Security Patterns for Automotive Systems

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Overview

- Background
- Review of threat surfaces
- Automotive Security Pattern structure
- Excerpts from Automotive Security Pattern repository

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Motivating example

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S ftware
E gineering &
N twork
S stems Lab

http://youtu.be/MK0SrxBC1xs

https://www.youtube.com/watch?v=2NQSE31OktQ

http://youtu.be/MK0SrxBC1xs

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Automotive Security Concerns

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``Hot off the press”

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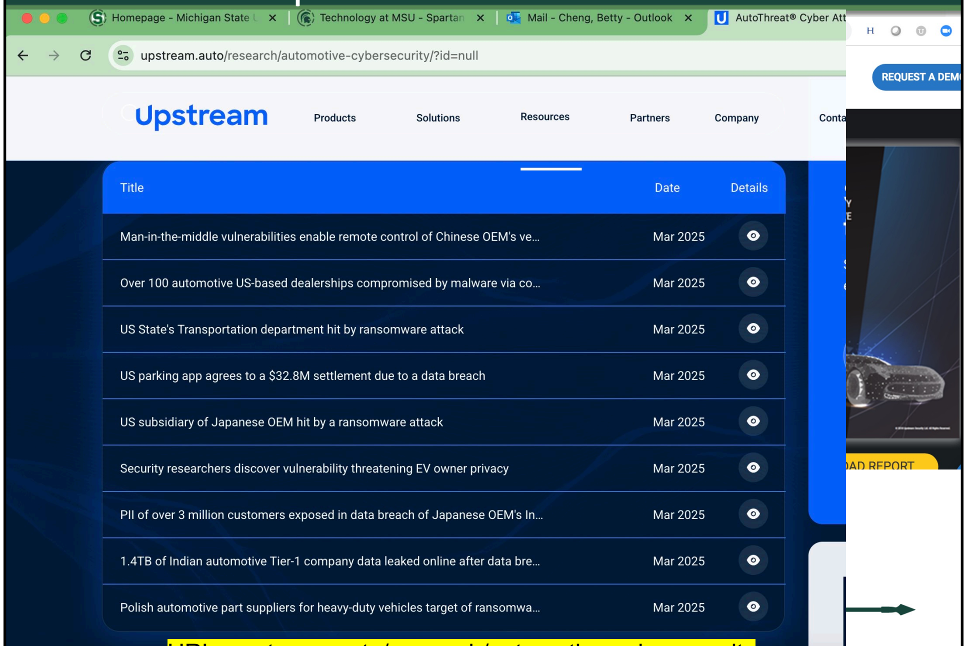

URL: upstream.auto/research/automotive-cybersecurity

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CAN-Bus Threat Surface

- Broadcast protocol available to any attached ECU [10]
- Lacks authentication and encryption [10]
- Message arbitration is based on a prioritization scheme [11]
- Subject to attacks:
  - ECU injection attacks [12]
  - Compromising sensitive data [10]
  - DDOS attacks [13]

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V2X Threat Surface

- Vehicular Ad-hoc Networks (VANET) allow network nodes to move freely within a range and stay connected [14]
  - Vehicles communicate with one another
  - Vehicles communicate with roadway infrastructure
- Nodes communicate with other nodes through node hopping,
  - routing is determined in real-time [15]
- Nodes freely enter and leave a given network [15]

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Other Threat Surfaces

- OBD-2 port [16]
- Bluetooth network [13]
- Telematics System [17]
- Key Fob [18]
- Media player/ Auxiliary port [19]
- Tire Pressure Monitoring System [20]
- Ad-Hoc Vehicle Networks [21]
- Over-the-air firmware updates [12]

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V2X Threat Surface

- Example possible attacks [14]:
  - DDOS
    - System resource flood attack originating from several sources
  - Sybil
    - A malicious node masquerading as many nodes
  - Node Impersonation
    - A node masquerading as a different network node
  - Message Suppression
    - A node intentionally dropping packets instead of forwarding them
  - Man in the Middle
    - Harvesting sensitive information from packets forwarded through the node

