FAKULTÄT FÜR ELEKTROTECHNIK UND INFORMATIONSTECHNIK

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Using characteristics during system design

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1 Basic terms

For purpose of this discussion it is necessary to clarify some basic terms, which are going to be used throughout the document.

A system is according IEC 60050 a „set of interrelated elements considered in a defined context as a whole and separated from their environment" [IEC60050-351]. As noted in the standard "elements of a system may be natural or man-made material objects, as well as modes of thinking and the results thereof (for example forms of organization, mathematical methods, programming languages)" [IEC60050-351]. Also: "The system is considered to be separated from the environment and the other external systems by an imaginary surface which cuts the links between them and the system" [IEC60050-351]. For purpose of this document it is important to note, that a system element in general is considered as a material object (at least as material as software object can be). Also it is important to note that a system element itself again may be considered as a system.

If we consider the "imaginary surface" mentioned in the definition of system, we have to observe that a system still may interact with its environment (or with external systems). This interaction occurs via interfaces, which are defined by IEC 60050 as „shared boundary between two functional units, defined by functional characteristics, signal characteristics, or other characteristics as appropriate"[IEC60050-351]. – Such an interaction is carried out by means of signals, which are defined by IEC 60050 as „physical quantity, one or more parameters of which carry information about one or more quantities " [IEC60050-351].

Please note that the 'interrelation' of system elements is considered as a precondition for the 'interaction' between the system elements. – A man-made system first needs to be composed before the system elements may interact. This composition creates relations between the system elements.

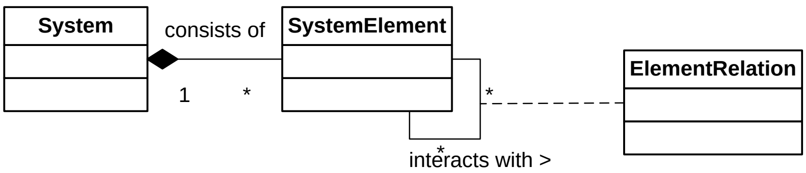

Figure 1 – Model for relations between System elements

The possibility of such relations typically is predefined by the intended use cases for the system elements. Such use cases are the starting point for definition of the system elements, their relations and, the respective interfaces.

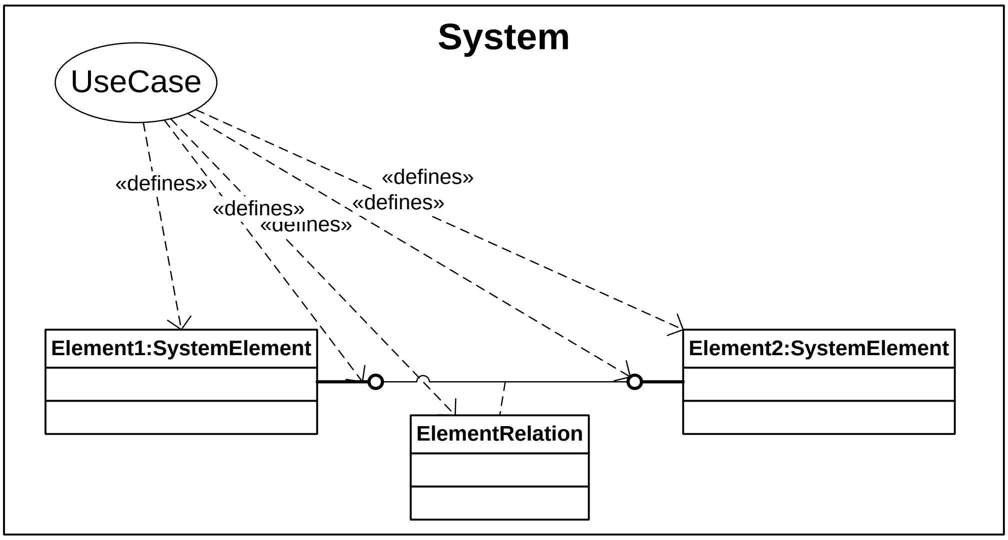

Figure 2 – Use cases are the base for definition of system elements and element relations

After creating such a relation, the interaction between the system elements is executed via the interfaces of the system elements. When two system elements shall interoperate, their interfaces must fit together. This means for a specific interface of one element, there is a corresponding interface of the other system element.

A system element may have a number of interfaces, which may be used to realize a number of relations. It is possible that an element relation may be implemented by a set of interfaces (one or more interfaces that are matched with the interfaces of the other element).

