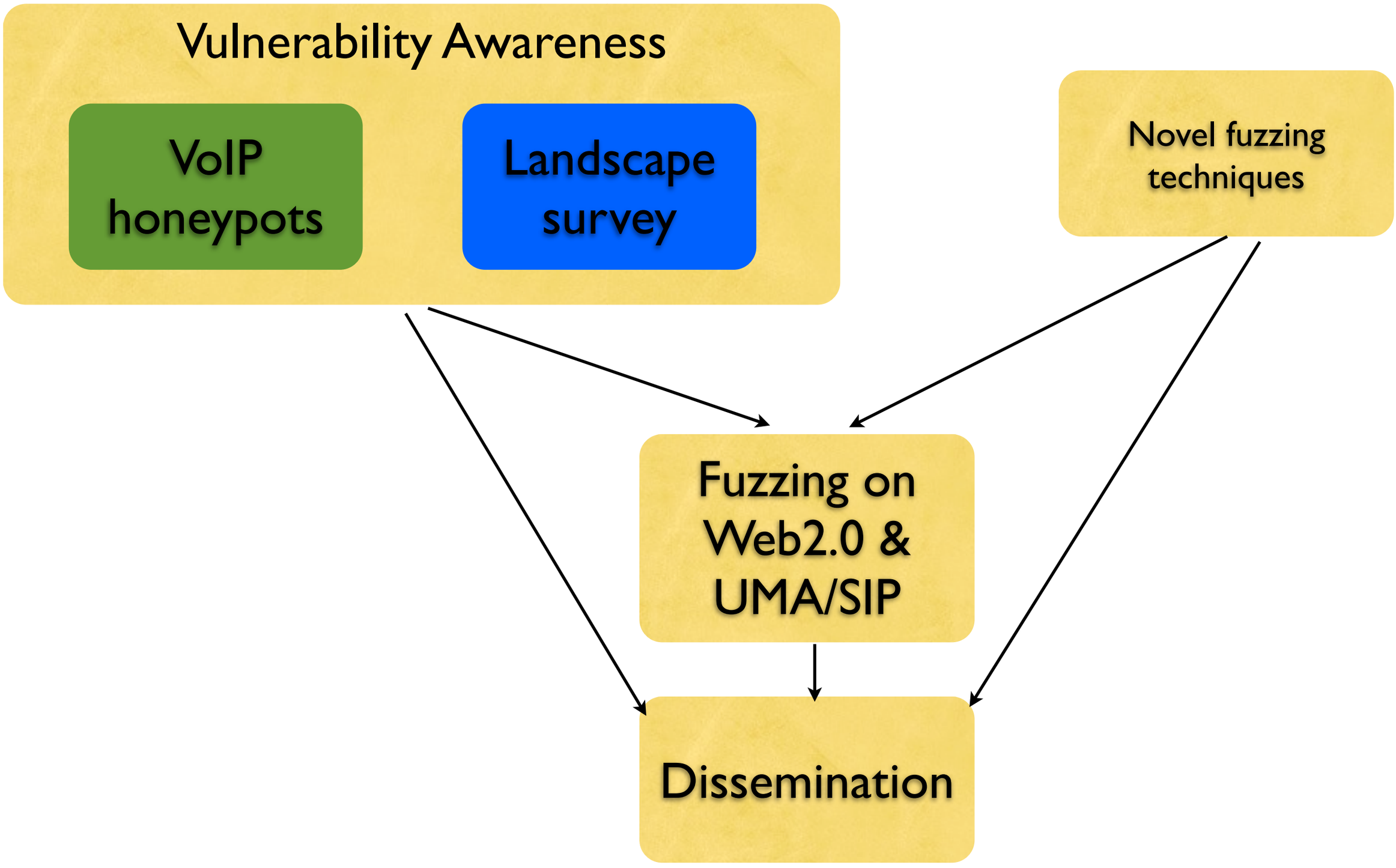
- Research project funded by Agence Nationale de Recherche (ANR; equivalent of US NSF)
  - duration: 3 years
  - start date: January 2009 (approximately...)

- Partners
  - INRIA (lead)
  - EURECOM
  - Symantec Research Labs Europe
  - Orange Labs (France Telecom)

Project goals

- *Design and experimentation of advanced vulnerability discovery methods based on smart fault injection -fuzzing- and passive host-level attack detection.*
  - Vulnerability awareness
  - Automated fuzzing of unknown protocols
  - Close-Loop fuzzing
  - Fuzzing frameworks assessment models
  - Application domains
    - SIP & Web 2.0 SIP interactions
    - IP Multimedia Subsystem

WP interactions



Vulnerability Assessment

- Guide our thinking in approaching the IMS security problem

- Static view: analysis of known vulnerabilities
  - you have seen some early work
  - also to come: analysis of research literature

- Dynamic view: behavior tracking of bad guys

VoIP honeypots

- Dynamic aspect of vulnerability assessment
- Develop techniques for lightweight emulation of IMS
- Track behavior of bad guys with respect to IMS

Dynamic view methodology

- Leverage ScriptGen
  - mechanism for “learning” protocol interactions
  - aimed at creating high-fidelity low-interaction honeypots
- Leverage and augment existing distributed honeypot infrastructure

SGNET

- Distributed honeypot deployment for the analysis of code injection attacks
  - How does malware propagate?
  - What kind of exploits are observed in the different locations of the Internet?

- Honeypot sensors distributed over the whole Internet
  - Deployed by volunteering partners
  - WIN-WIN partnership: hosting a sensor, the partner receives access to the whole data
  - Non-Disclosure Agreement to protect the identity of the participants, attackers and victims

ScriptGen

- Protocol-agnostic algorithm
- Observe conversation samples between a client and a real server
- Infer semantics using bioinformatics algorithms
- Proved good results in handling deterministic exploit scripts

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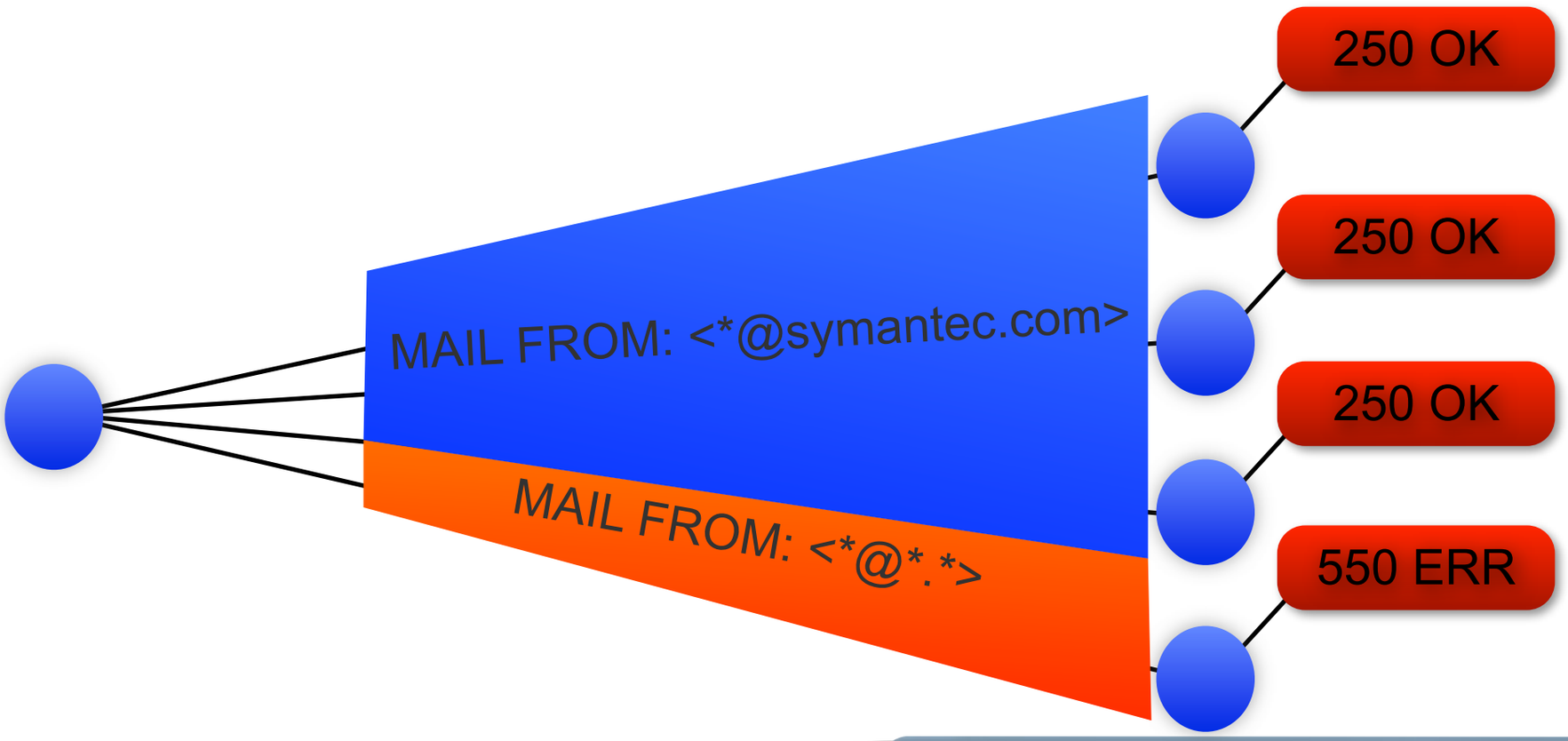

