TU Vienna

The Data-Information-Time (DIT) Model

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March 2022

Outline

- Introduction
- Data in the Communication among Humans
- Data in Cyber Space
- Data in Biological Systems
- Consequences for System Design
- Conclusions

Purpose of the DIT Model

It is the purpose of the DIT Model

- to establish the semantics of the terms *Data* and *Information*.
- to provide a framework to show how the flow of time can effect the *meaning* of a *data item* and the *sense* of an *information item*.
- to investigate the communication among humans, the communication among a human and a machine, and the communication among machines.
- to explain the differences between *archival data* and *real-time data*.
- to show how the understanding of the DIT model can help to improve the design of a computer system.

Communication, Data and Information

The *Merriam Webster* dictionary defines communication as follows:

- *"A process by which information is exchanged between individuals through a common system of symbols, signs or behavior;*
- *the function of pheromones in insect communication."*

In human communication, sequences of natural language words, i.e., sentences, are exchanged between involved *speakers* and *listeners*.

The ***meaning*** of a natural language *word* (a *data item*) is the associated ***concept*** ***—****the unit of thought*—in the mind of the speaker. A word has a *denotation* and a *connotation*.

In the DIT model the ***sense*** of a natural language proposition, i.e., the ***idea*** communicated by a *proposition composed of meaningful words*, is called an *Itom* (*Information Item*).

A *word* has a *meaning*, a *proposition* makes sense.

Concept Formation—*Grounding* of Words

According to *embodied cognition* humans develop a *basic concept* and therewith assigns *meaning* to—i.e. ***ground*** —the sounds of the *identifying word* when a plethora of bodily sensations (visual, acoustic, haptic, smell, taste) of a thing are perceived during a purposeful process.

Ex**amples:**

sensual impression associated with the word "*pacifier*"

This is a "*tree*"

After a set of basic concepts has been formed in this way, the *grounded words* can be used to ground new words and thus form more advanced concepts.

Conceptual Landscape

The totality of all concepts, relations among the concepts, and mental models forms the *conceptual landscape* in the mind of a human that is built up during the lifetime of an individual, partly by *human nature* and partly by *nurture, i.e.,* the lived and remembered personal experiences.

The conceptual landscape is in ***continuous flux***.

Each fully developed concept has a rich set of *conscious* and *unconscious* (*tacit*) relations to other concepts in the conceptual landscape.

The *conceptual landscape* is the *dynamic subjective knowledge base* in the mind of a human.

More Fundamental Terms

Entity: A ***thing*** in the real world or a ***construct*** of the human mind.

System: A system is a collection of related entities (subsystems) that forms a *whole* and provides a *service* to its environment. It is encapsulated by a *physical* or *virtual* skin that separates the system from its environment and contains *interfaces*.

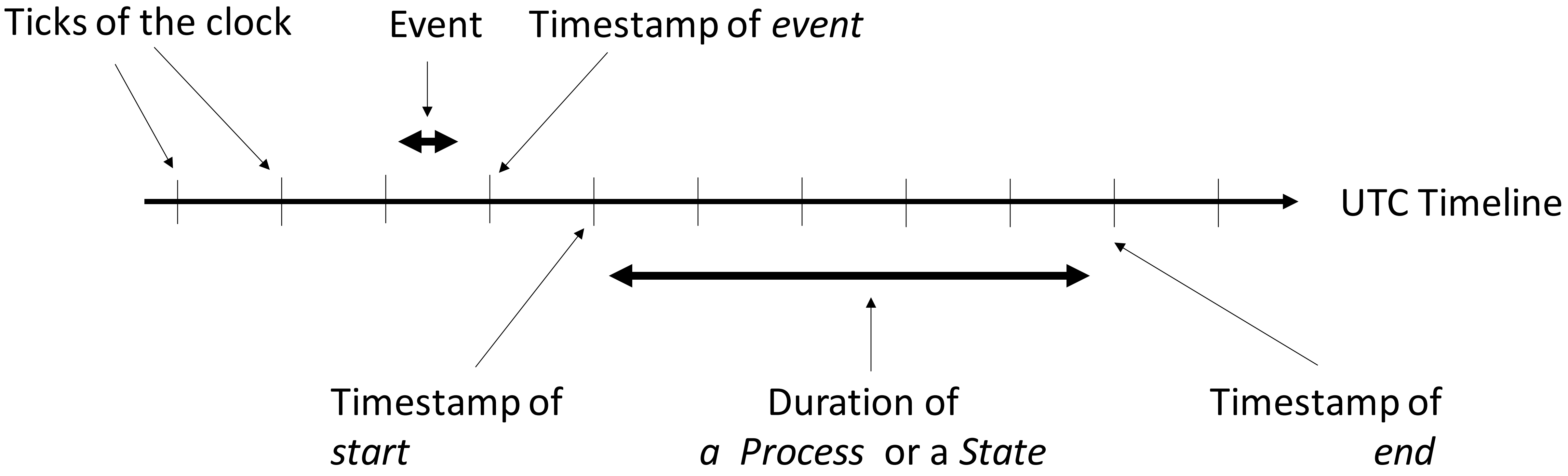
Property: A characteristic of a *thing* or of a *construct*. e.g., the *weight* of a stone

Value: A refinement of a property. e.g., a *value* of the weight in measurement units.

Category: A construct that denotes a set of things or a set of constructs that share identified *properties*. e.g., *lime-stone.*

Time: A construct that can be depicted by a line that proceeds from the past to the future and is marked by the ticks of an UTC synchronized clock (Newtonian).

Model of *Time* in the *DIT Model*



Happening is an umbrella term denoting an event or a process.

Symbols in the DIT Model

Symbol: A construct that consists of two parts, a ***signifier*** and a ***signified***. The *signifier* denotes the *signified* *(*the something*)*.