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Threat Surfaces

COMPONENT	SURFACE	THREAT TYPE
OBD-2 Port	•Direct Access •Access via pass-thru devise	•Interception •Interruption •Modification •Fabrication
Key-Fob*	•Duplicate RFID chips	•Interception •Fabrication •Theft
Media Player & Auxiliary port (e.g. - audio jack or USB port)	•Connected media (e.g. - Memory stick, iPods, CD etc)	•Interruption •Fabrication
Dealer Pass-thru device	•Connected service computer/device	•Interruption •Modification

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Threat Surfaces (cont)

COMPONENT	SURFACE	THREAT TYPE
Telematics Unit	•Compromised software •Compromised connecting device	•Interception •Interruption •Modification
Vehicle Bluetooth Network	•Network PIN breakage by proximal device	•Interception •Interruption
ECU*	•Duplicate/malicious non OEM component installation	•Modification •Interruption •Fabrication
Tire Pressure Monitoring System	•Intercept broadcast of readings to Dashboard cluster	•Interruption •Fabrication •Interception

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Threat Surfaces (cont)

COMPONENT	SURFACE	THREAT TYPE
Vehicular Ad-hoc Network	•Transmission from compromised node to another	•Interception •Interruption •Fabrication
Telematics Service	•Service parameters like I.P. address and subscriber identity module (if present)	•Interception •Interruption
Digital Car Radio	•Broadcast data processing	•Fabrication •Interruption

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Template for Security Patterns

- Several templates have been used in previous security pattern research:
    - Security Patterns in Practice [2]
    - Security Patterns Repository [22]
    - Security Patterns: Technical Report [9]

- We constructed our template following the one defined by Gamma et al for general design patterns and extended by Wasserman and Cheng [9] for security-specific patterns
    - Incorporation of UML
    - Incorporation of guiding security principles

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Template for Security patterns

- Pattern Name and Classification
- Intent
- Also Known As
- Motivation
- **Properties**
- Applicability
- Structure
- Participants
- Collaborations
- **Behavior**
- Constraints
- Consequences
- Known Uses
- **Related Security Patterns**
- Related Design Patterns
- **Related Security Principles**

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Guiding Principles

- Guiding Security Principles:
  - Viega-McGraw: Ten principles for building secure software [23]
  - SAE Standard J3061: Cybersecurity Guidebook for Cyber-Physical Vehicle Systems [24]
  - Overlaps exist between the two sources
- Principles facilitate understanding of Security Patterns and provide security insight [9]

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Viega-McGraw Security Principles

- V1 - Secure the weakest link
- V2* - Practice defense in depth
- V3 - Fail securely
- V4* - Follow the principle of least privilege
- V5 - Compartmentalize
- V6 - Keep it simple
- V7* - Promote Privacy
- V8 - Hiding secrets is hard
- V9 - Be reluctant to trust
- V10 - Use community resources

Source: [23]

* Indicates overlap between Viega-McGraw and J3061

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SAE standard J3061

- J1* - Protect Personally Identifiable Information and Sensitive data
- J2* - Use principle of least privilege
- J3* - Apply defense in depth
- J4 - Prohibit changes to calibrations and/or software that have not been thoroughly analyzed and tested
- J5 - Prevent vehicle owners from intentionally or unintentionally making unauthorized changes to the vehicle's systems that could introduce potential vulnerabilities

Source: [24]

* Indicates overlap between Viega McGraw and J3061

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STRIDE Properties

- Industrial collaborators requested inclusion of Microsoft STRIDE properties [31] for each pattern:
  - Inline with their security-based development process
  - Commonly used in industry

Threat	Property	Security Questions
Spoofing	Authentication	Does system use multi-factor authentication? Enforce credential creation, use, and maintenance principles?
Tampering	Integrity	Detect/prevent parameter manipulation? Protect against tampering? Secure design principles used?
Repudiation	Non-Repudiation	Log and verify all user interaction with attribution?
Information Disclosure	Confidentiality	Follow standard encryption for secure connections?
Denial of Service	Availability	Built/tested for high availability?
Elevation of Privilege	Authorization	Support management of all users/privileges?