SGNE

- Normal operation
- New exploit encountered
- Global update of the FSM knowledge
- Submission of a shellcode sample
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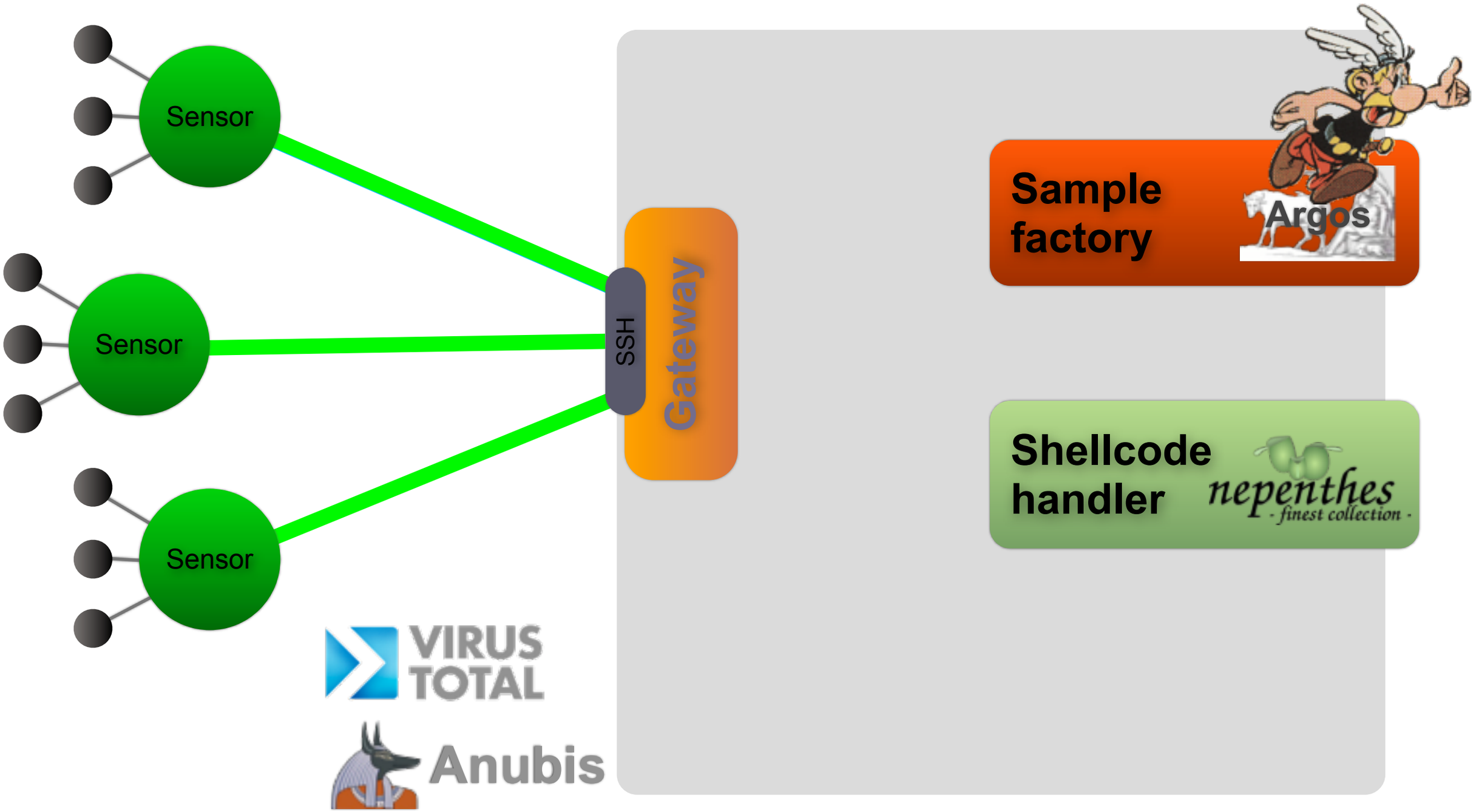

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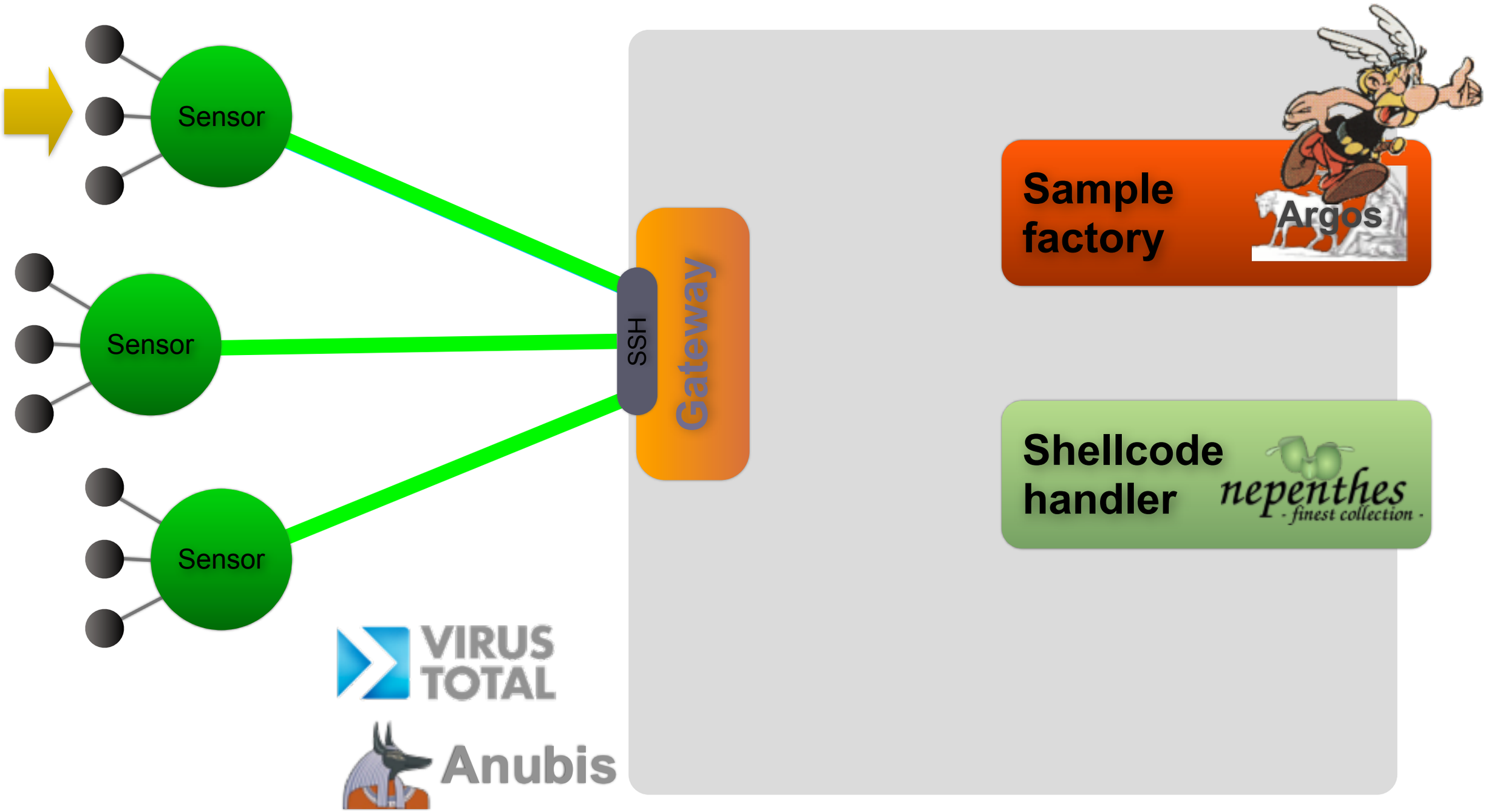

