

Information Quality in Critical Infrastructures

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Introduction

- ▶ Critical Infrastructures and the pervasive IoT which will surround us are and can be thought as **Time Aware Cyber-Physical Systems of Systems**
- ▶ There many facets on a cyber physical SoS but in this talk we will focus on **Information**.
- ▶ We first point out how physical channels (stigmergic channels) play a fundamental role in defining the (sometimes emergent) behavior of the SoS
- ▶ Later we focus on **Information Quality** issues.
- ▶ We extend the conceptual model and related supporting tooling (SysML- Eclipse) for Systems of Systems developed in a previous work including the possibility to deal with Information Quality.



What is a Cyber Physical System-of-Systems?

Constituent Cyber Physical System (CS)

An autonomous subsystem of an SoS, consisting of computer systems, controlled physical objects and possibly interacting humans.



System-of-Systems (SoS)

A System-of-Systems (SoS) is an integration of a finite number of constituent systems (CSes) which are **independent and operable**, and which are networked together for a period of time to achieve a **certain higher goal**.



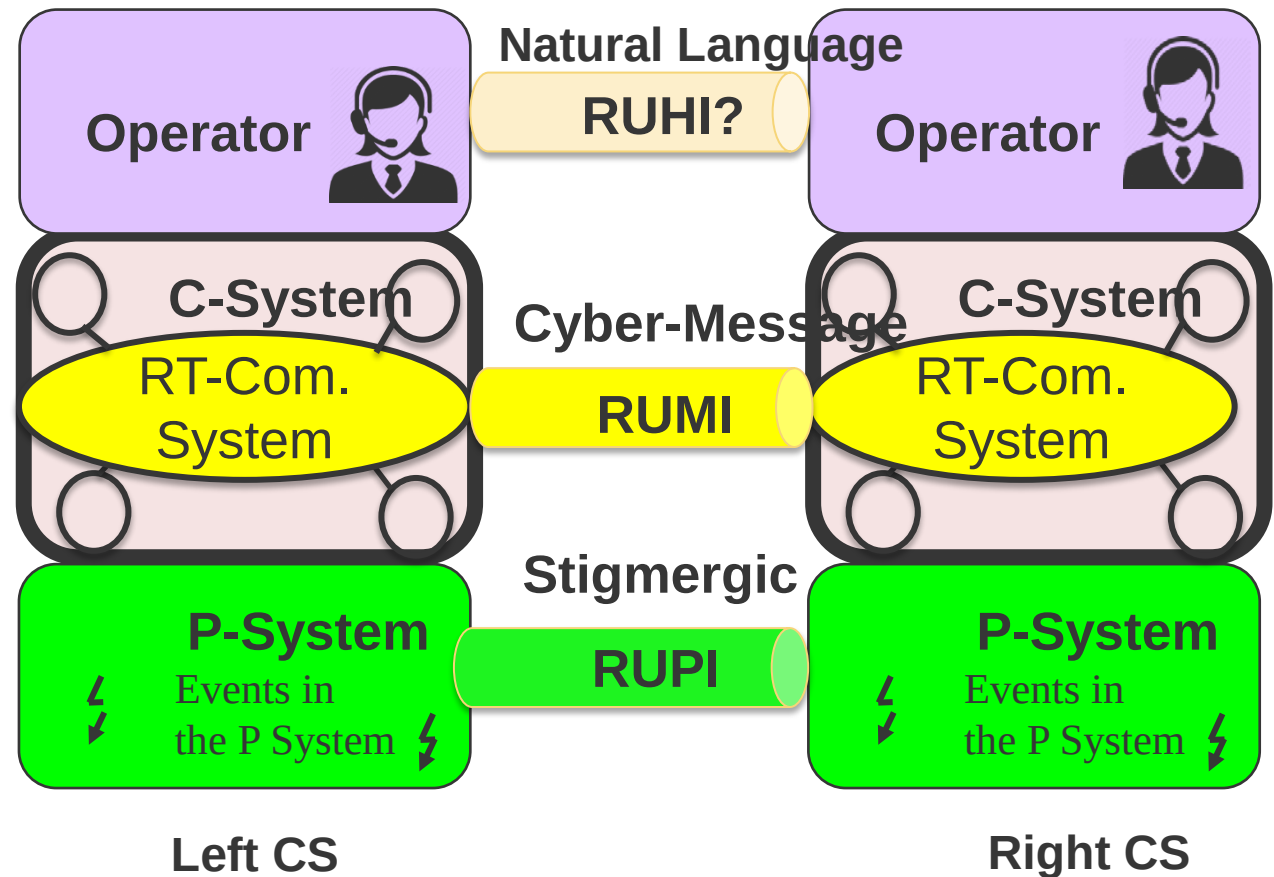
Constituent Systems and Communication Channels

▪ C-System

- Controlled by program execution
- Execution time
- Sparse Time-base

▪ P-System

- Controlled by laws of physics
- Physical time
- Dense time





Stigmergic Channels

A *stigmergic information channel* is present if one CS acts on the environment (common to many CSs,) changes the state of this physical environment and another CS observes the *changed* state at some later point in time.

In biology the term *stigmergy* describes the *indirect* information flow among the members of a termite colony when they coordinate their nest building activities.

According to the present understanding, the nearly blind ants orient themselves on the information captured by the *olfactory sense* following the intensity of the smell of the chemical substance *pheromone*.

Stigmergy in Biology...



- Ants find food and build/enforce trail by leaving traces (*pheromone*) in environment on way back.
- Environment evaporates traces autonomously
⇒ *environmental dynamics*.
- In case food source depleted, ants stop leaving traces, and trail disappears.

Emergence

A phenomenon of a whole at the macro-level is emergent if and only if it is new with respect to the non-relational phenomena of any of its proper parts at the micro level.



Many emergent phenomena come about by feedback loops among CSes closed via stigmergic channels



Emergence in Critical Systems and Infrastructures

Emergent Behaviour	Beneficial	Detrimental
Expected	Normal case	Avoided by appropriate rules
Unexpected	Positive surprise	Problematic case

- ▶ As SoS designers and or users we would like to gain a complete **awareness** of emergent phenomena and be able to **CONTROL** (or mitigate the effects of) the detrimental one
- ▶ With proper **observation** and **documentation** of interactions among the CSs (**including Stigmergic ones**) the occurrence of the emergent phenomena in SOSes can be explained.