- The *signifier of a symbol* can be a picture, a sound, a gesture, a letter, a digit, a word, or any kind of *physical pattern* that stands for *something*. The *signifier of a symbol* is also called the *name of the symbol* that identifies the *something*.
- Depending on what a signifier stands for we distinguish between four types of signifiers in the DIT model:
  - (i) a **word:** of a natural language that *denotes* a *concept*
  - (ii) a **proper name;** *denotes* a specific person, thing or construct
  - (iii) a **literal:** the form of the signifiers *denotes* the *signified*
  - (iv) a **token name:** *denotes* a meaningless placeholder, a *token*

Literals: The *Gestalt* of the *signifier* denotes the *signified*

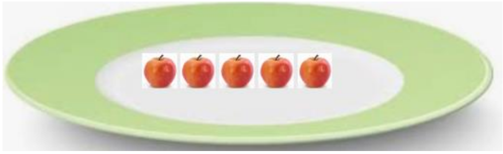
Signifier
a pattern(acoustic, visual)

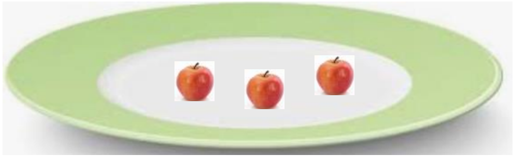
Signified
an abstraction

Example: sequence of digits

(*numeric value* of a scenario, not indicating what the value refers to)

(decimal) base 10	roman	(binary) base-2	base-4	
5	**V**		**101**	**11**
3	**III**		**11**	**3**





What determines whether *"11"* means
five
or *eleven*
or *three* ?

the context!

Context

The *context* of a *symbol* is the general situation that relates to it, and which helps it to be understood.

In the DIT model we distinguish between the

- **Outer Context**: The *outer context* of a *word* is the objective reality in the current situation. It is determined by the prevailing physical, cultural and social environment.
- **Inner Context**: The *inner context* of a *word* consists of those parts of the ***conceptual landscape*** in the brain of a ***conscious human*** that are related to the concept denoted by the word and the current perceptions of relevant events in the physical environment (i.e. the outer context) that are delivered to the *conceptual landscape* by the human senses.

What is Consciousness? The TNGS Theory

- According to the he *Theory of Neuronal Group Selection* (TNGS) ***consciousness*** is an an *emergent property* as a consequence of the intense interactions among a large number of neurons in the *thalamocortical system* of the human brain.
- At any moments, a ***conscious*** person is only aware of the small part of the conceptual landscape—called the ***dynamic core***— that relates to the momentary situation.
- By shifting the attention from one topic to another topic, the composition of the d*ynamic core* is changed. **The *attention shift time* is in the order of *hundred of milliseconds to seconds*.**
- The dynamic core interacts with the other areas of the brain, where a plethora of powerful concurrent autonomous neural processes are active, by *input ports* and *output ports.*
- The current perceptions of the physical environment are preprocessed and categorized by ***unconscious autonomous neural processes*** before they are delivered in the form of a *high-level concept* to an input port of the dynamic core.

Communication among Humans

Human Communication uses predominately sentences composed of natural language words. A *basic natural language* sentence communicates and *idea—an Information Item (**Itom**)*—by the use of *symbols* (words). It consists of a *subject*, a *predicate* and an *object phrase*.

<Subject> **<Predicate>** **<Object>**

Often a proper name of an entity

- a person
- a thing
- a construct

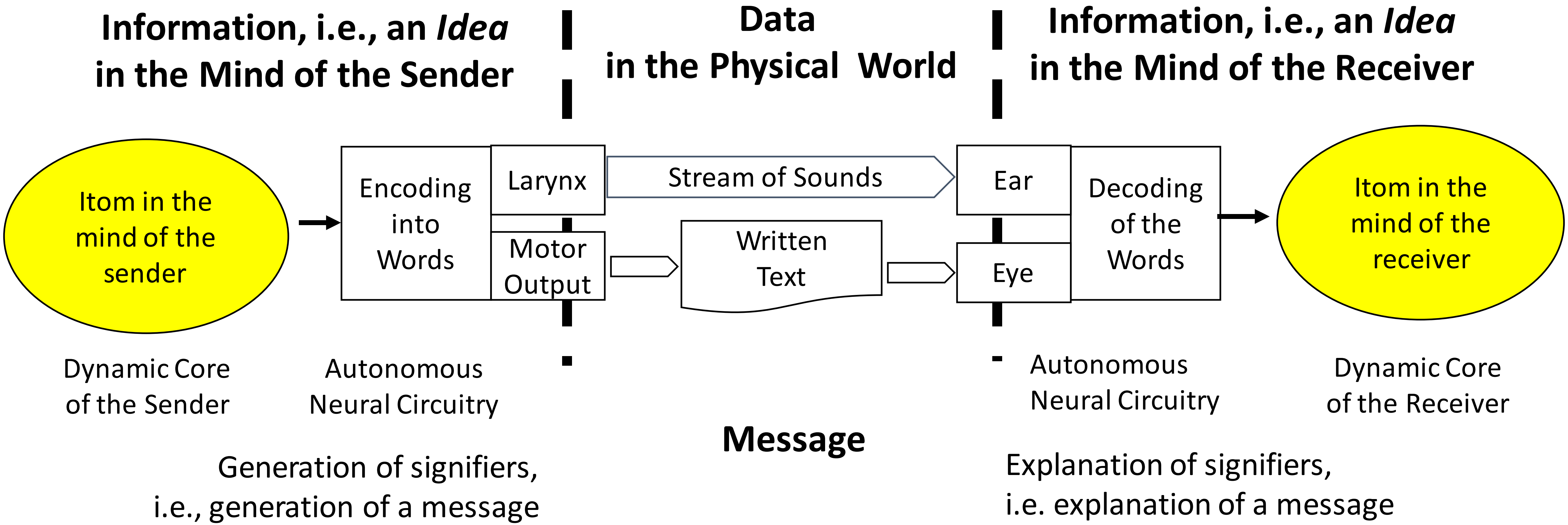
Often a relation, e.g.

- a property
- tensed

Often a refinement of the relation

A sentence only makes sense, if all words of the sentence are grounded.

The DIT Model of Human Communication



An Example

<subject>	***<predicate>***	***<object>***
Tom	*possesses*	*a valid passport.*

This sentence is *semantically meaningful*! But is it *true*?

This depends on whether the *zero point* (i.e., the *utterance event*) lies within the time interval contained in the passport.

In order to make a sentence *denotationally meaningful* we have to add to a semantically meaningful sentence the the instant (the zero point) when the sentence has been uttered.

Written Text

When looking at a *written text*, we have two deal with two events:

- the *write event* (W-event), i.e., the instant when the text is written
  and
- the *read event* (*R-event*), i.e., the instant when the text is read.

The interval between the *W-event* and the *R-event* can have an impact on the meaning of the text and the truth-value of a proposition.