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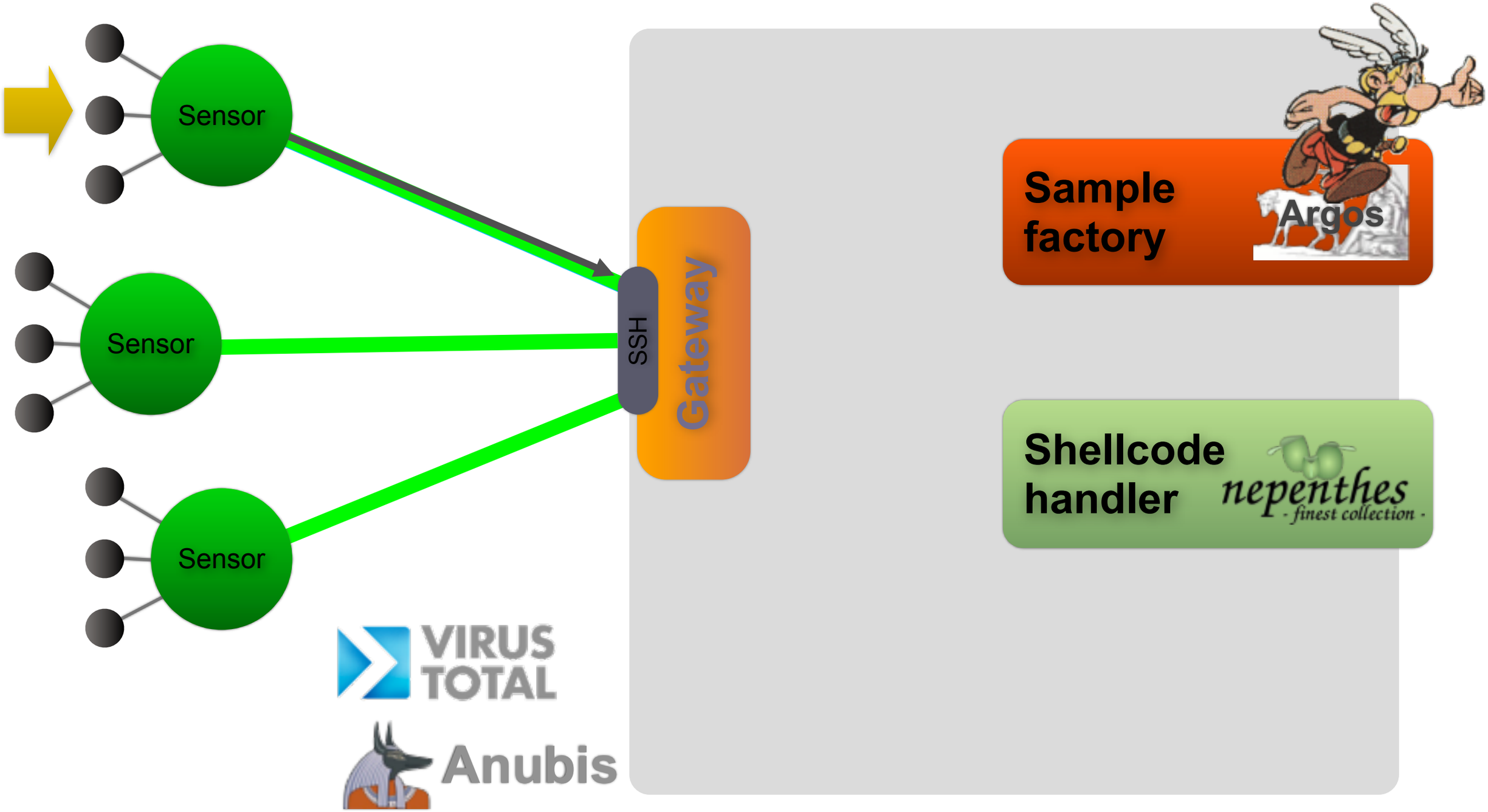

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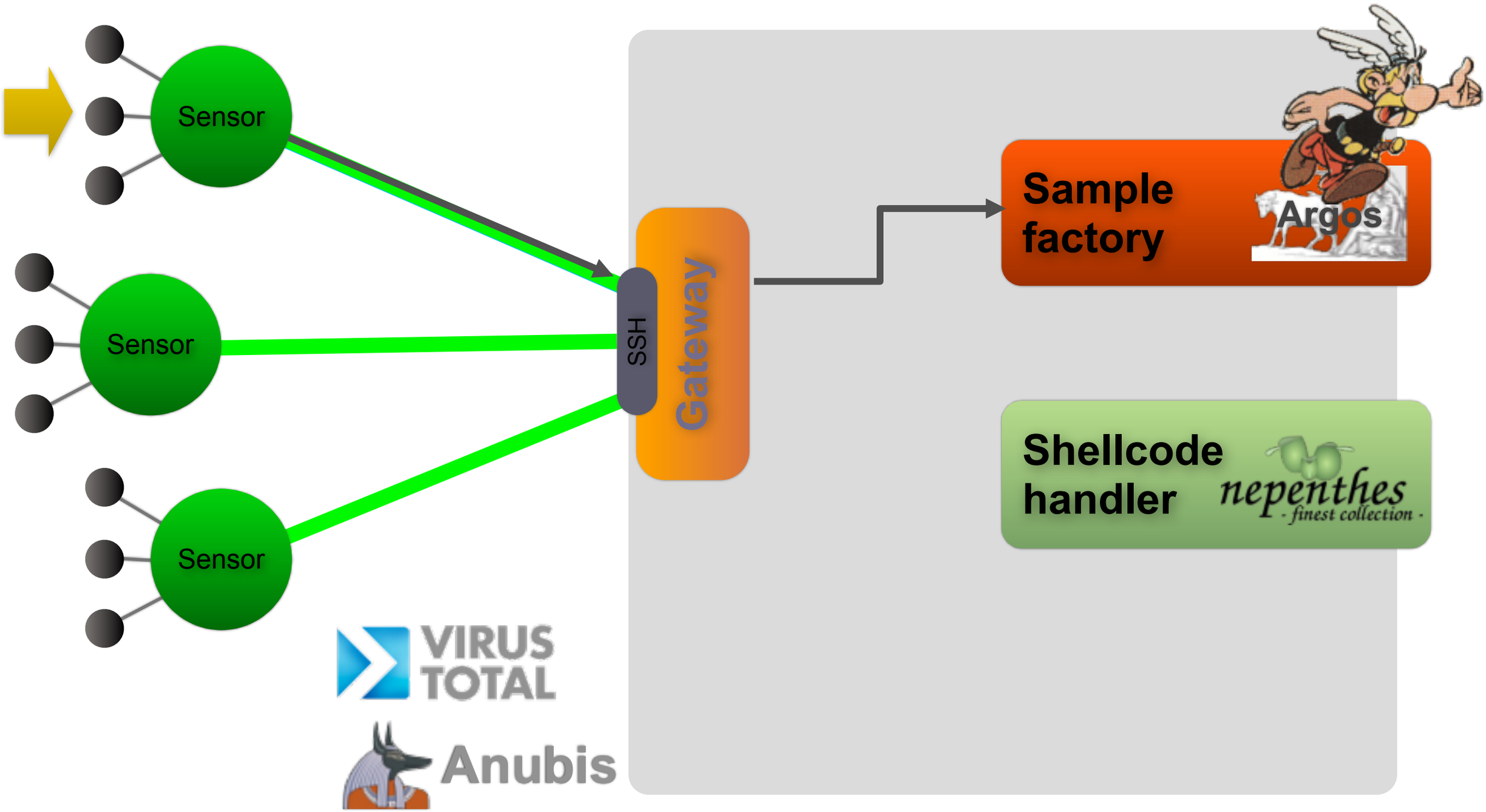