Stigmergy in SoSes

- Stigmergic channels, if one CS acts on the environment common to other CSs:
 - Sender changes state of environment
 - Environmental dynamics (E-dynamics) act concurrently on state of environment
 - Receiver observes changed state of environment

	Open Channel	Hidden Channel
Message Channel	Cyber Channel	Human Communication
Stigmergic Channel	Material Flow in Control Loop	Physical Side Effects



Unidirectional Stigmergic Information Flow

- Sender must have capability to cause an effect in environment.
 - Actuator design determines how bit-patterns affects environment
- Intermediate state / Environmental dynamics (E-dynamics)
 - Produced by output actions of CSs and E-dynamics.
 - No single CS has full control over state of environment.
- Receiver
 - Perception phase: Sensors measure relevant properties of things as raw data.
 - Recognition phase: Transformation of raw data to refined data.



Cyber versus Stigmergic Information Flow

Viewpoint	Stigmergic	Cyber Message
Information Type	Properties of Things	No Restriction
Tense	Present	Past, Present, Future
Inform. Transfer	Pull	Push/Pull
E-Dynamics	Considered	Not Considered
Comm. Delay	Unbounded	Bounded
Source	Unknown	Known
Representation	Single Context	Multiple Contexts

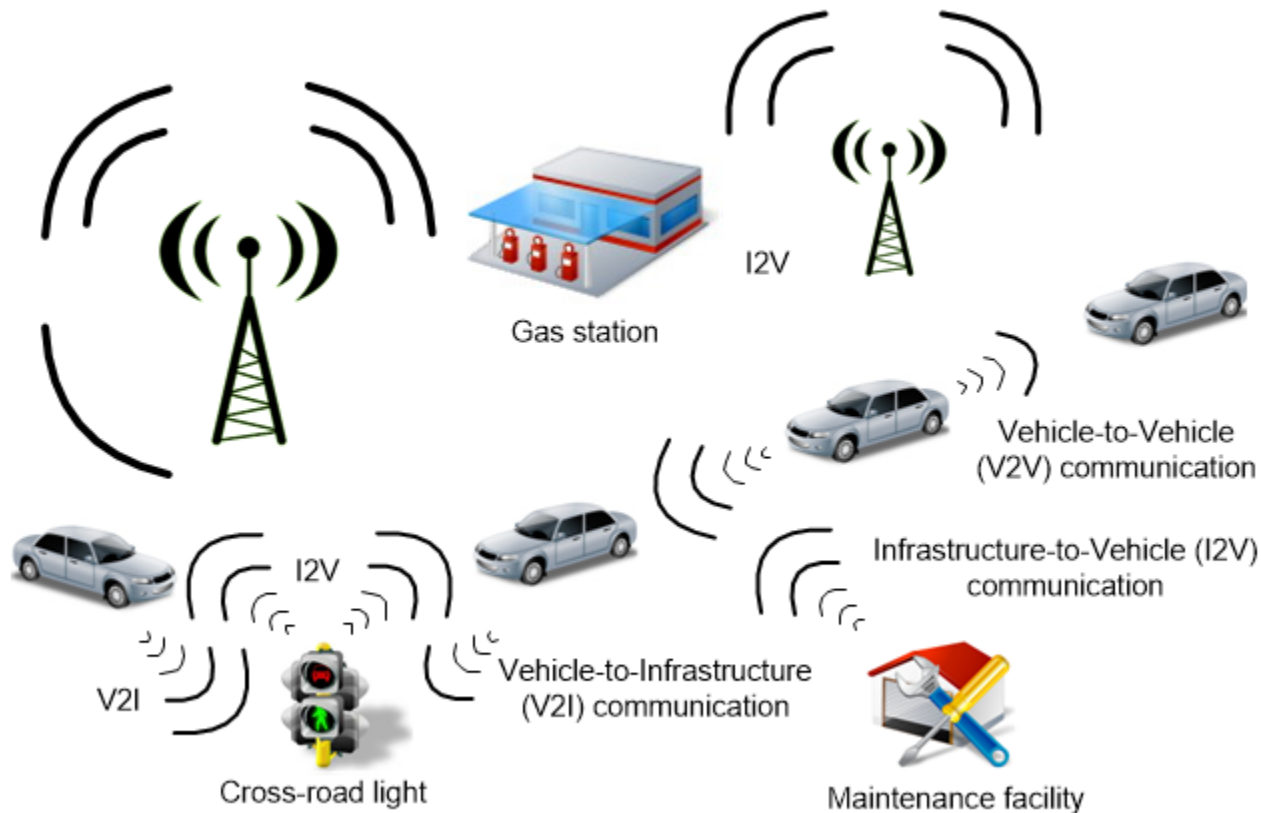


SoS and Information

- SoS, the integration of **CSs** can be achieved depending on **information**. Yet,
 - Existing work focused mainly on how information can be exchanged and understood by **CSs**, **not on the quality of such information**.
 - Existing IQ models are not able to deal with some of the needs of SoS, i.e., no existing IQ model is able to deal with information that is exchanged through indirect (**stigmergic**) channels .
 - Most **CSs** may not have complete knowledge about their operational environment, i.e., they may not be able to identify whether information is complete for performing an activity.
 - Ensuring information consistency for the overall SoS might not be possible or at least it is not feasible due to the decentralized nature of SoS.