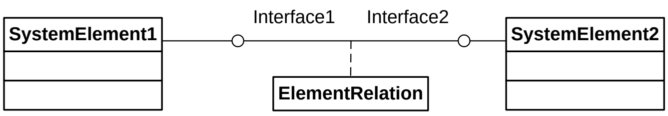

Figure 3 – Interfaces

When a number of system elements are integrated into a system, the interfaces of the elements are connected to each other. It is possible to differentiate the interfaces according to the type of functional relation that is supported by the interfaces:

- bilateral interfaces support a binary relation only (e.g. RS-232 interface).
- multilateral interfaces may support relations between multiple system elements (e.g. RS-485 or fieldbus interface)q

If system elements are connected to each other by using a bilateral interface, the interface is ‘consumed’ and cannot be used for creating relations. E.g. if an electrical drive and the rotary pump are joined by their mechanical interface, the interface cannot be used for integration of additional equipment.

If system elements are integrated to each other by using multilateral interfaces, these interfaces still may be used for additional relations. For instance if a sensor is integrated with a robot via a fieldbus interface, the fieldbus interface may be used for integration of additional equipment.

If interfaces are not used during integration of the system elements, they still are available for use. Such interfaces may become interfaces of the system.

For example a system "Electropump" shall be considered. The system is composed of an electrical drive and a rotary pump. The electrical drive has an electrical interface (electrical energy input) and a mechanical interface (mechanical energy output). The rotary pump has a mechanical interface (mechanical energy input), a fluid inlet and a fluid outlet. These system elements are integrated via the mechanical interface (energy flow) into a composite system ("Electropump"). The mechanical interfaces are consumed. They cannot be used for further integration and their properties are not relevant for describing the system. The electrical interface, the fluid inlet and the fluid outlet are still available interfaces and their properties are relevant for describing the system, because they may be used to integrate the system "Electropump" as a system-element into a larger system.

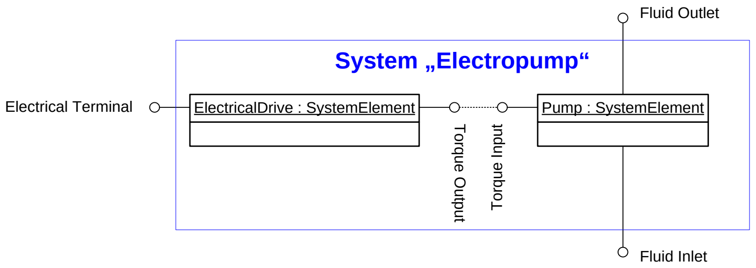

Figure 4 – System „Electropump"

2 Characteristics and properties

System and system-elements may be described by characteristics.

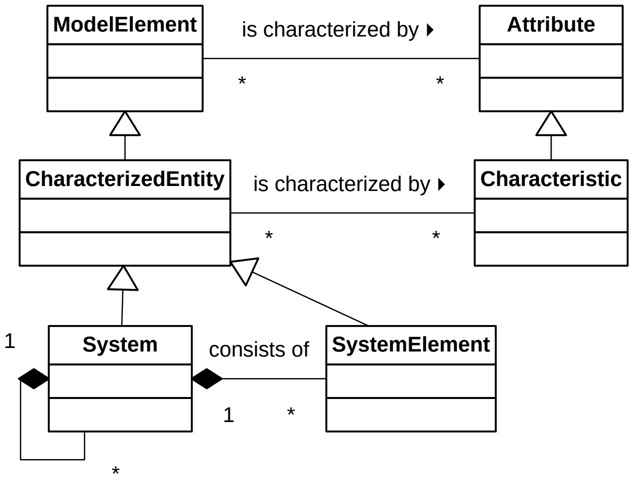

Figure 5 – Model for Characteristics

A characteristic is a formally defined attribute with well defined meaning. Such a characteristic is a ModelElement (this generalization relation is not shown in Figure 4) defined with:

- name
- definition
- symbol
- formula
- value range
- unit of measure
- depiction
- literature reference / source of definition
- relation to other characteristics

There are standards defining list of properties that provide well defined descriptions for specific types of devices – e.g. IEC 61360 and the IEC 61987 series [IEC61360-1], [IEC61987-10].