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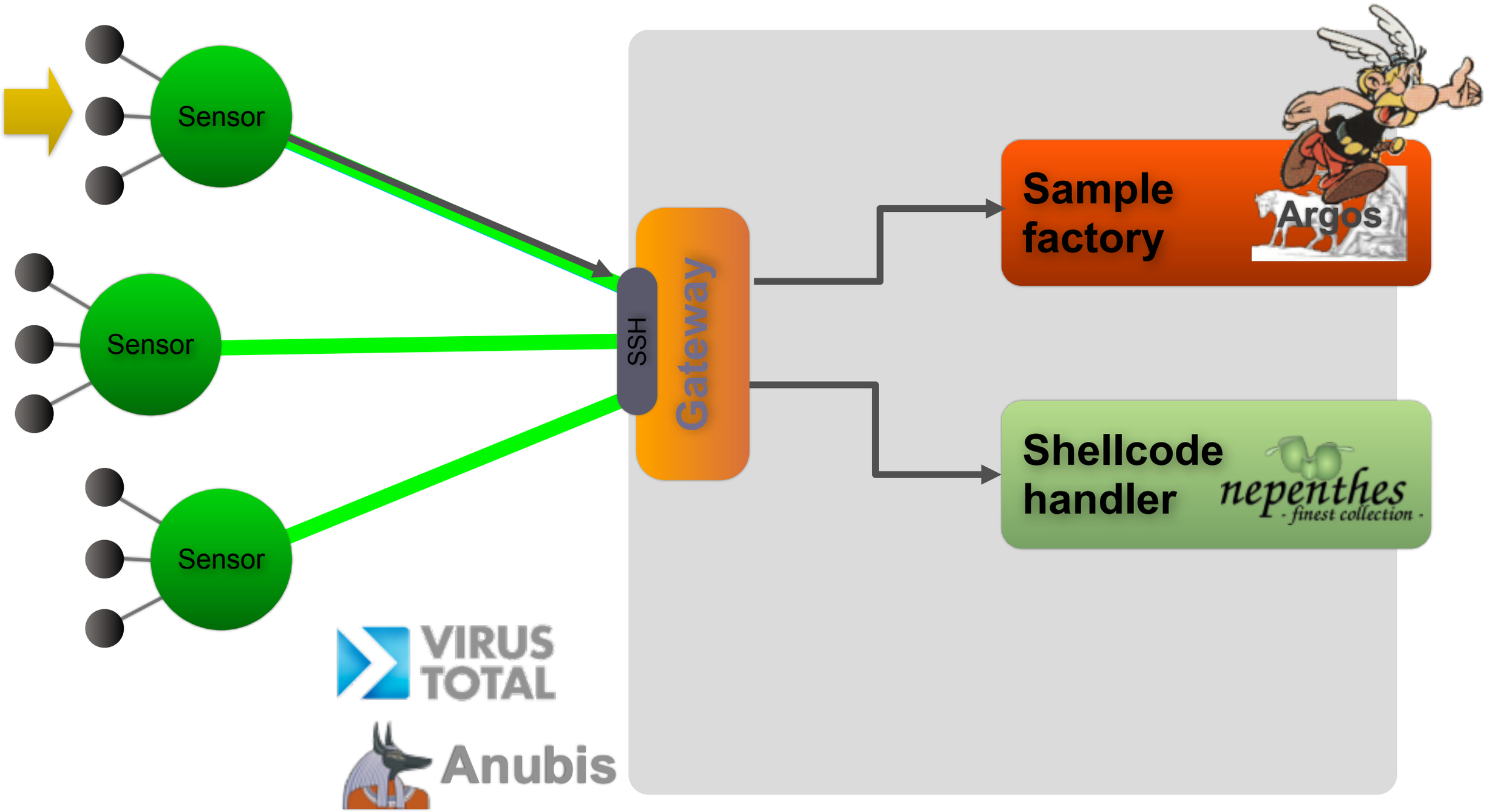

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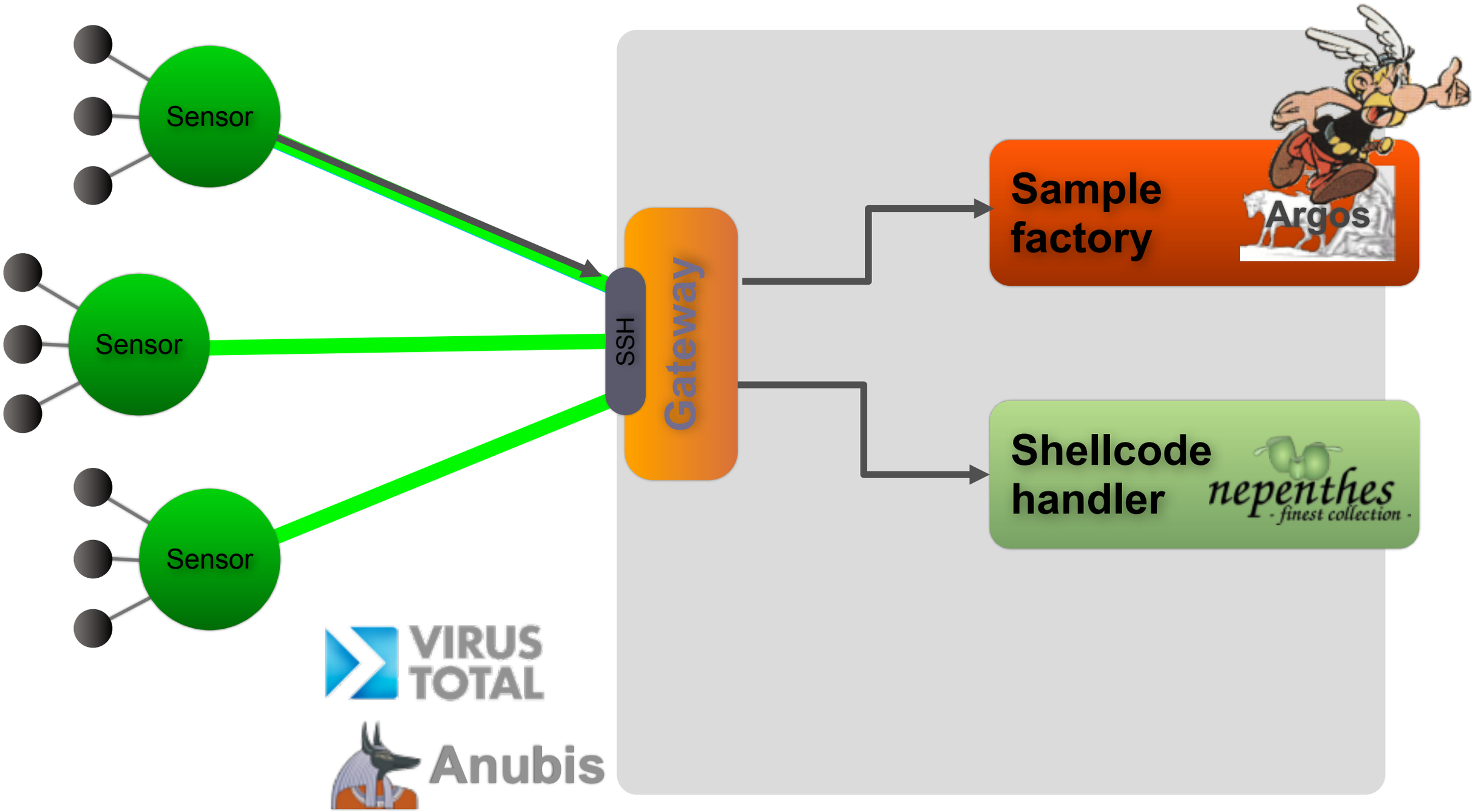