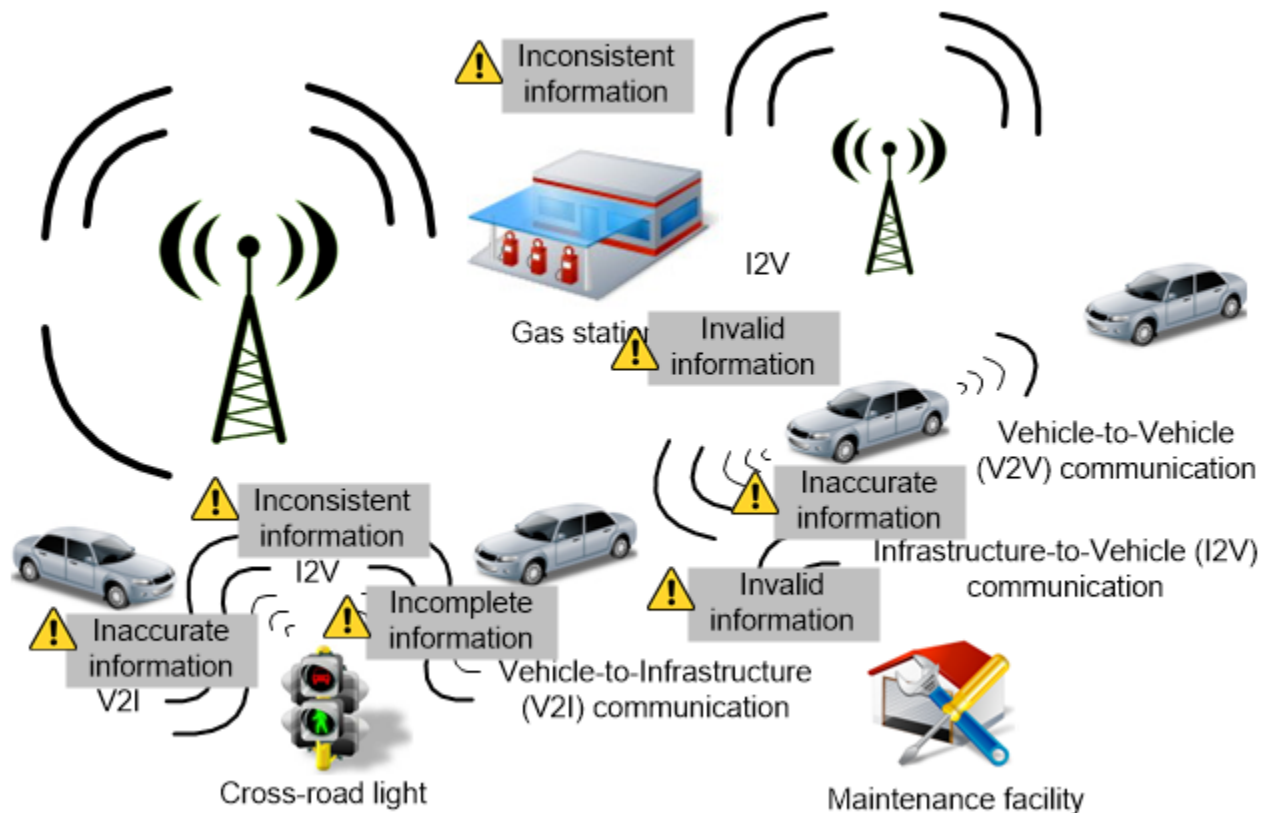
An IQ model that tackles these problems is a great step forward in designing SoS.

Example: Vehicular Communication NETWORKS (VANETs)



- **Actors:** 1- Vehicles, 2- Road Side Units, 3- Point of Interest.
- **Communication links:** 1- Vehicle-to-Vehicle (V2V), 2- Vehicle-to-Infrastructure (V2I), and 3- Infrastructure -to-Vehicle (I2V).

Example: Vehicular Communication NETWORKS (VANETs)



- These **Constituent Systems** depend on information to perform and coordinate their activities, and the efficient performance of such systems or even their correctness heavily depends on the **quality** of such information.



Information & Information Quality

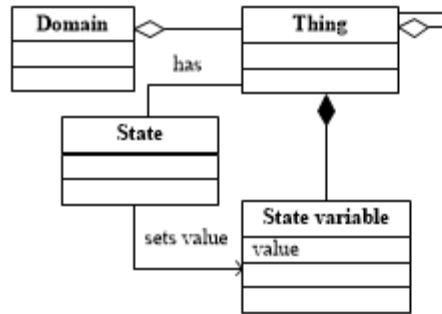
► Information sources

- Information can be classified into three main types based on its source: 1- created internally, 2- acquired from objects, or 3- obtained by communication.

► Information Quality (IQ) is a hierarchical multi-dimensional concept that can be characterized by different dimensions

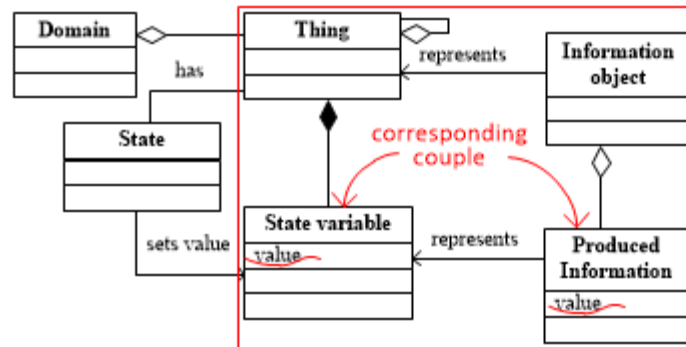
- **Accuracy** is the extent to which information is true or error free.
- **Completeness** is the extent to which information is complete for performing a specific task.
- **Timeliness** is the extent to which information is valid in term of time for performing a specific task.
- **Consistency** is the extent to which all multiple records of the same information are the same across time and space.

A conceptual model for IQ in SoS



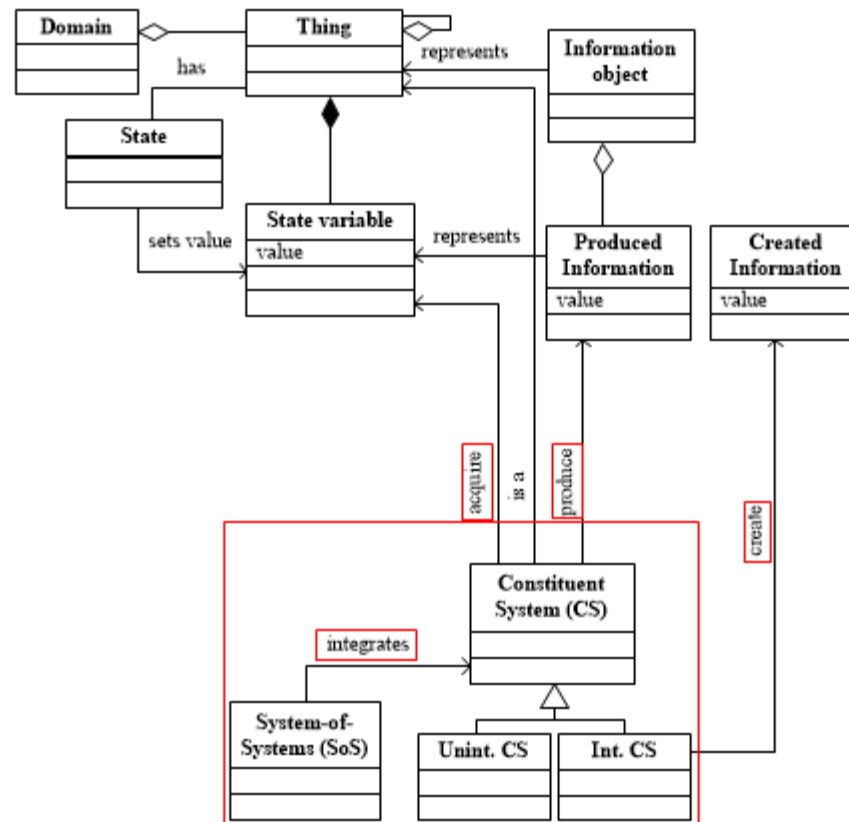
- ▶ A **domain** is made up of **things** (cars..) that have **states** (moving).
- ▶ **States** have a set of values (we call **state variables**) that represent properties of a **state** (speed), and the value of each property is contained in a **value** attribute.