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Automotive Security Patterns Repository

Pattern Name	Description
Authorization	Manage authorization for use of secured resource
Blacklist	Prevent suspicious addresses from participating in a network
DDoS Redundancy	Makes a network more resilient to a (Distributed) Denial of Service Attack (DDoS)
Firewall	Filters traffic from external entities to allow only authorized uses of a system
Multi-Factor Authentication	Provides redundant authentication scheme and stronger defense against unauthorized access
Multi-level Security	Separate levels of access rights in a system
Signature IDS	Monitor traffic on network for concerning behavior
Symmetric Encryption	Encrypt message so that only intended receiver may read it
Tamper Resistance	Deters unauthorized changes to a system
Third Party Validation	Provides third party validation of a message broadcasted in a network

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Characterstics of Patterns in Repository

Pattern	Appl	V1	V2, J3	V3	V4, J2	V5	V6	V7, J1	V8	V9	V10	J4	J5
Authorization	P				X	X		X					
Blacklist	P, M		X			X				X			
DDoS Redundancy	P, M		X	X		X							
Firewall	P, D	X			X					X			
Multi-Factor Authentication	P		X			X				X			
Multi-level Security	P, M				X	X		X	X	X			
Signature IDS	P, D, M									X			
Symmetric Encryption	P							X		X			
Tamper Resistance	P, D, M			X	X							X	X
Third Party Validation	D, M							X		X			

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Sample Patterns from Repository

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Authorization Pattern

- Classification
  - Structural
- Intent
  - Facilitate access to protected resource
- Motivation
  - Restricting access to a resource, differentiating access rights
  - In automotive systems this may be CAN bus, ECU controller interface, etc.
- Properties
  - Can be used to satisfy the ***Authentication*** property, and the ***Authorization*** property

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Authorization Pattern

- Applicability
  - Automotive systems where supervision is required
  - Such management may not exist in system or protocol i.e., CAN bus [11]
- Participants
  - Protection Object
  - Rights
  - Subject
- Collaborations
  - Subjects access Protection Objects.
  - Rights object finds appropriate association between Subjects and Protection Objects

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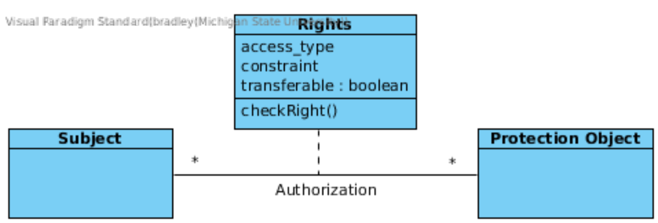
Authorization Pattern

- Structure



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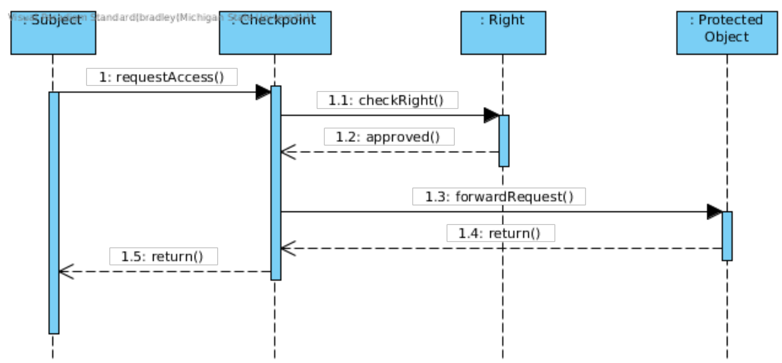
Authorization Pattern