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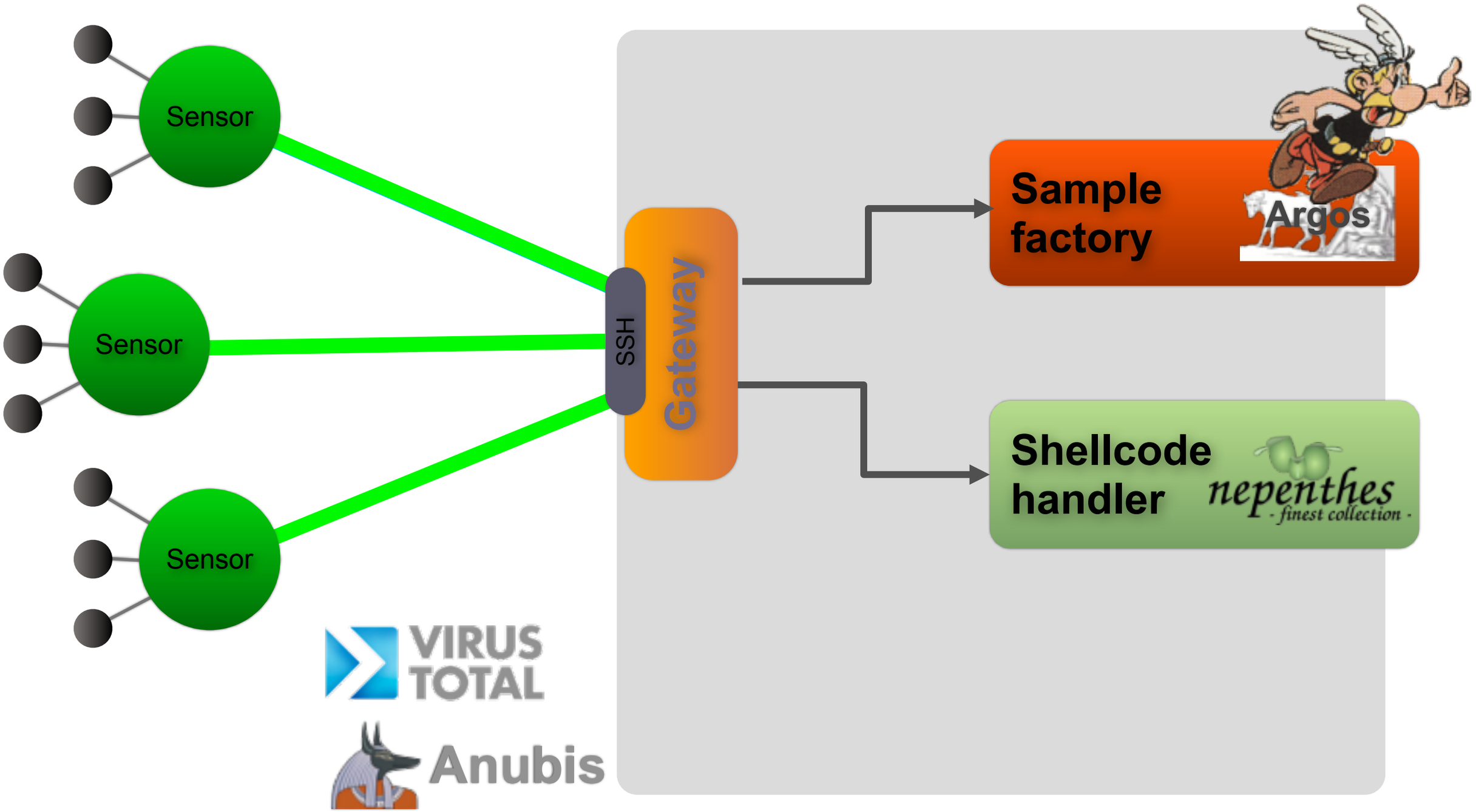

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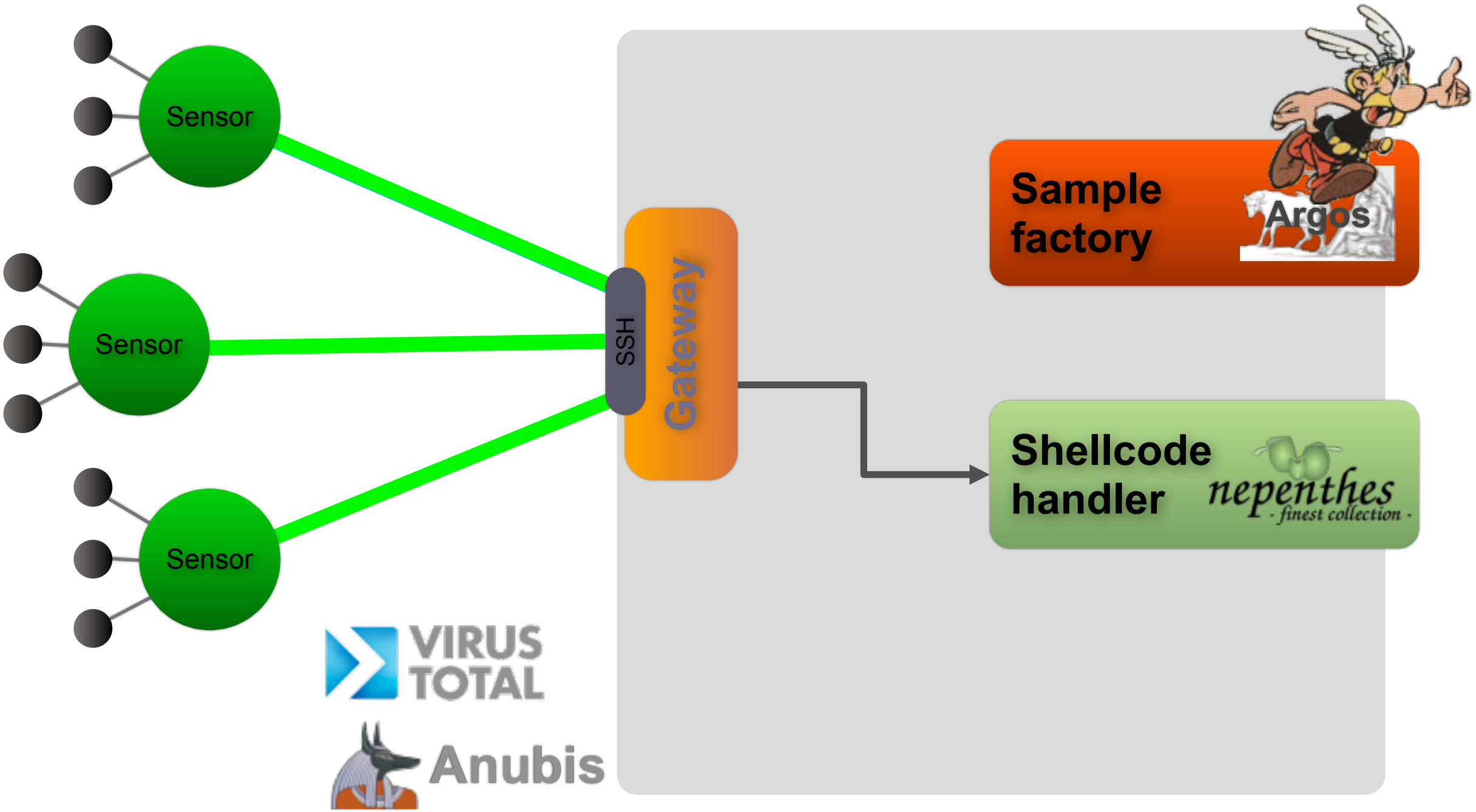

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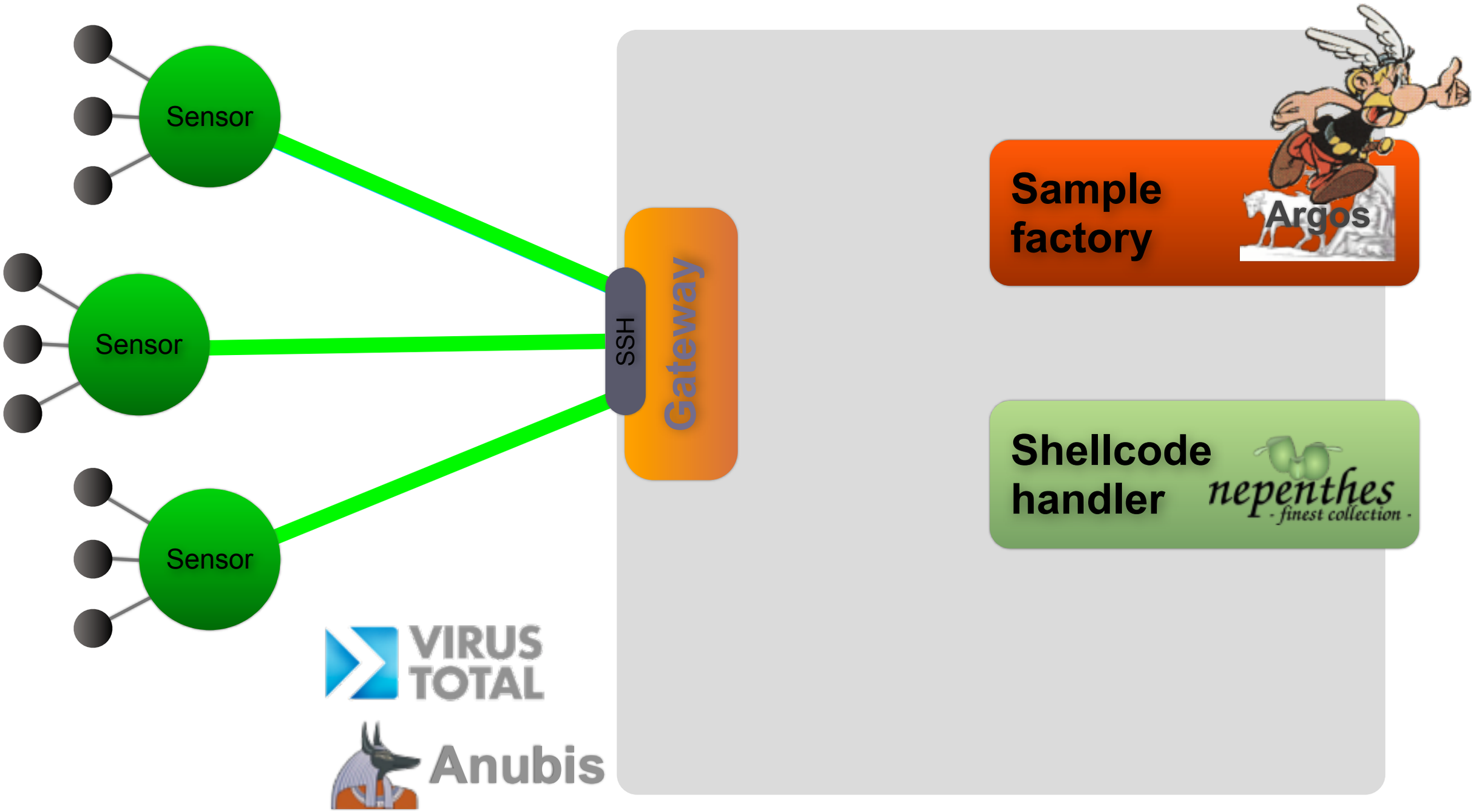