A conceptual model for IQ in SoS



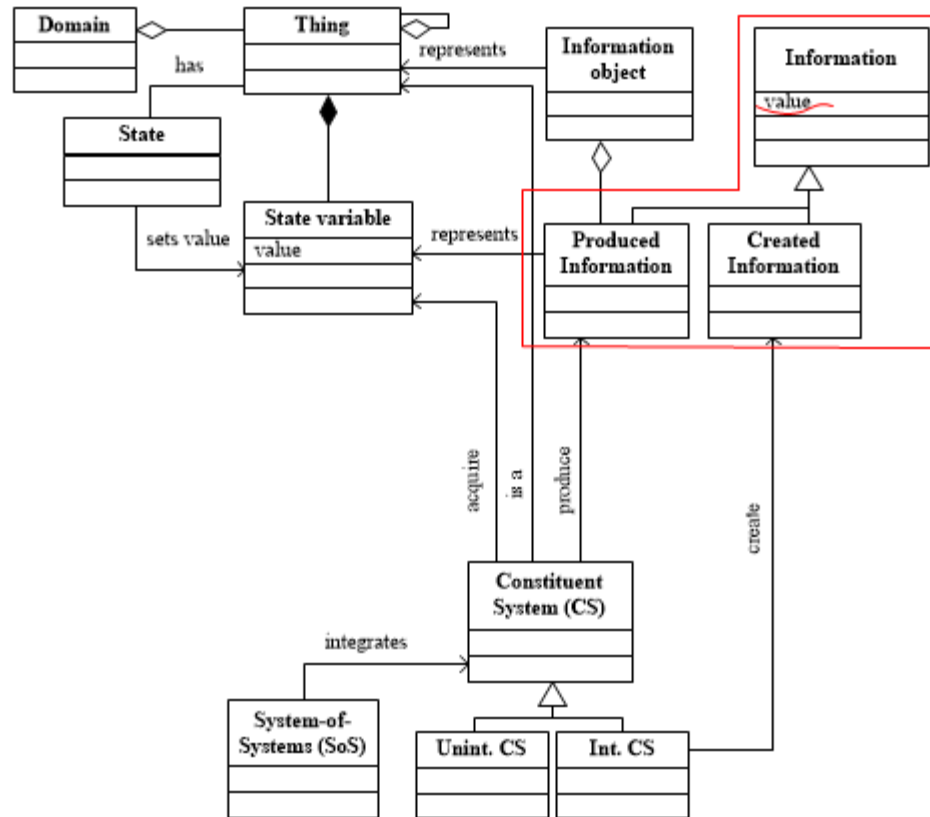
- **Things** can be represented by **information objects**, which have a defined set of **produced information**.
- Each **state variable** can be represented by **produced information**, and they are called a **corresponding couple**.

A conceptual model for IQ in SoS



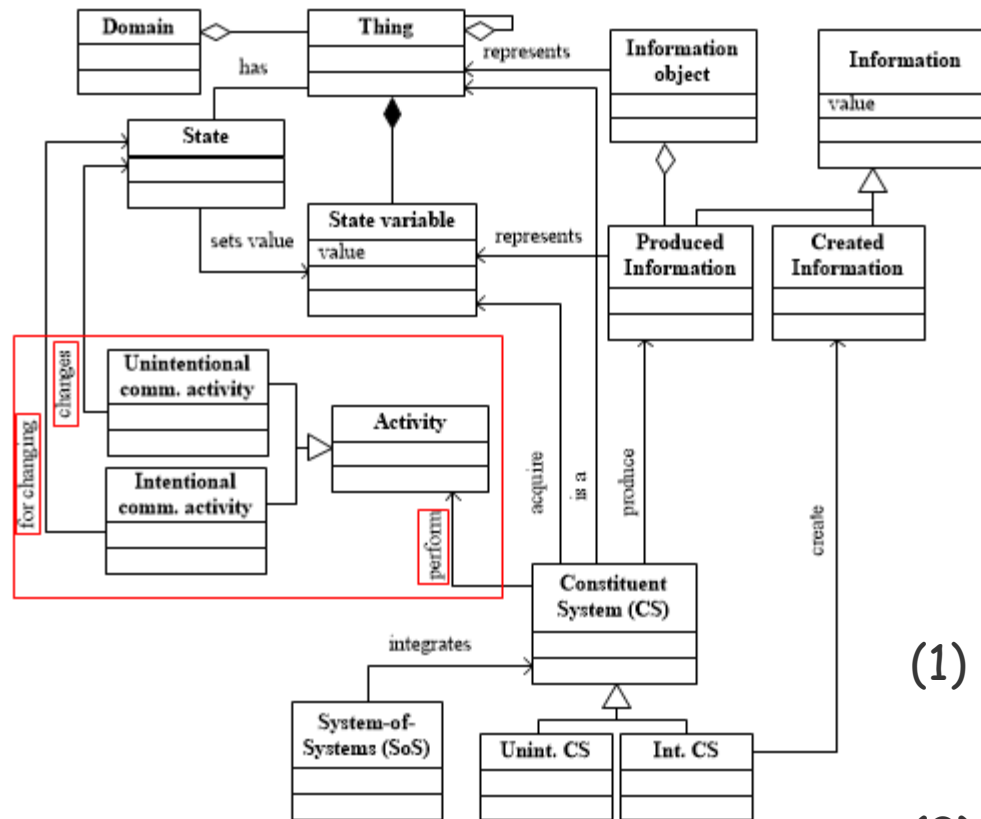
- ▶ A **SoS** integrates **CSs** that can be **intentional** or **unintentional CSs**. A **CS** can produce "**produced information**" by *acquiring* its value from its corresponding **state variable**.
- ▶ **Intentional CS** can *create* "**created information**" based on information it has.