If the R-event of the previous sentence, where the tense is the *present,*

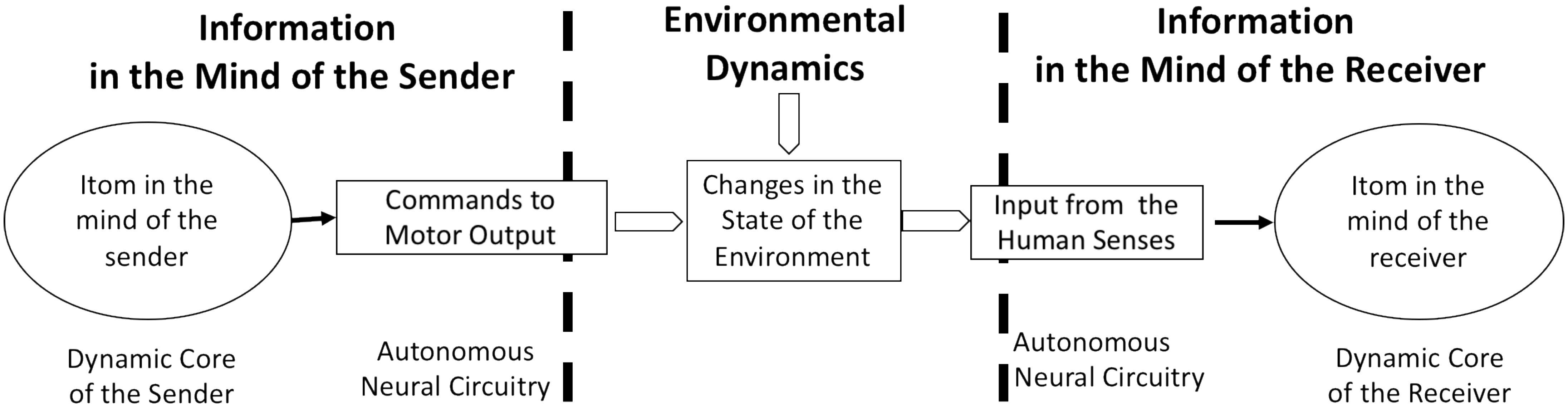
Tom *possesses* *a valid passport*

is outside the validity interval contained in the passport,
then this sentence is false.

Stigmergic Information Flow

We call the transmission of Itoms between a sender and a receiver via an observable modification of the state of a shared physical environment *stigmergic communication*.

Example: Communication among Drivers.



A *stigmergic information flow* can form the final link in the formation of a causal loop.

The Impact of Time

(i) The predicate of a proposition (the *Zeitwort*) is tensed,
causing a displacement of the Itom on the time line.

(ii) Over time, the contents of the conceptual landscape are changed,
causing a change in the *denotation* and *connotation* of words

(iii) During the interval between the *W-event* and the *R-event* the context is altered,
causing a change in the truth value of the proposition.

In oral communication where the *zero-point of an utterance* is also the *instant of interpretation,* point (iii) is of no concern.

Handling of *Time* in the *DIT model*

In the DIT model, the *predicate of a proposition* must be attributed with temporal parameters:

- If the communicated happening refers to an event, then the timestamp of the occurrence of the event must be attached to the predicate.
- If the communicated happening refers to a state or a process, then two timestamps, the timestamp of the start event and the timestamp of the end event of the happening must be attached to the predicate.

It is assumed, that all involved parties have access to the global UTC time, distributed by GPS, such that the precise interpretation of the timestamps is possible.

Tokens in Cyber Space (i)

A ***token name*** *denotes* a meaningless placeholder, a *token.*

Consider the Statement

token (variable) names:	**a**	**x**	**b**	**=**	**c**
values of the tokens (*ungrounded*):	**3**	**x**	**5**	**=**	**15**

If we consistently change the names of all tokens in a complete program,
e.g., d,e,f, instead of a,b,c
then the result of the computation is not changed.

The *token names* and the *values* are *not grounded*!

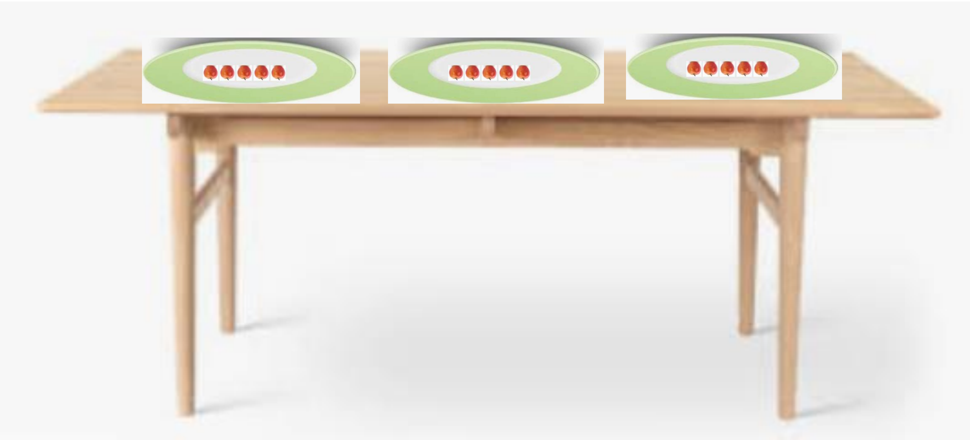
Tokens in Cyber Space (ii)

A meaningless **token name** *denotes* the placeholder of a *value.*

Consider the Program

token (variable) names:	**a**	**x**	**b**	**=**	**c**
Values of the Variables:	**3**	**x**	**5**	**=**	**15**

The grounding of statement replaces *the token name by a meaningful word phrase* and *grounds the value,* thus forming a (possibly degenerate) *Itom*.