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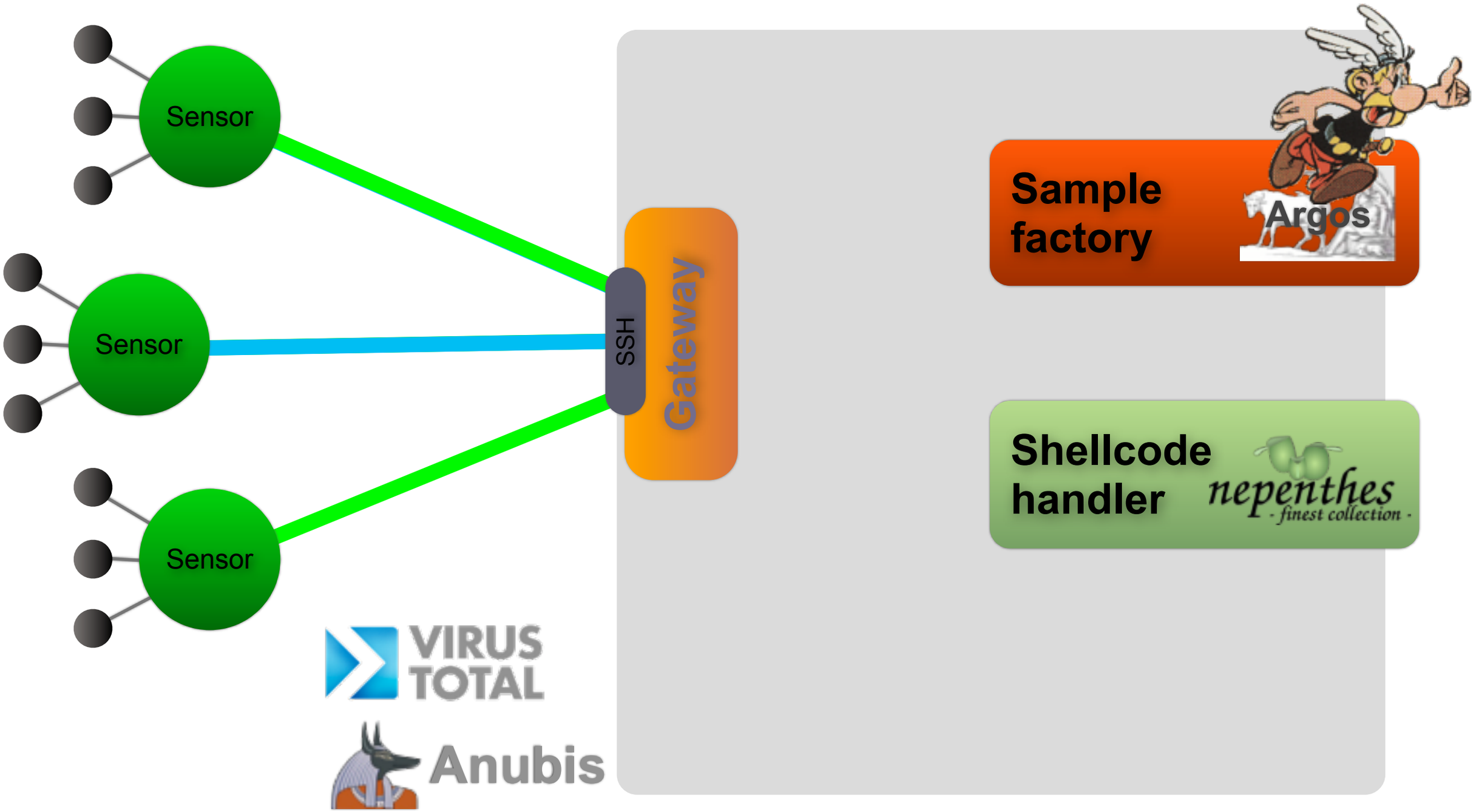

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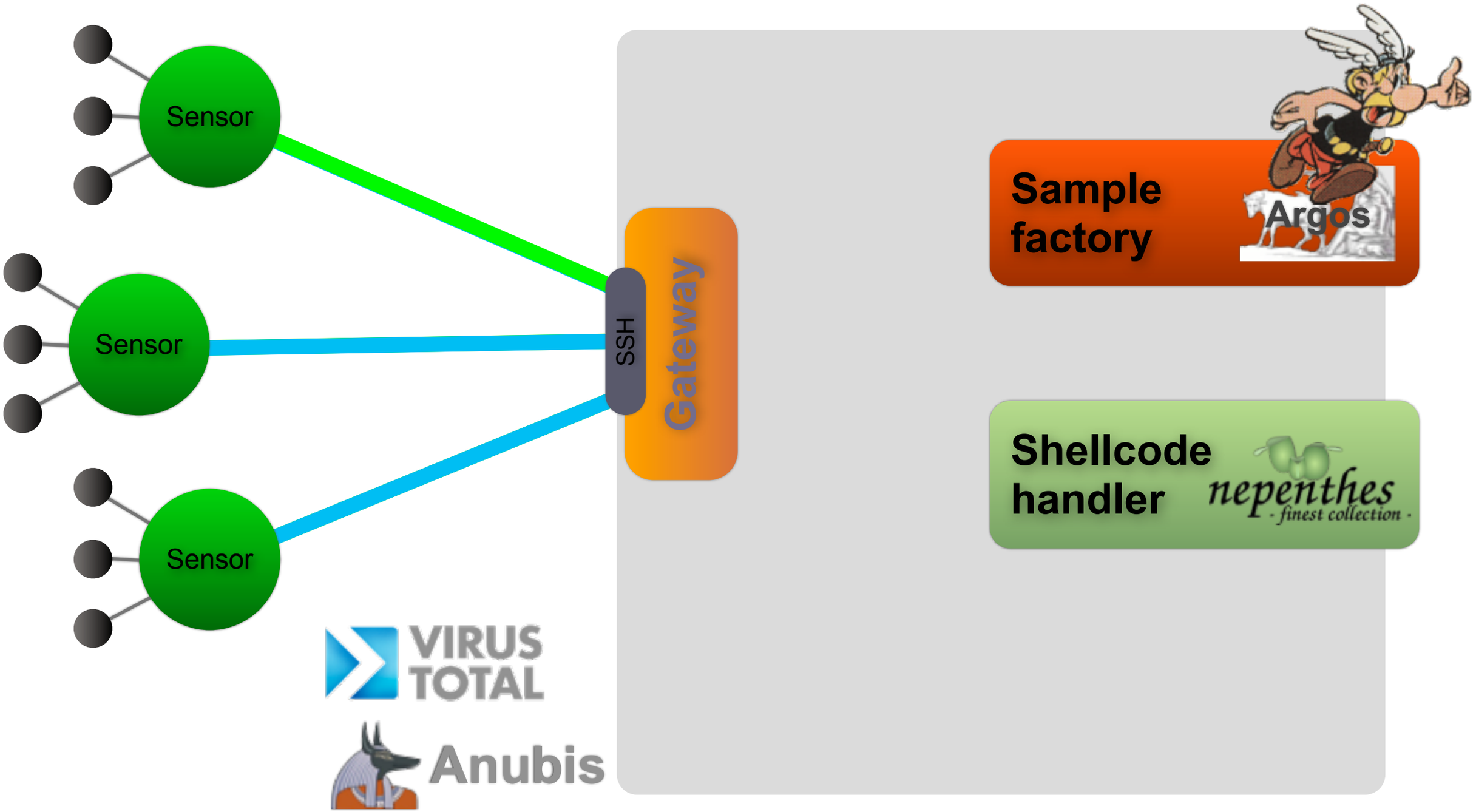