A conceptual model for IQ in SoS



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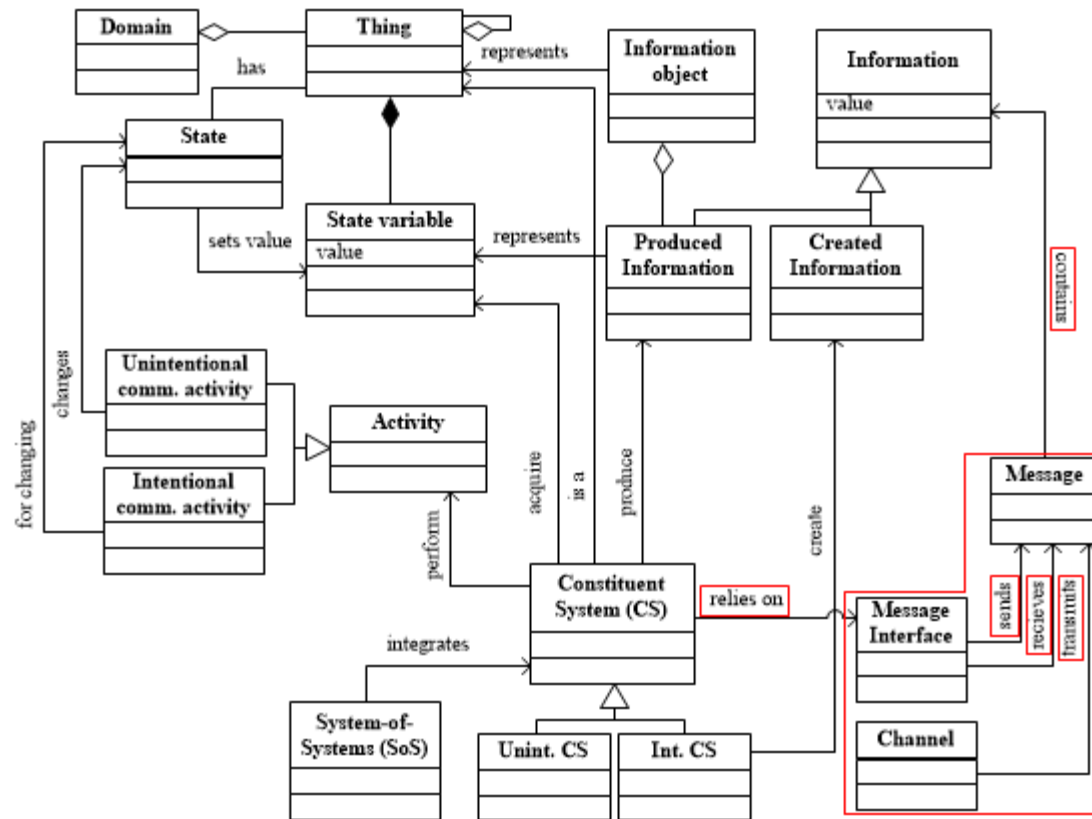
A conceptual model for IQ in SoS



- (1) car turning lights (notify other drivers)
- (2) speed increase

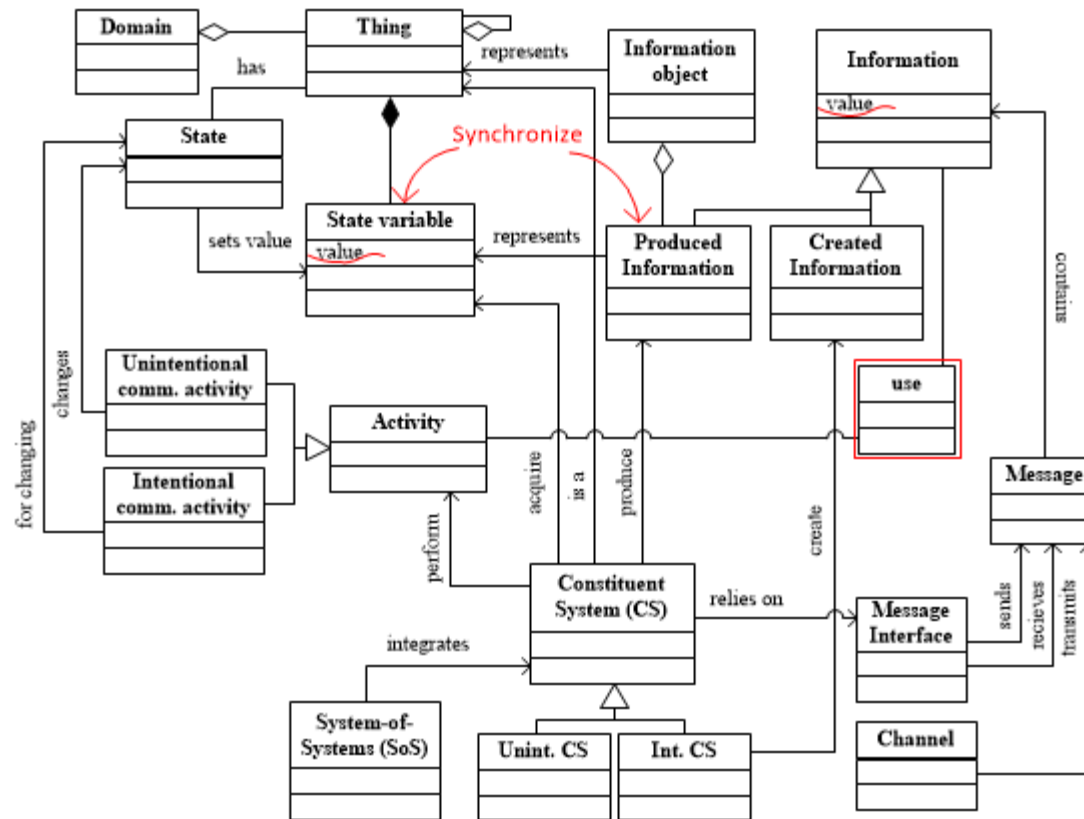
- A CS may perform activities that can be either
- **Intentional communicative activities**, which are performed with the intention of changing a state of a thing to convey a message.
- **Unintentional communicative activities**, which are not performed to communicate any kind of information.