- Behavior



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Authorization Pattern

- Constraints
  - Performance considerations for authorization protocol
  - Performing authorization outside shared resource
- Consequences
  - Confidentiality, Integrity, and Availability can all be improved through rigorous rights enforcement
  - Performance may derogate from extensive rights checking
  - Additional hardware may incur cost to system
  - Authorization may limit utilization of shared resources

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Authorization Pattern

- Known uses
  - Access control unit [25]
    - Hardware based authorization and authentication system attached to communications bus similar to CAN
    - Allows for authorization to be done concurrently with bus communication
    - Hardware allows for faster authentication and authorization protocols
- Related Patterns
  - Checkpoint pattern [9] [26]
  - RBAC pattern [9] [26]

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Authorization Pattern

- Supported Principles
  - Least Privilege
  - Compartmentalization
  - Promotes Privacy

Skip to end

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Multi-Level Security

- Classification
  - Structural pattern
- Intent
  - Provides mechanism for handling access in a system with various security classification levels
- Motivation
  - Limit access to data and resources to guarantee confidentiality and integrity of resources
  - In automotive systems some components are more susceptible to attack
    - Outward facing ECUs on a CAN bus
- Properties
  - Authorization
  - Confidentiality

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Multi-Level Security

- Applicability
  - Systems that require several security levels for subjects
  - Reflect object and subject sensitivity level in hierarchical structure
- Participants
  - Object Category
  - Object Classification
  - Object Level
  - Subject Category
  - Subject Classification
  - Subject Level

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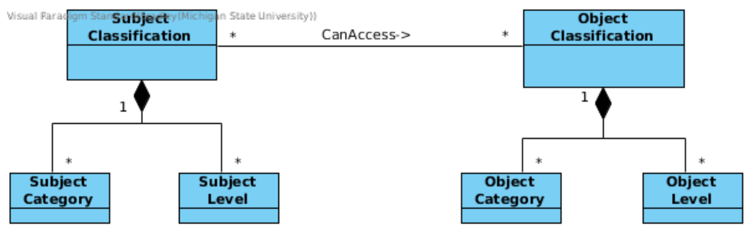
Multi-Level Security

- Structure



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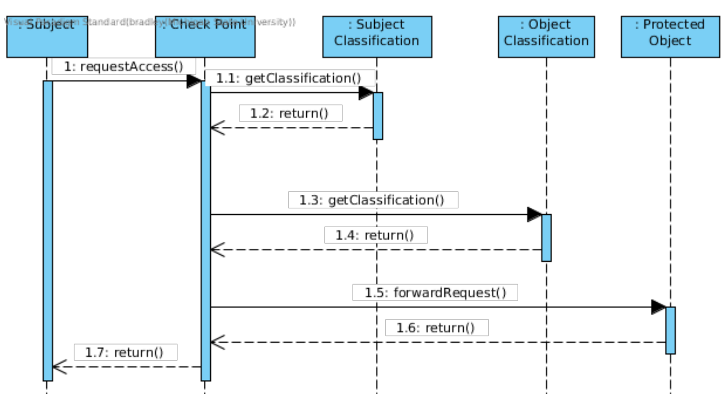
Multi-Level Security

- Behavior (Access Granted)



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Multi-Level Security

- Collaborations
  - Subject and Object classifications contain set of category and level classes to determine object classification
  - Access is granted if requesting subject dominates the protected object
- Constraints
  - Verification of objects must be efficient in real time system

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Multi-Level Security

- Consequences
  - Mechanism ensures Confidentiality and Integrity
  - Performance may degrade with many evaluations of rights
  - Cost may be incurred with hardware implementation of evaluation
  - Subjects may be limited by restrictive rules, may affect usability

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Multi-Level Security

- Known Uses
  - VeCure CAN security system [27]
    - Multi-tier security for ECUs on CAN bus
    - External facing ECUs trusted least while performance critical ECUs given higher access rights
    - Verification is done concurrently in hardware to improve performance
- Related Security Patterns
  - Checkpoint [9]