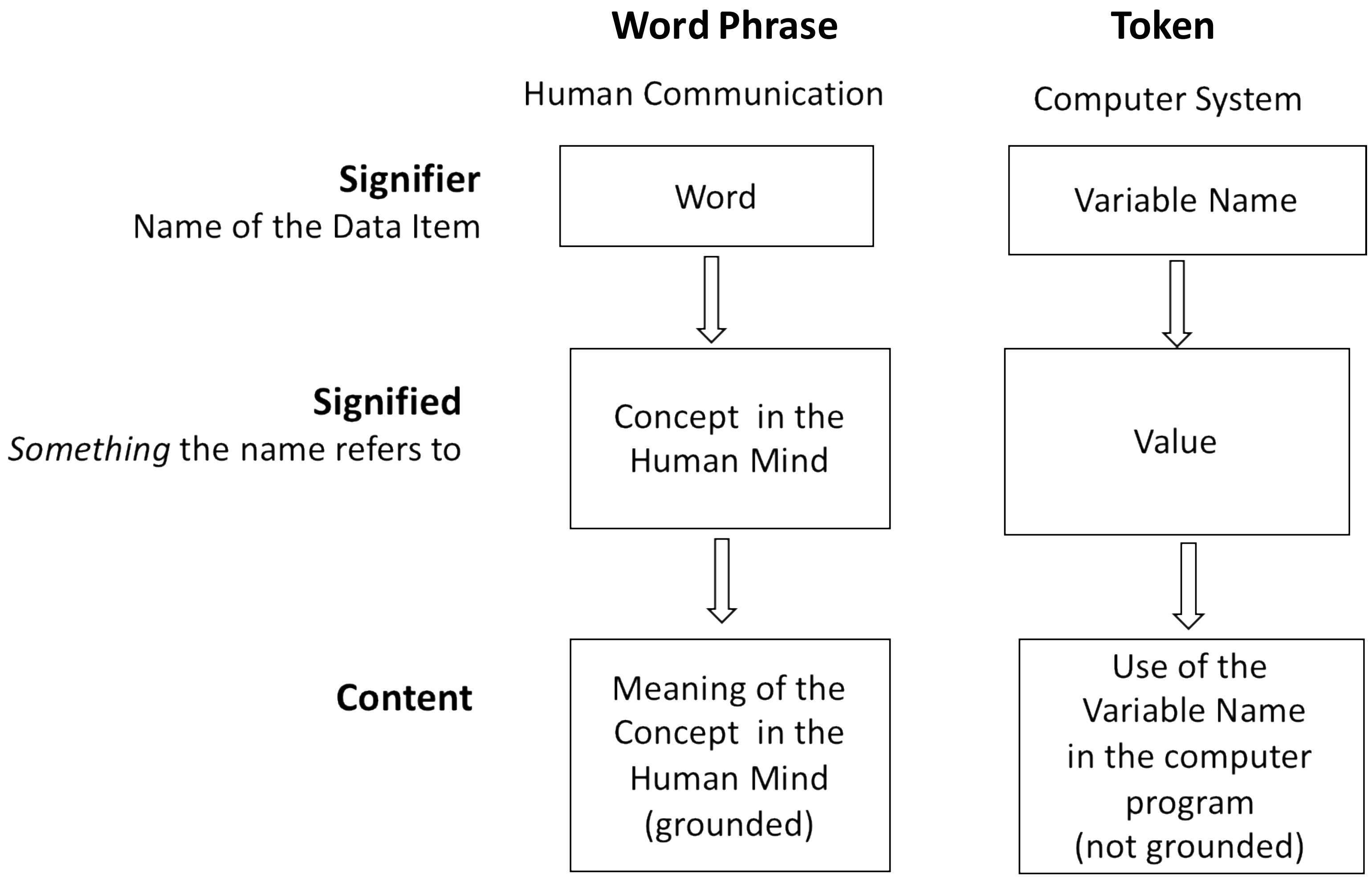


a	**x**	**b**	**=**	**c**
↙		↓		↘
Number of dishes on the table		Number of Apples on a dish		Number of apples on the table
Itom 1		Itom 2		Itom 3

Correctness of an Algorithm

- An algorithm, implemented by a program, establishes formal relations among a set of tokens.
- If we ground the tokens by assigning meaningful words to the tokens, then these *formal relations* model *actual relations* about the assigned concepts that are supposed to exist in reality.
- If these *actual relations* are *true* in reality, then we say that the program is *accurate*.

Comparison: *Natural Language Word* to *Token Cyber Space*



If the name of a variable in a program is a meaningful word that denotes (as its *signified*) an established concept in the mind of a human, then the value of this *variable is grounded* and can be considered a (possibly *degenerate*) information item (*Itom)* that carries *sense*.

Summary: Characteristics of a *Data Item*

In the DIT model a *data item* is a symbol that consists of a *signifier* and a *signified*. The *signifier*—the name of the symbol — is the physical pattern that represents the ***data item*** in the physical world.

- In human communication the signifier is a *word* and the *signified* of this symbol is the *meaning of the word*, determined by the assigned concept in the mind of an conscious human receiver, forming a *meaningful data item*.
- In a computer system the *signifier* is a *meaningless token (variable) name and the signified* of this symbol is the *value* housed by the token that is operationally explained by the use of the variable name in the computer program, forming a *meaningless data item, if* ***the variable name is not grounded*****.**

In both cases a *data item* is a *whole* that consists of two parts, the *signifier* and the *signified.* If we take the whole apart and look at each part in isolation, then the notion of a *data item* breaks**.**

Summary: Characteristics of an *Itom*

In the DIT model an Itom is a *proposition* that makes *sense*—informs about an *idea*—and has the following characteristics:

- **Temporal Aspects:** The Itom must inform when the predicate of the proposition holds.
- **Truthfulness:** Our conception of an Itom does not make any assumptions whether the information carried by an Itom is *true.*
- **Relativity:** Any representation of an Itom must consider the context, which is given by the current physical and cultural environment.
- **Newness:** The aspect of *newness of information* to the receiver and associated metrics about the subjective value or the subjective utility of the Itom to a receiver are not part of the DIT model.

Archival Information

An *archive* is a repository that holds documents of *permanent historical information (a **vast plurality of Itoms**)* that are dated and stored on different kinds of media in order that this information can be accessed and analyzed at some future date.

An *Itom*, the *sense of a proposition*, consists of four *data items*:

Subject	an entity
Predicate	a relation (property)
Time	timestamps
Object	a value (e.g., a literal)

Explanation of the value

An Itom consists of a value and the explanation of the value.

In a database, the explanation of the values, which makes the Itoms, is contained in the *schema* of the data base.

Explanation of the *Value*: *A simple File*

A simple file is a tabular two-dimensional data structure, containing a

- A file name—should explain the context of the file and the ***grounding of the values*** (and possibly the time).
- A row name—explains the entities
- A column name — explains the relation (property)
- A value field —contains the value, often a *literal*, at the intersection of *row* and *column*..

Every value field together with its explanation, forms a (degenerate) *Itom.*

What is often missing is the temporal information.