A conceptual model for IQ in SoS



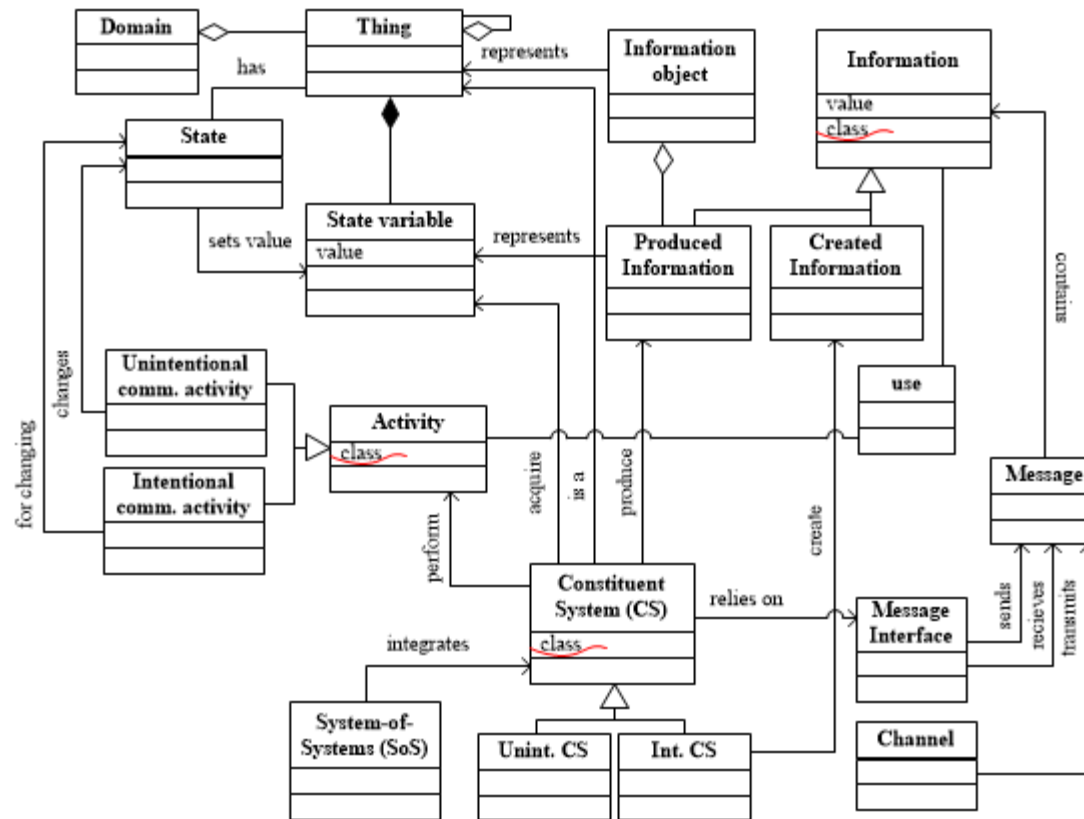
- A CS may send/receive messages that contain information by relying on message interface that transmits messages depending on a channel.

A conceptual model for IQ in SoS - accuracy



- ▶ A produced information is accurate at a point of time if its value is equal to the value of its corresponding state variable.
- ▶ We can guarantee the accuracy of produced information by synchronizing its value with the value of its corresponding state variable.

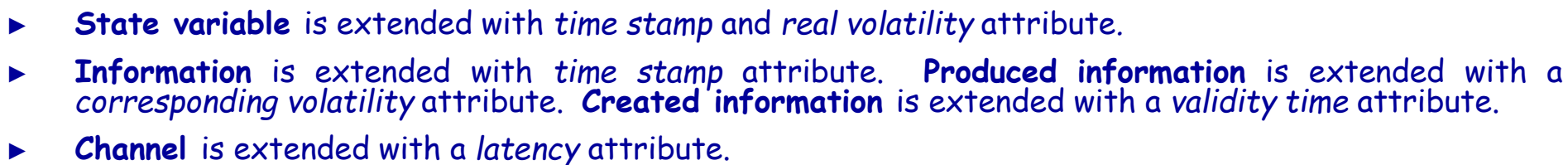
A conceptual model for IQ in SoS - accuracy



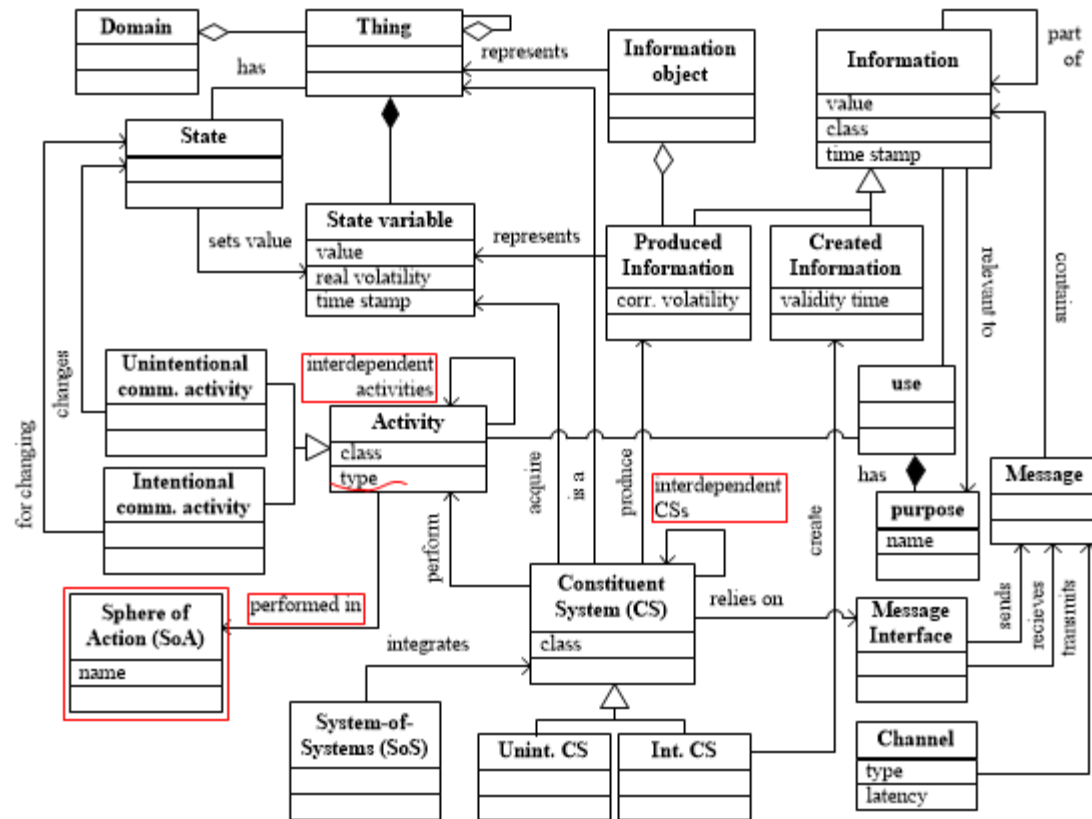
- ▶ A created information does not have a corresponding state variable, i.e., its value cannot be *synchronized* with a reference accurate value.
- ▶ The accuracy of **created information** can be analyzed based on the **trustworthiness of its provenance** (information source and providence).