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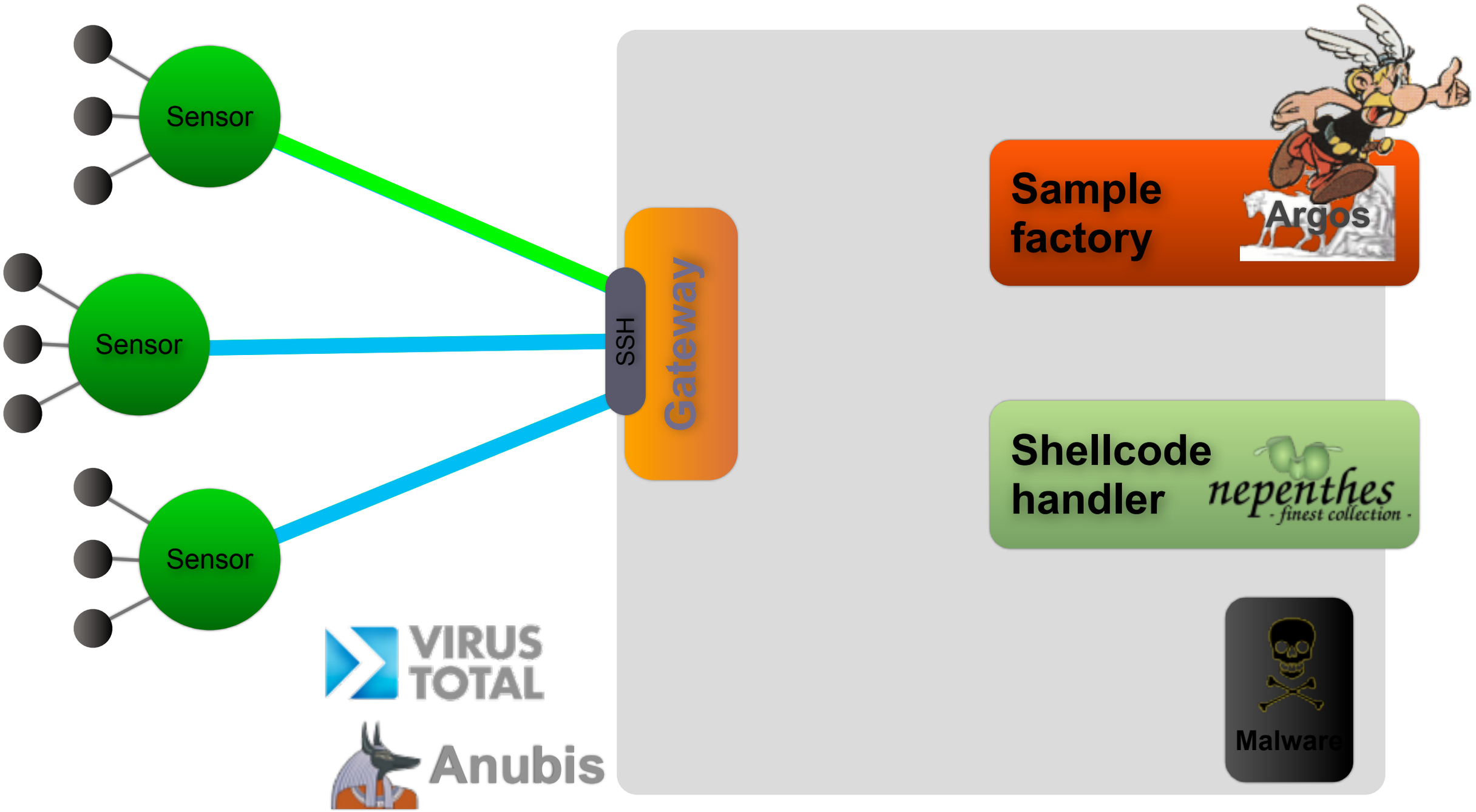

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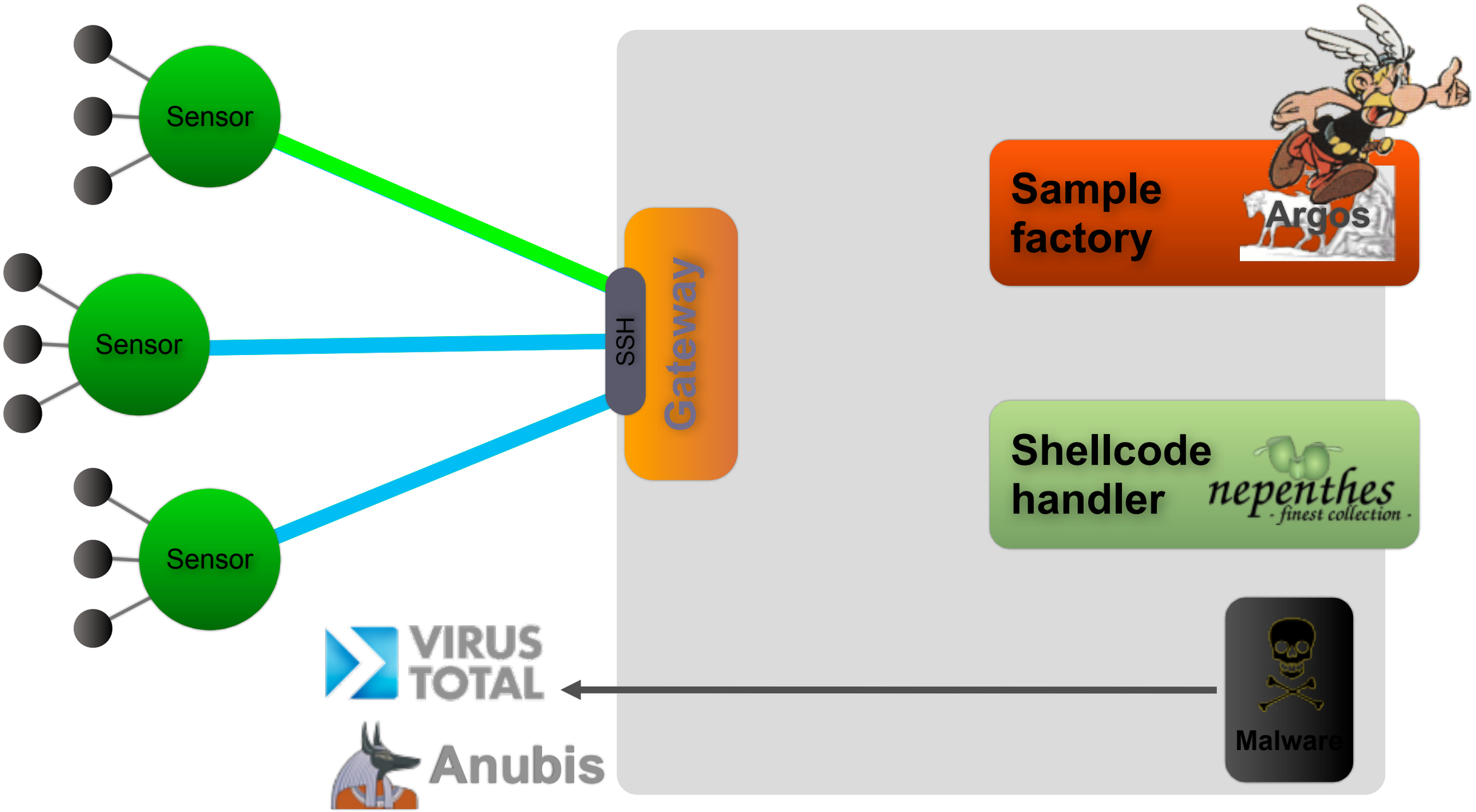