Example of a Table

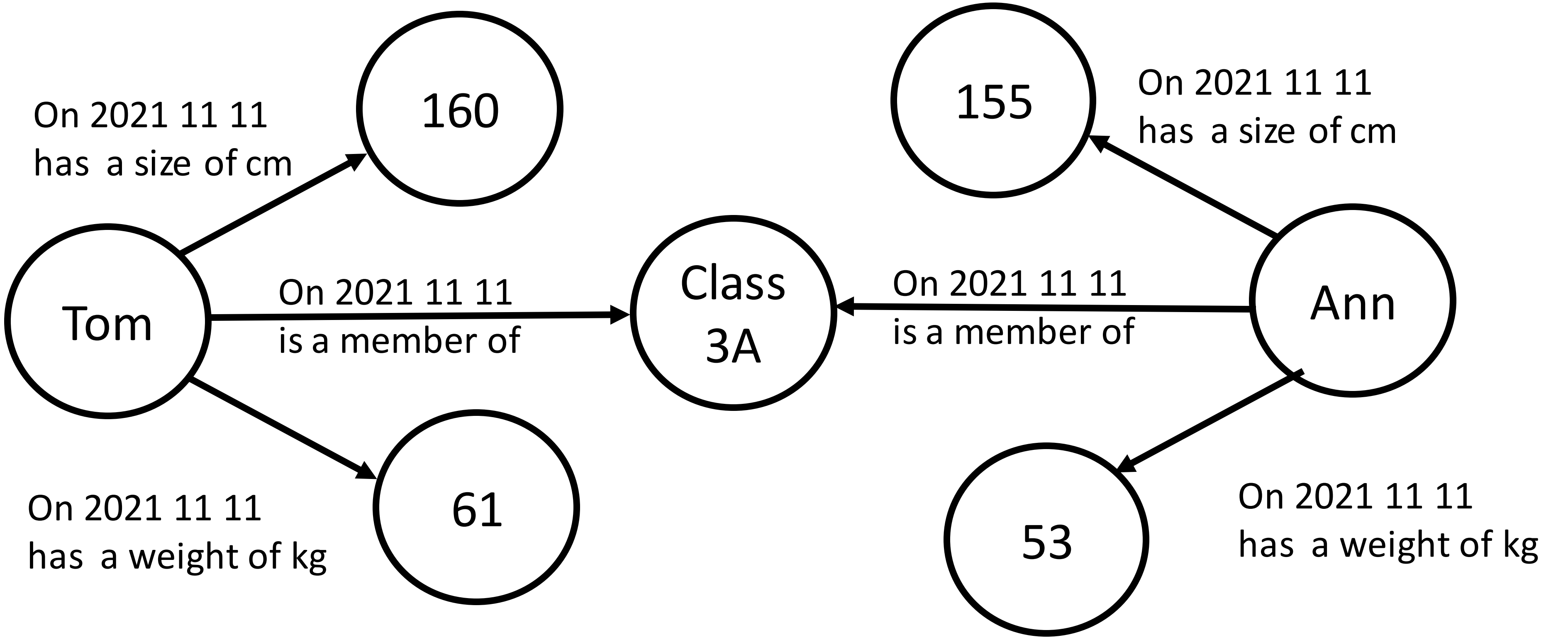
Size and Weight of the Students in Class 3A, measured on 2021 11 11

Name/Property	Size in cm	Weight in kg	-------------
Paul	160	61	...
Ann	155	53	...
---------	...	...	...

This information can be represented by the following six Itoms:

- *On 2021 11 11 Paul has a size of 160cm.*
- *On 2021 11 11 Ann has a size of 155cm.*
- *On 2021 11 11 Paul weighs 61 kg.*
- *On 2021 11 11 Ann weighs 53 kg*
- *On 2021 11 11 Paul belongs to Class 3A*
- *On 2021 11 11 Ann belongs to Class 3A*

DIT Knowledge Graphs



An *Itom* is a *primitive* of an DIT knowledge graph.

Example: Two different Tables for the same *Itoms*

Size and Weight of the Students in Class 3A, measured on 2021 11 11

Name/Property	Size in cm	Weight in kg	-------------
Paul	160	61	...
Ann	155	53	...
---------	...	...	...

1

Size and Weight of Paul

Property/Date	*2020 11 10*	*2021 05 08*	*2021 11 11*
Size in cm	153	157	160
Weight in kg	58	60	61
Member of Class	2B	2B	3A

Itoms in Real-Time Systems

- In a real-time system, the validity (and utility) of an *Itom (which must be part of the Itom)* is limited by the dynamics of the controlled object.
- A short response time of the computer system improves the quality of control
- The communication time can be reduced by a recoding the representation of an Itom for the transport. Separate the specification of an Itom (using natural language) from representation (the encoding) of the Itom.
- The processing time can be reduced by the deployment of anytime algorithms. A *satisfying result* produced in time is more important than a *precise results* that arrives too late.

Generation of Data

An Itom consists of a data item and the explanation of the data item:

- **Identification of an entity:** We have to identify an entity or categorize the entities in order to restrict the number of entities in the CSTD.
- **Identification of a property:** If the property specification changes in the IoD, then the value will probably change as well.
- **Timestamp of the observation of the phenomenon:** In a real- time control system, a second timestamp for the end of the validity time of the observation must be part of the temporal data.
- **Value of the property:** this is often a literal (e.g., a string of digits) representing a numeric value. The measuring units of the numeric value must be included in the property specification.

Explanation of Data

The explanation of the data is somehow the inverse of the generation of the data.

- Care must be taken that the context of explanation of data is the same as the context of the generation of data. This is of particular importance when the *change of context* between the ins*tant of data generation* and *instant of data explanation* has an effect on the explanation of the data.
- At the human-machine interface (HMI) the representation of the *values of interest* must be framed by an explanation that is grounded in the mind of the human reader. Also, the measurement units of values must be familiar to the intended clientele of the Itom.

Data in Biological Systems

Phases in the Life of a Plant

The genome, stored in the DNA, can be considered as the ***control data base*** that controls the development of an organism.