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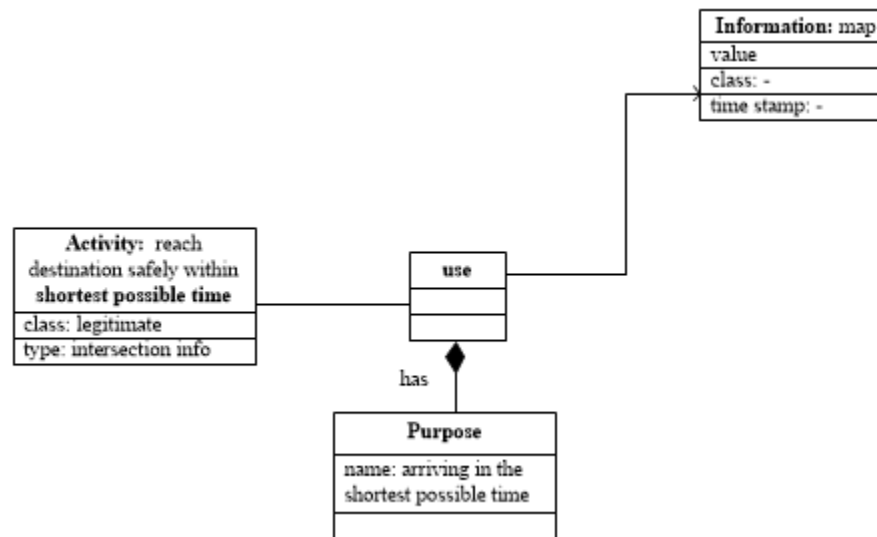


A conceptual model for IQ in SoS - consistency



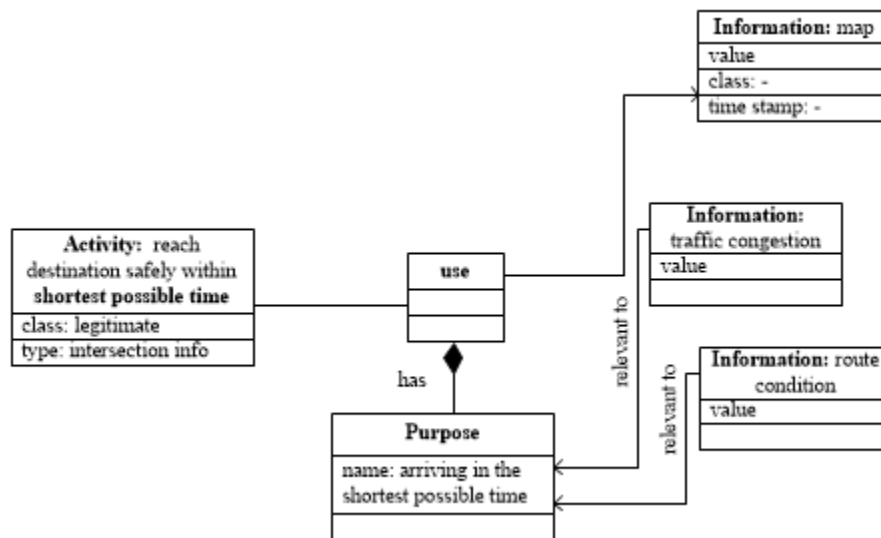
- Information consistency arises when multiple records of the same information is being used by several CSs for interdependent activities.
- **Interdependent activities** are activities that belong to the same activity type, and they are performed in the same **Sphere of Action (SoA)**.

Illustrative example: VANETs



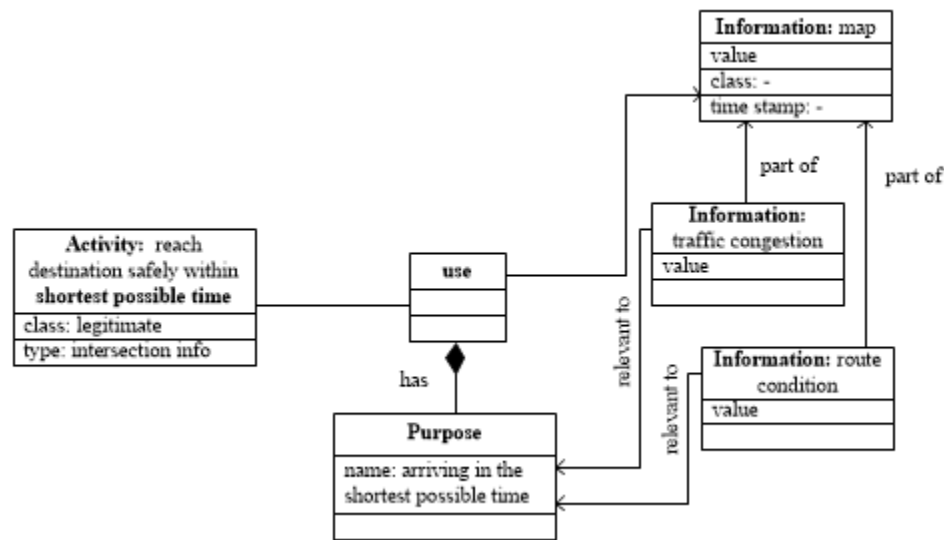
- ▶ A driver aims to reach his destination safely within the shortest possible time.
- ▶ He needs to depend on a **map** that is made available to drivers by a **trusted maps provider**.

