## TU Wien

**A Conceptual Model for the Information Transfer in Systems-of-Systems**

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## System of Systems

- A *system-of-systems* (SoS) is a large information processing system formed by the integration of autonomous computer systems, physical systems and humans for the purpose of providing new synergistic services and/or more efficient economic processes.
- The integration is achieved by the exchange of *information* among the constituent systems.
- In a *monolithic system*, where a single context for the representation of information prevails, the issue of *context dependence of information representation* is of little concern.
- With the advent of SoSs the context dependence of the information representation in the diverse constituent systems becomes a critical issue.

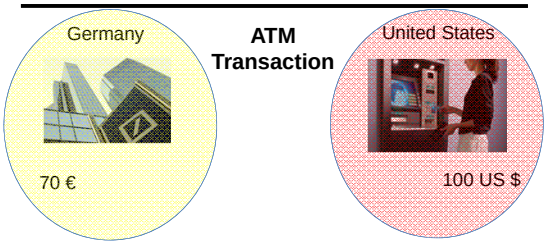
## Properties of an *SoS*

| Characteristic | Old-Classic | New-SoS |
|---|---|---|
| Scope of System | Fixed (known) | Not known |
| Structure | Hierarchical | Networked |
| Requirements and Spec. | Fixed | Changing |
| Control | Central | Autonomous |
| Evolution | Version control | Uncoordinated |
| Testing | Test phases | Continuous |
| Implement. Technology | Given and fixed | Unknown |
| Faults (Phys., Design) | Exceptional | Normal |
| Emergent Behavior | Insignificant | Important |
| System development | Process model | ??? |

## Emergence

- Emergent behavior is behavior that occurs at the system level but cannot be found in any of the isolated subsystems (constituent systems).
- In Cyber Space, emergent behavior is caused by the *information exchange* among the subsystems.

## *Data* versus *Information in an SoS*: An Example




The *semantic content, the information,* is the same in both contexts, but the representations in the different contexts of an SoS are different (and in this case time dependent).

## Quote from the TArea SoS SRA:

*Indeed, many SoS failures result from inadequacies at the semantic level (i.e. the information is understood differently by the receiving system to how it was understood by the sending system) (p.12).*

## *Implicit Explanation of the Data*

In many situations, part or all of the explanation of the data is taken *implicitly* from the context. This can give rise to serious misunderstandings and has been identified as the cause of serious accidents, e.g.:

- Loss of the 125 Mio $ NASA MARS Orbiter on Sept. 23, 1999 was caused by a mismatch between English Units and Metric Units.
- The crash of an airplane on Jan 20, 2002 was caused the *misinterpretation of* the rate of descent into an airport -- *Controlled Flight Into Terrain Accident* (CFIT).

## *Data* versus *Information*: some Definitions

- Information *is a proposition about some state of the world at a specified instant.*
- In our model, the smallest *unit that can carry information* is an ***I****nformation A****tom***, called ***Itom***. An Itom is a tuple, consisting of *data* and an *explanation of the data.*
- *Data* is an ***artifact***, a (bit) pattern or symbol created *for a given purpose* by a *data generation process* at a specified instant.
- The *explanation of the data,* which is an integral part of an Itom, gives *meaning* to the data. The given environment determines the *context* for the explanation.
- We distinguish between *afferent data* (flowing into a system) and *efferent data* (coming out of a system).

## *Afferent Data* vs *Efferent Data*

- *Afferent Data* (input data) is created at an instant by an observation of the environment by a *data acquisition process*.
- *Efferent data* (output data) is produced by a system and published at an interface to the environment.
- The acquisition of *afferent data* can often be compared to taking a snapshot of an entity *at an instant* to create an *image e.g.*, taking a snapshot of a *person*.
- If a dynamic entity is observed, the *instant of observation* is relevant.
- The *raw data (i.e. the pattern* of the image*)* is determined by the *elementary discriminatory capabilities of the sensor system*.
- The *specified purpose* determines the data reduction, the processing of the *raw data* to arrive at *refined data*.

## An Example: Electronic Toll Collection


- **A camera observes the traffic and generates pictures of the passing cars. The *raw data* is an array of bits.**
- **The raw data is preprocessed for the *purpose* of identifying the license plate of the car, the *refined data*.**
- **The license plate is used as a pointer to the bank account associated with the *owner* of the passing car.**
- **The toll is automatically deducted from the identified bank account.**

## *Explanation* of the *Data*

The Explanation of the Data must give answers to the following five questions:

- *What entity is involved*? (Identification)
- *Why is the data created*? (Purpose)
- *How has the data to be interpreted by a human or manipulated by a machine*? (Meaning)
- *What are the temporal properties of the data*? (Time)
- *Who owns the data?* (Ownership)

The explanation of the data of often derived *implicitly* by the context.