In these standards the properties are defined with a unique ID and with further attributes similar to the attributes of a characteristic listed above. In these standards one important attribute is missing: “relation to other characteristics”. With this relation it is possible to document how a characteristic is related to other characteristics on the same CharacterizedEntity. This attributes describes how a characteristic (e.g. weight) may depend on another characteristic (e.g. material of the housing). Other relations may be arithmetic relations as represented by the formulas. – The attribute “relation to other characteristic” is useful when during design the possible impact of decisions is evaluated. It allows to capture ‘insight’ in the internal relations of the characteristics of the CharacterizedEntity. Such relations are named “intra-relations” (see Figure 5).

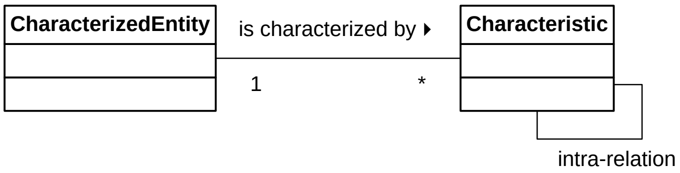

Figure 6 – Intra-relation

Definition: *An intra-relation is a property-relation between characteristics of the same CharacterizedEntity.*

Figure 6 shows the relation between Characteristic and Property. Basically a Characteristic can be considered as a Property, which has additional information about relations to other Characteristics.

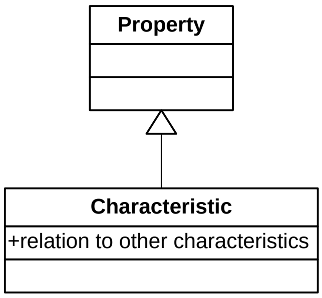

Figure 7 – Relation between Characteristic and Property

In this document the terms “Characteristic” and “Property” are used synonymously. The term “attribute” is used to describe the aspects of a ModelElement (e.g. the aspects of a Property).

The standards define different lists of properties for different device types. These lists of properties may be used to describe actual devices by providing property values. These device descriptions may be used during the process of selecting and purchasing equipment and during design of automation systems. As shown in Figure 7 the properties may be grouped together into blocks, where each block contains properties that describe the same context (e.g. a person with a set of contact information or an interface). The properties are defined individually in CCD. The actual meaning of each property can be derived from the context within the property list. For instant the property ‘version number’(ADA004) may apply to ‘Identification numbers’(AAA651), ‘Internationally registered identification system’(AAA652), ‘Nationally registered identification system’(AAA653), ‘Named organization identification system’(AAA654) or ‘Identification’(AAA651). ‘Identification’ again may apply to description of persons or equipment.