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Multi-Level Security

- Supported Principles
  - Least Privilege
  - Compartmentalization
  - Promoting Privacy
  - Hiding Secrets is Hard
  - Reluctance to Trust

Skip to end

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Signature Based IDS

- Classification
  - Structural pattern
- Intent
  - Provides a mechanism for detecting anomalies in network traffic
- Motivation
  - On an open network, there is a need for detecting malicious traffic
  - Given a baseline characteristic by all subjects acting on a network, changes in the characteristics should indicate suspicious activity
- Properties
  - Authorization
  - Integrity

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Signature Based IDS

- Applicability
  - Systems where deviation from a typical behavior/characteristic of network activity is cause for concern
- Participants
  - IDS
  - Event Processor
  - Attack Detector
  - Signature Information
  - Signature
  - Response

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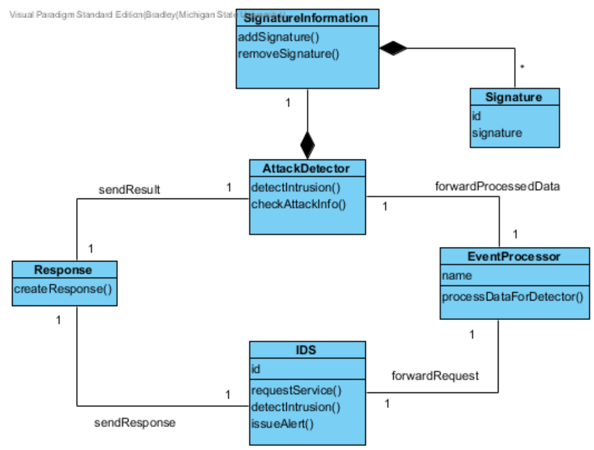
Signature Based IDS

- Structure



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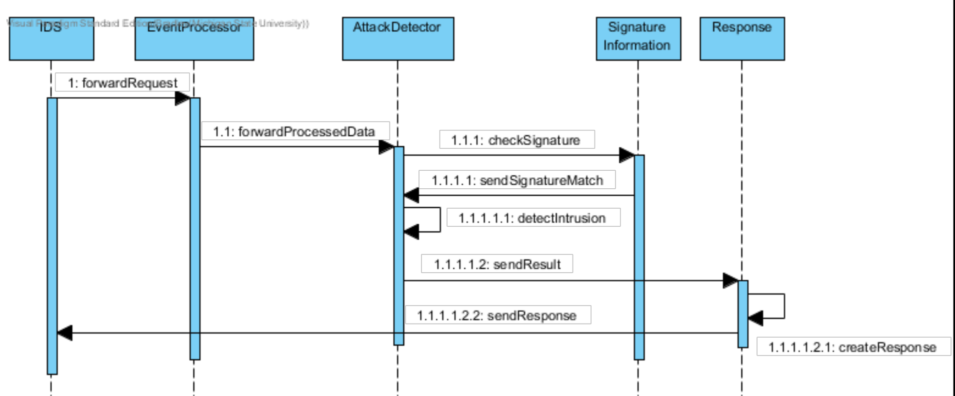
Signature Based IDS

- Behavior



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Signature Based IDS

- Constraints
  - Real-time system constraints
  - Limitations of existing protocol in automotive system
- Consequences
  - Signature Based IDS improves system Accountability and Integrity
  - Performance may derogate due to overhead of signature verification
  - Cost may be incurred if verification is implemented in hardware
  - The usability of a system may be limited to a pre-defined subset of subjects

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Signature Based IDS

- Known Uses
  - Lightweight IDS for CAN bus [28]
    - Clock-based finger-printing using predictive algorithms to determine expected clock-skews of ECUs.
- Related Security Patterns
  - Abstract IDS [2]
- Supported Principles
  - Be reluctant to trust