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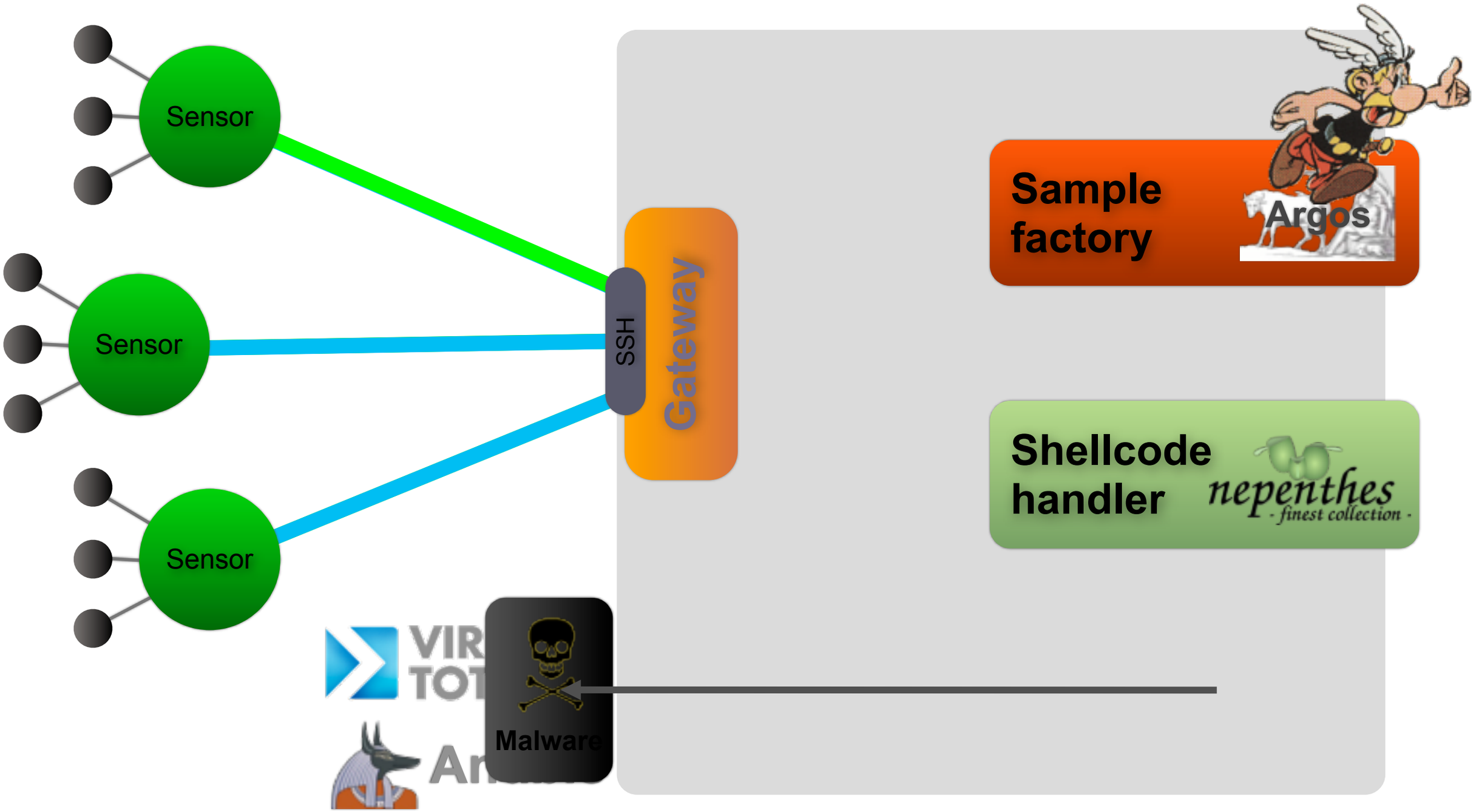

Data enrichment

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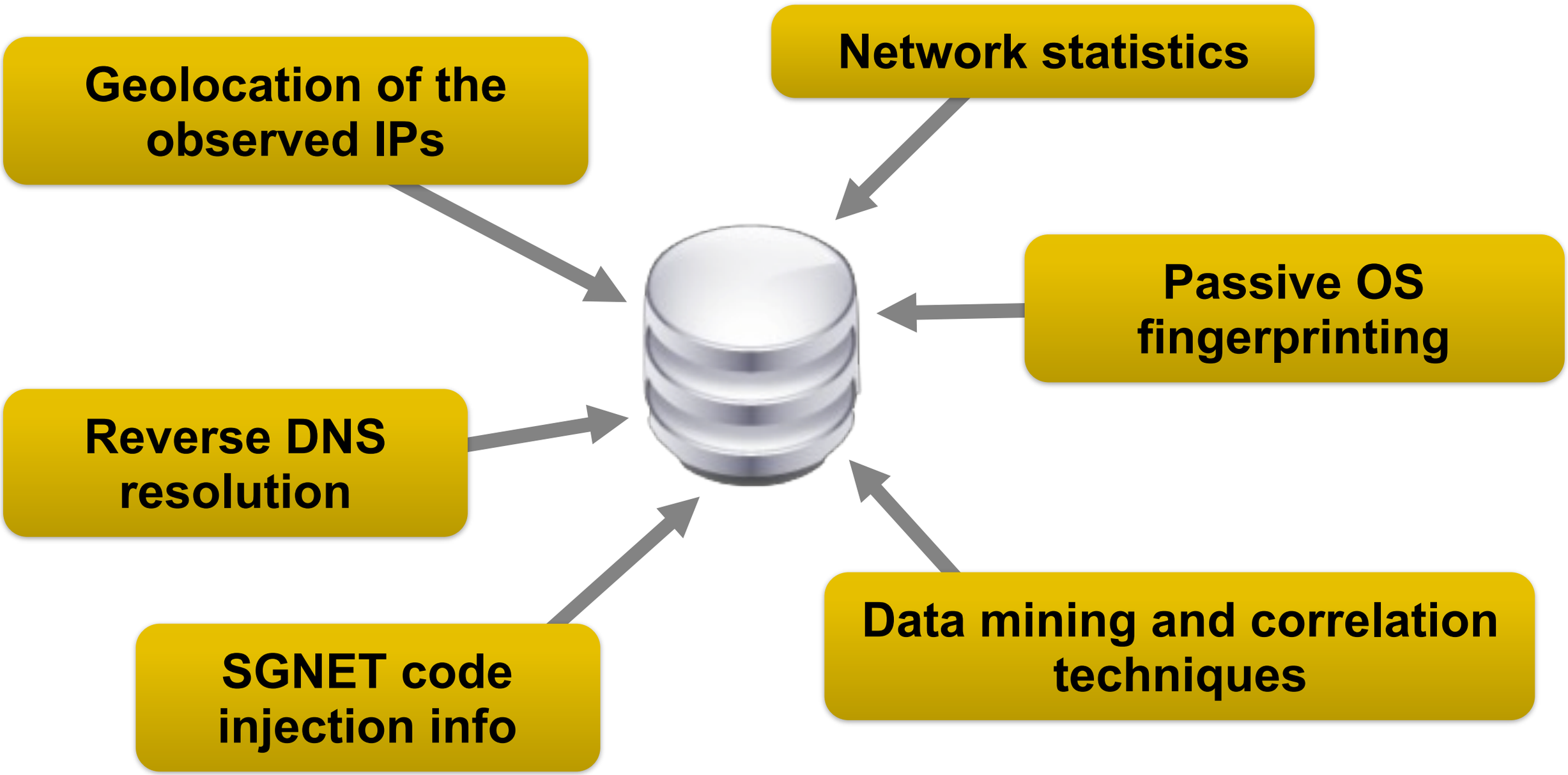

VoIP honeypots

- Simulate PBXes, end-devices
  - e.g., Cisco phones, Nokia SIP-enabled cellphones, Android?

- Look for low-level vulnerabilities and misconfigurations
  - pre-requisite: analysis of common misconfigurations
  - challenge: how do we setup believable and trackable SIP honeypots?

Summary

- What we covered
  - VoIP protocols theory of operation
  - perceived threats against VoIP infrastructures
  - actual vulnerabilities in VoIP systems
  - Research being done
  - VAMPIRE project
- Availability threats are predominant
  - clients and servers equally vulnerable; little research being done
- Of the rest, weak/bad configurations and cross-protocol problems are the hardest to detect
  - often the most catastrophic as well
- How do we secure a complex infrastructure of this scale and complexity?