Illustrative example: VANETs



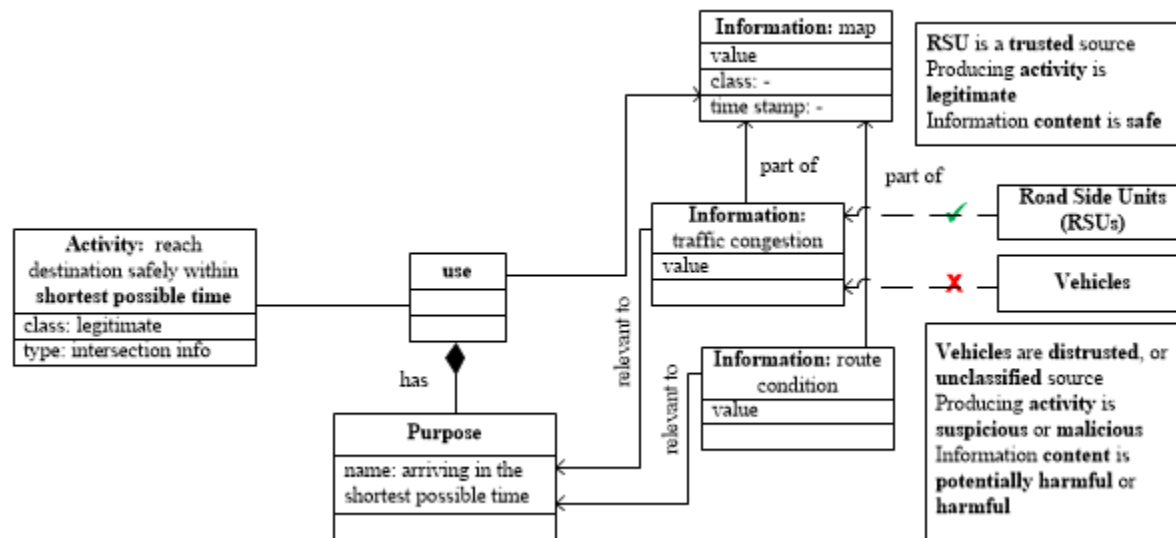
- ▶ To facilitate arriving in the *shortest possible time*, 1- route condition information, and 2- traffic congestion should be known to the driver
- ▶ Both of them are **relevant to the purpose** of this activity, and in turn they are considered as **part of the map**.

Illustrative example: VANETs

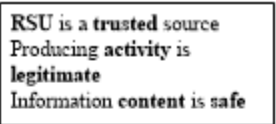


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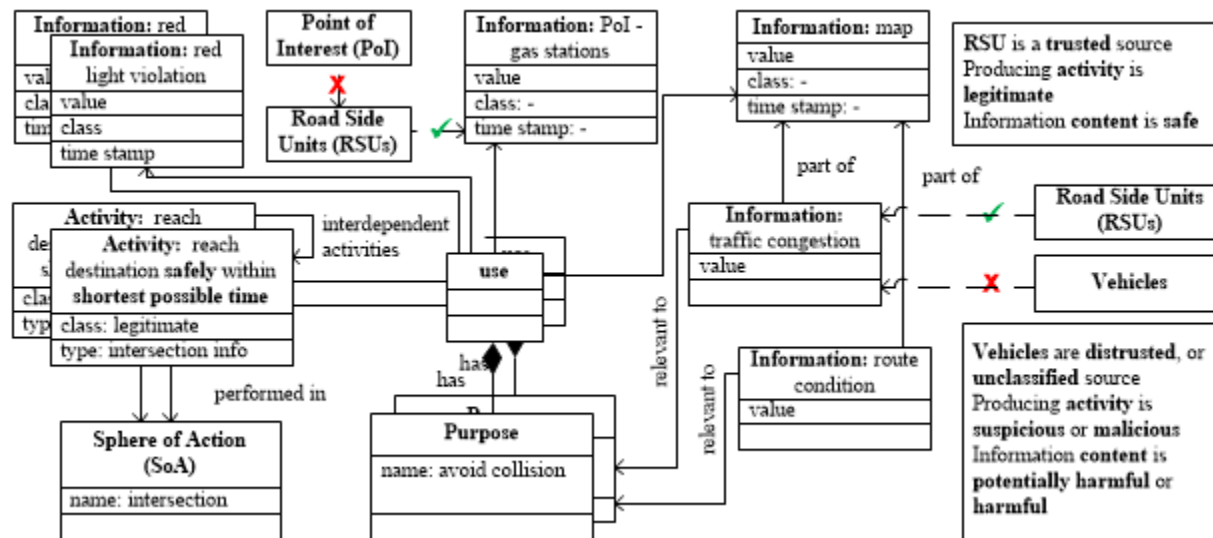


- ▶ **Traffic congestion information** can be obtained either from RSU (a trusted source) or other vehicles using the same route.
- ▶ Vehicles may not be **trusted** for such information, because they may disseminate inaccurate (false) information (e.g., bogus information attack).



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Illustrative example: VANETs



- PoI notifications are produced by PoI (a **distrusted** source) and sent to RSUs (a **trusted** source) to be broadcast to passing vehicles.
- RSU needs to **verify** the **timeliness** of such notification before providing them to passing vehicles.

Conclusions and Future Work

- We elaborated on Information in Critical Infrastructures seen as Systems of Systems:
 - We first pointed out how physical interactions through physical (stigmergic) channels deserve specific attention in SoSes and
 - then we presented a new conceptual model that provides concepts/attributes specialized for analyzing Information Quality for SoS in terms of the four core IQ dimensions.
- Extension of the conceptual model for designing SoSs introduced in AMADEOS project (<http://amadeos-project.eu/>) and extension of our SysML SoS profile..