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Firewall

- Classification
  - Structural pattern
- Intent
  - Allows for network traffic to be filtered by a set of predefined rules to prevent malicious intrusion.
- Motivation
  - Unfiltered traffic may allow for unauthorized access to a system or its services
  - A predefined list of permitted users and access rights are needed to enforce access control
- Properties
  - Authentication
  - Authorization
  - Integrity
  - Non-repudiation

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Firewall

- Applicability
  - Systems that interface with external entities, such as over a network.
- Participants
  - Client
  - Application
  - Firewall
  - Policy Authorization Point
  - Identity Base
  - Policy Base
  - Policy Enforcement Point
  - Content Inspector

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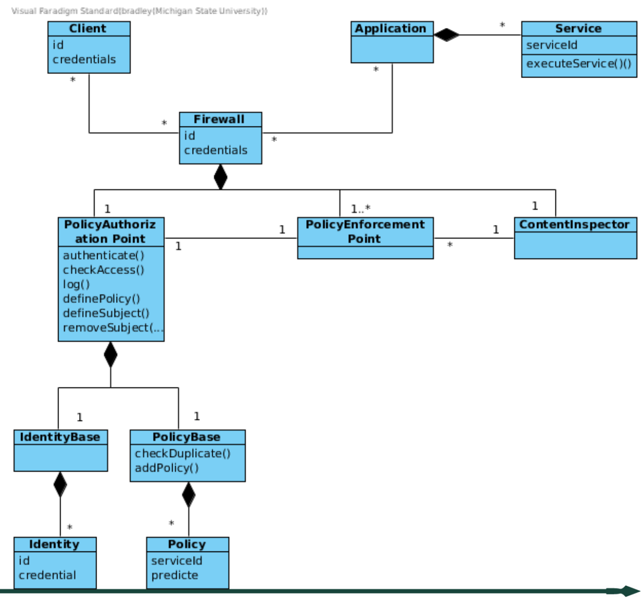
Firewall

- Structure



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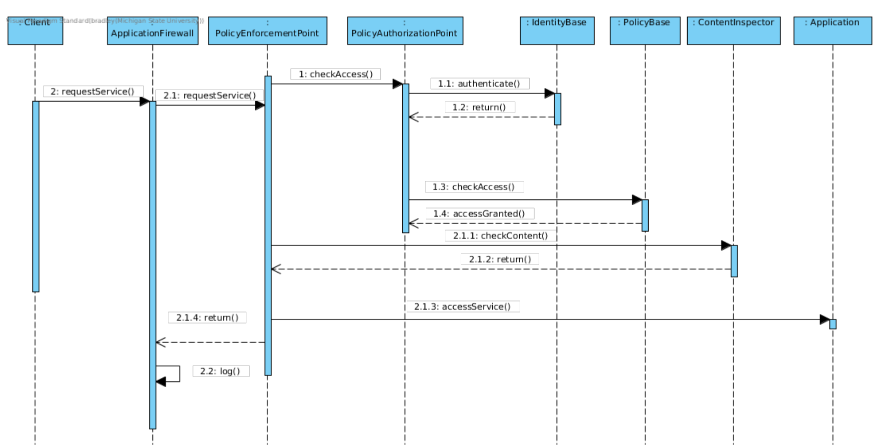
Firewall

- Behavior



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Firewall

- Constraints
  - Real-time system constraints
  - Difficulty enforcing policy among a variety of vendors
- Consequences
  - Confidentiality better protected
  - System integrity preserved by preventing unauthorized access
  - Firewall may increase both cost of a system and derogate performance with overhead
  - The usability of a system may be limited to a pre-defined subset of subjects

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Firewall

- Known Uses
  - Firewall installed to prevent unauthorized use of ECUs [29]
    - Firewalls process all messages coming from CAN-Bus to a given ECU to ensure authorized use of ECU's service
- Related Security Patterns
  - Role Based Access [2]
- Supported Principles
  - Practicing defense in depth
  - Reluctance to trust
  - Compartmentalization