Seed contains the genome of an organism

dormant phase	germinating phase	growth phase	mature phase

One Generation of the Phenotype

Seed

Next Generation of the Phenotype

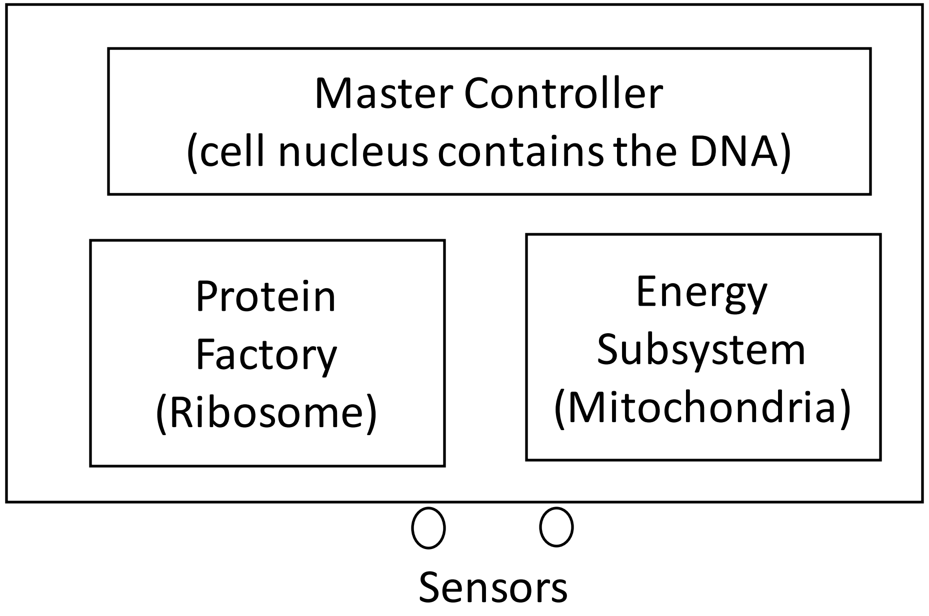
dormant phase	germinating phase	growth phase	mature phase

Seed

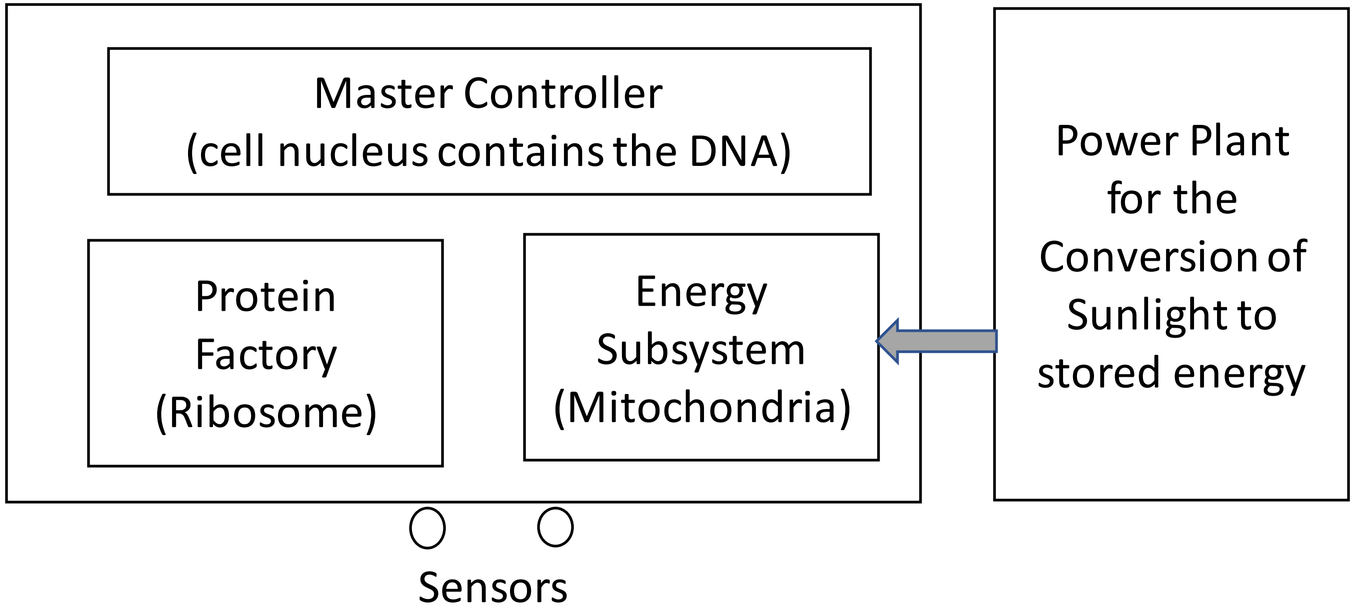
Timeline

Main Subsystems of a Plant

The *Codons* of the DNA control the structure of the protein production in the Ribosomes.



(a) Main Subsystems of a Seed



(b) Main Subsystems after Germination

Comparison of the Notion of *Data*

	Computer	**Plant**	**Human**
Signifier	variable	codon	word
Signified	a specific value	a specific amino acid	concept in the human mind
Meaning of the *signified* derived from	its use in a program	its use in protein synthesis	concept formation
Physical Embodiment generated by	Human	Nature	Nature
Modification of the Physical Embodiment by its use	No	Yes	Yes
Reproduction capability	No	Yes	Yes

An important Conclusion

Humans deal with *Itoms*

while

Machines deal with *Tokens*

Consequences for System Design

- Specification Dilemma
- Human Machine Interface Design
- Benefits of a Global Time—Data Reduction
- Partitioning of a Safety-Critical Control System

Specification Dilemma

The fact that the precise meaning of a natural language word is subjective and unique to a single person and may thus differ among different persons is the cause of the *specification dilemma.*

The use of natural language is unavoidable in

- the specification of the purpose of a system,
- the grounding of the symbols or
- the interfaces between cyberspace and the real-world

However, the data interfaces within and between the computers in cyberspace can, and should be formally specified.

Consequence: Project Dictionary of all technical terms!

Human Machine Interface Design

At an interface to a human user, the display must include the *value* and the *explanation of the value* in an appropriate *display format*, such that the human user can grasp the *meaning of the value* with a minimal mental load:

- Consider the mental models in the mind of the user
- Study the cultural background and the work profile of the user
- Distinguish between occasional and experienced users
- Take advantage of established color codes (green, orange, red)
- Implement the explanation of the data and the provision of the results in separate subsystems.

Benefits of a Global Time

The DIT model requires a global time in order to arrive at a *non-tensed design*. A global time is required to

- to interpret time-stamps
- to design unidirectional communication protocols. A unidirectional control flow avoids a failure propagation of a faulty receiver back to a correct sender.
- Time-triggered protocol avoid queuing delays in communication systems.