## Representation of an *Itom*

- The *representation* of an Itom (the data and the associated explanation) depends on the cultural and/or technological context of the *Itoms environment,* and whether the Itom is destined for a human or for a machine.
- Since an Itom must be represented by *symbols* that are *determined by* and *understandable in* the given context and there exists no absolute context, the representation of an Itom is always relative, while the *semantic content* carried by an Itom, the *information,* has a connotation of *absoluteness*.
- To facilitate the exchange of information among heterogeneous systems in the Internet, *markup languages,* such as the *Extensible Markup Language XML* [WWW13] that help to explain the meaning of data have been developed.

## Some Properties of *Itoms*

- **Name**: The *name of the Itom* is used to reference the Itom and should also designate the concept that helps to explains the meaning of the Itom to a human.
- **Purpose**: Every artifact is directly or indirectly created for a purpose by a human author.
- **Truthfulness**: Our concept of an Itom does not make any assumption about the truthfulness of the information carried in the Itom.
- **Temporal Aspects**: The utility of the sem*antic content* of an Itom, the *information*, can be time-dependent.
- **Neutrality**: The semantic content of an Itom does not depend on the state of knowledge of the human receiver of the Itom.
- **Physicalism**: The storage of every Itom requires a physical data carrier.

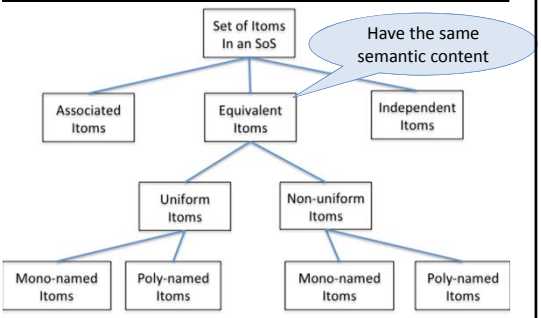
## *Itoms* for *Humans*

- An *Itom* destined for a human must be *understandable* to the human receiver.
- *Understanding* means that the patterns, symbols, concepts and relations that are used to represent the data and the explanation of the Itom can be connected with the existing concepts in the *conceptual landscape* in the human mind of the receiver.
- The *utility of the information* carried in an Itom is *relative to the human* who receives the information.
- In general it is *not possible* to quantify the *utility of information* to a human receiver because the state of the conceptual landscape of the human receiver at the instant of receiving an Itom cannot be grasped.

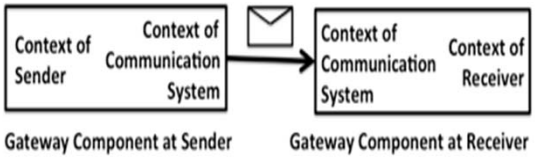
## *Itoms* for *Machines*

- In cyberspace all *data* is encoded in *bit strings.* The *explanation* within an Itom consists of two parts, we call them *computer instructions* and *explanation of purpose*.
- We call the data bit-string *object data* and bit-string that *explains* the object data (e.g., the instructions) *meta data*.
- A computer Itom thus contains digital *object data* and digital *meta data*. The recursion stops when the *meta data* is a sequence of well-defined machine instructions for the *destined* computer. In this case, the *design of the computer* serves as an *explanation for the meaning of the data*.
- The second part of the explanation of an Itom, the *explanation of purpose,* is directed to humans who are involved in the design and operation of the computer system.

## Classification of Itoms




## Communication among *Constituent Systems*




Gateway components must transform the representation of equivalent itoms at the interfaces.

## Conclusion

- In a System of Systems (SoS) the same information (the semantic content) may be represented differently in different constituent systems.
- An *ITOM (Information αTOM)*, consisting of data and an explanation of the data, is the smallest unit that can carry information.
- Constituent Systems exchange *Itoms*, not *data*.
- In many situations, part or all of the explanation of the data in an Itom is taken *implicitly* from the context. This can give rise to serious misunderstandings and has been identified as the cause of fatal accidents.

## Post Scriptum

- This is unpublished work in progress.
- If you would like to receive a draft paper about this topic, please send an email to
  H.Kopetz@gmail.com
- Your comments will be highly appreciated!

**Thank you!**