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Blacklist

- Classification
  - Structural pattern
- Intent
  - Blocks traffic originating from malicious nodes
- Motivation
  - Inability to identify compromised nodes opens a network to attack
  - By maintaining a list of addresses that are known to be malicious, a network can secure nodes better from known malicious activity or suspicious activity
- Properties
  - Authentication
  - Authorization
  - Non-repudiation

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Blacklist

- Applicability
  - Systems that interface with external entities, such as over a network.
- Participants
  - Access Point
  - Requesting Node
  - Protected Node
  - Blacklist

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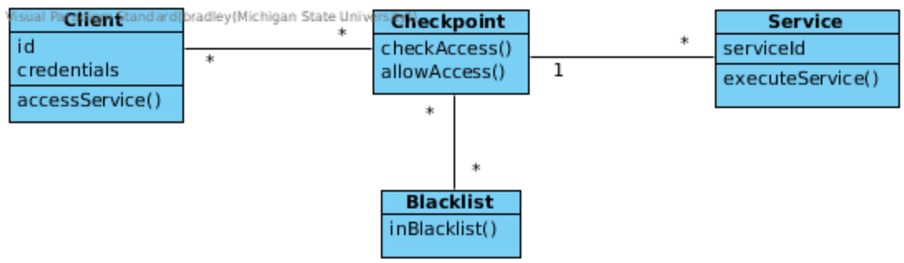
Blacklist

- Structure



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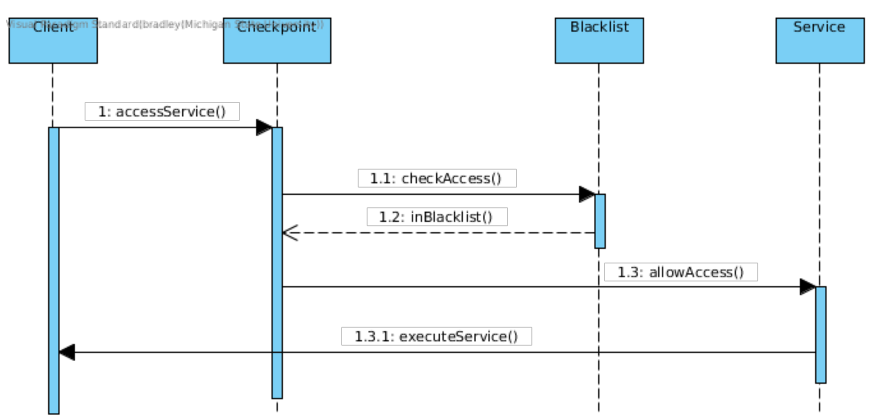
Blacklist

- Behavior



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Blacklist

- Constraints
  - Real-time system constraints
  - Developing a policy for when to blacklist a node
- Consequences
  - Confidentiality and Integrity better protected by preventing known malicious nodes from participating in routing and sending messages
  - Blacklist may increase both cost of a system and derogate performance with overhead
  - The usability of a system may be derogated as a result of an over-zealous blacklist protocol

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Blacklist

- Known Uses
  - Blacklisting protocol for a VANET [30]
    - Trusted nodes in a VANET monitor the behavior of other nodes. When a node shows odd behavior, a trust metric is decreased. If the trust metric is decreased enough, the node is blacklisted.
- Related Security Patterns
  - Firewall pattern [2]
- Supported Principles
  - Reluctance to trust

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Conclusions

- Security Patterns for Automotive Systems
  - Take into consideration automotive-specific constraints
  - Target automotive-specific threat surfaces
  - Promote/facilitate cybersecurity-focused development
- Next Steps:
  - Continue to add to Automotive Security Patterns Repository
  - Integrate into Software development processes
  - Incorporate emerging Automotive Cybersecurity standard ISO/SAE 21434 (due for release in 2020) [32]

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