Example: Smart grid

Architecture Design

Given a *clearly specified purpose*, it is the most difficult—and *most important*—challenge in the development of a large system to find a structure a that will minimize the cognitive complexity.

At the level of Architecture Design—**reason in *Itoms, including the temporal parameters.*** In an *highly iterative design process*:

- Partition the System into nearly independent subsystems.
- Minimize the interface complexity.
- Define the *Itoms* that must flow between the subsystems.
- Ensure that the system integration will not produce emergent effects.
- Ensure that the project organization maps the evolving system structure.

Two Techniques for *Complexity Reduction*

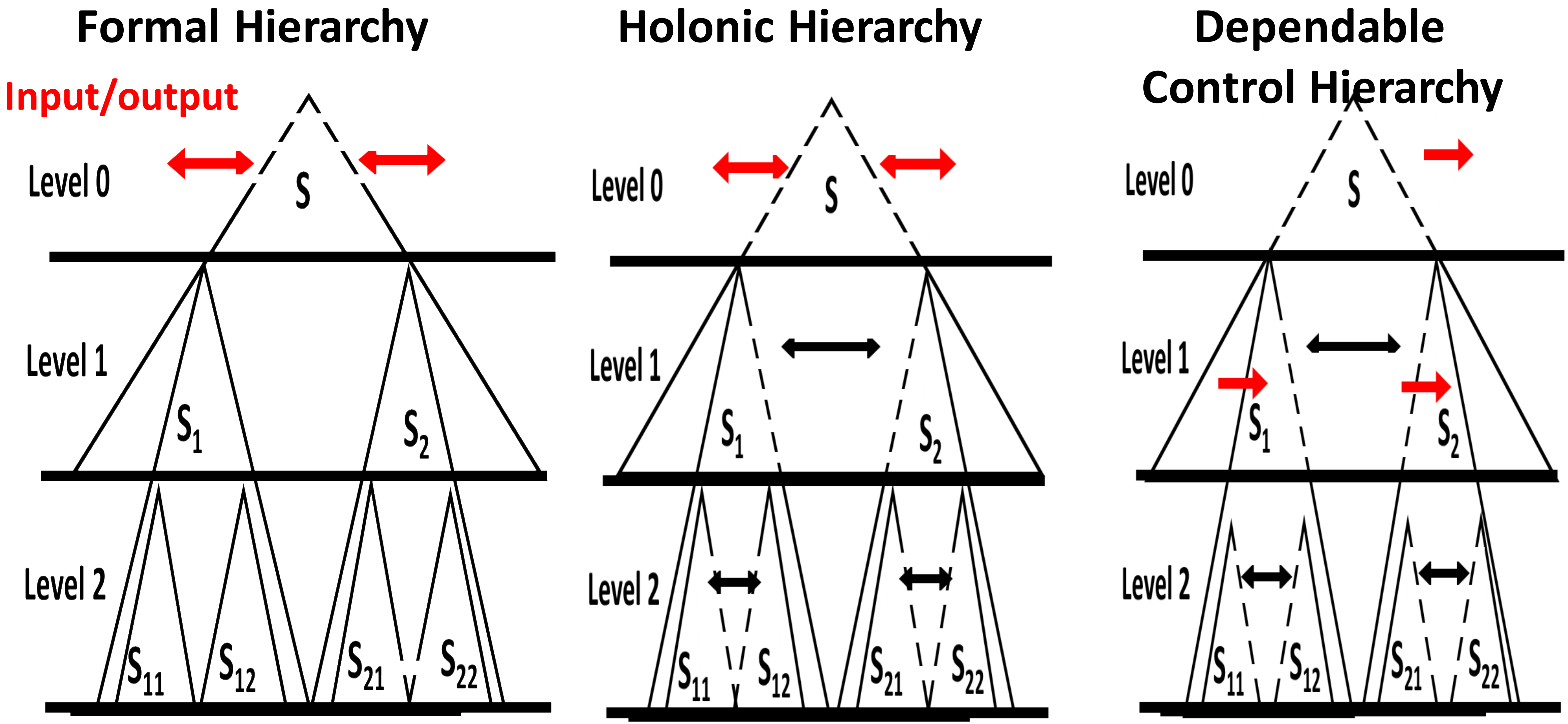
Abstraction: Find a hierarchy of reduced representations—and of *design artefacts*—primarily from the point of view of the intended system service.

- Formal Hierarchy
- Holonic Hierarchy
- Dependable Control Hierarchy

Divide and Conquer: Partition the system into nearly independent subsystems.

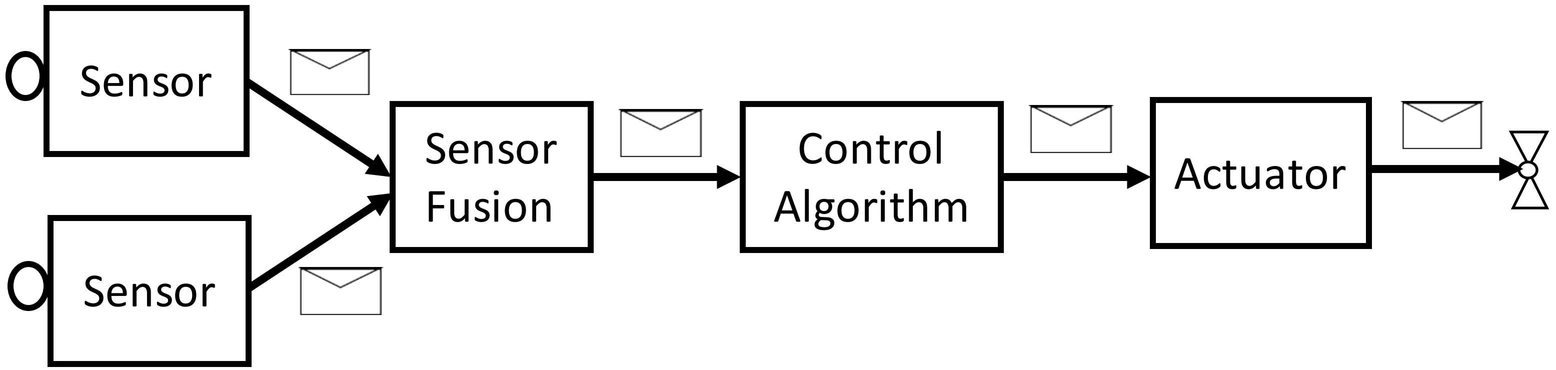
- Minimal Interfaces (where ever possible, unidirectional)
- Avoidance of unintended *Emergent Effects*.

Abstraction



Minimize the Interface Complexity

In a real-time system many *Itoms* flow periodically and unidirectionally from the sensors to to the actuators



- Place the interfaces at positions, where a *minimal number of Itoms* must cross the interface and where future changes are unlikely to change the interface.
- Maintain the unidirectionality of the communication at all levels of the communication protocol in order that *by design* a failure of a receiver has no impact on the sender—use *time-triggered protocols*!

Define the *Itoms* in *natural language* and in a *formal notation* in carefully monitored *Interface Control Documents (ICDs)* that meet *the mutual expectations*

Avoid unintended Emergence

A phenomenon at the system level is called *emergent* if it is of a new kind with respect to the non-relational phenomena of any of its proper subsystems.

- In many cases of emergent behavior, we find a causal loop exists between interacting subsystems.
- Try to avoid unnecessary bidirectional communication links.

Architecture Design of a Safety-Critical System

Starting point: The purpose of the proposed system, giving rise to set of funct*ional requirements* and *safety requirements*.

Partition the overall system into Fault-Containment Units (FCUs) and specify the dependability properties of the FCUs

- Assign the top level functional and safety requirements to the FCUs
- Specify the *Itoms* that cross the interfaces of the FCUs.
- Analyze if the required safety will be attained and can be argued by the proposed structure.

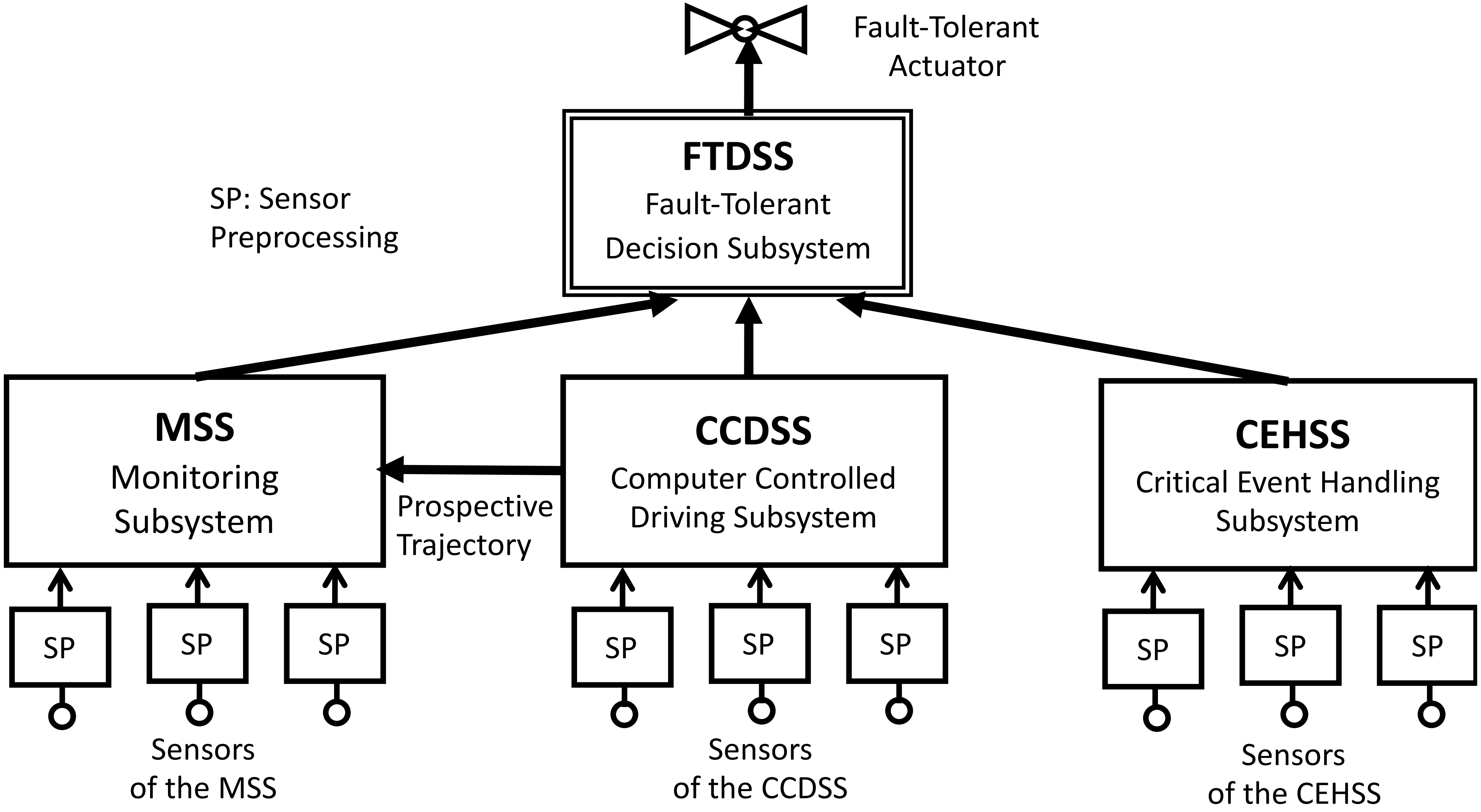
Take into consideration widely accepted *impossibility results*.

I*mpossibility Results* for Autonomous Driving

There is strong experimental evidence that it is impossible in ultra-dependable systems to overcome the constraints that are summed up in the following *five impossibility results* :

- It is impossible to find all design faults in a large and complex *monolithic* Software System.
- It is impossible to avoid single event upsets in non-redundant hardware during the life-time of an ultra-dependable system.
- It is impossible to establish the ultra-high dependability of a large monolithic system by testing and simulation.
- It is impossible to precisely specify all edge cases that can be encountered in driving situations.
- It is impossible to shift human attention without a significant *attention shift time*.

Example of an FT-Architecture for an SAE Level 4 System



Conclusion

- The DIT Model makes a clear distinction between the terms *data item* and *information item*.
- A *data item* is a symbol that is *meaningful* if the signified is grounded, while an information item—an *Itom*—is a timed proposition that is composed of *grounded data items* and carries an *idea*—makes *sense*.

Humans deal with *Itoms* while

Machines deal with *Tokens.*

Thank you.

Publication Date: April 25, 2022