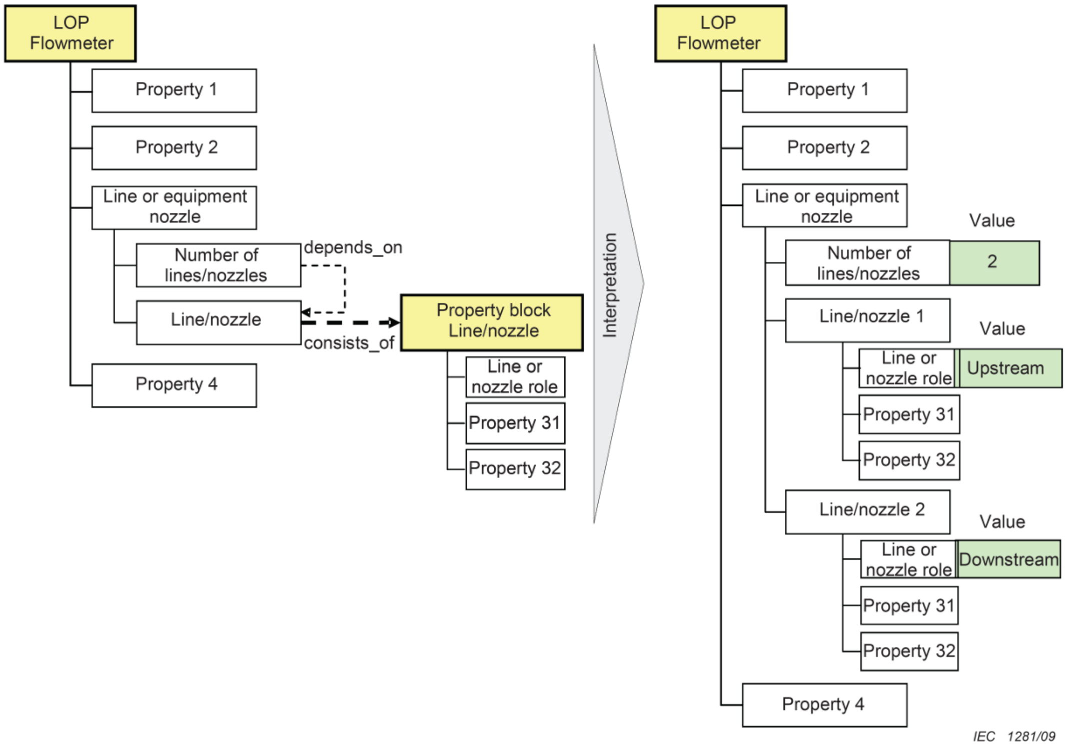

Figure 8 - Explanation of cardinality in [IEC 61987-10]

An important fact is, that properties and characteristics do not have a complete semantic on their own. The significance of a characteristic is defined by the relation to the CharacterizedEntity. For instance the standards define a property “version number” (ID ADA004). The actual meaning of the value can be derived only from context, for instance it may describe the version of the current document, the version of a referenced document or the version of a device type. That is why it is important to consider the context of a characteristic.

3 System development process

The development process for automatic systems typically is structured into stages, e.g. basic design stage, detailed design stage, implementation stage.

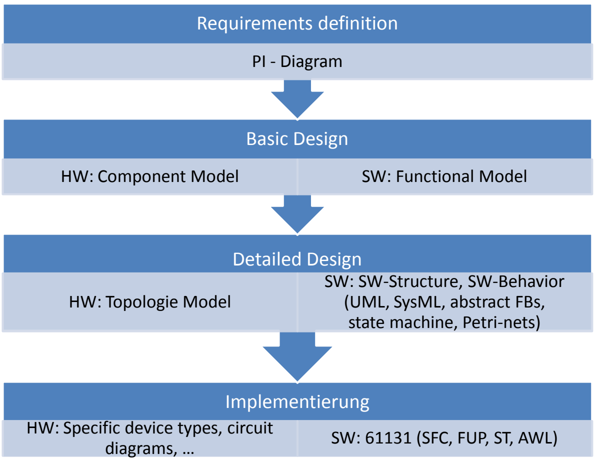

Figure 9 – Model for development process

On each stage a different level of detail is used for modeling the system.

Results of previous stages serve as requirements descriptions for succeeding development stages. E.g. the conceptual model that was designed during basic design stage, serves as requirement description for the detailed design stage.

At each development stage the system is assembled by selecting system elements from a library. - Sometimes it is necessary to introduce new system elements, but this step shall not be considered here. (Even if a new system element has been introduced, it will be added to the library and then will be selected for inserting into the system.)

The process at each development stage is depicted in Figure 9.

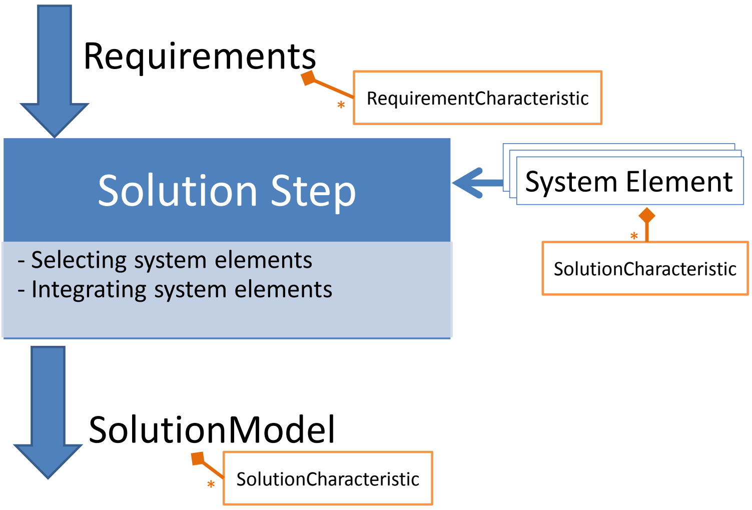

Figure 10 – Depiction of a solution step

The requirements, the system elements as well the resulting system may be described by characteristics. For instance when designing a plant, the P&I-diagram is a result of the conceptual stage. The process conditions are defined and may be reflected into the OLOP (as defined by [IEC61987-10]). During the succeeding design stage, the system engineer now selects instruments and devices from a set of available devices according to the requirements defined in the OLOP. Each device is described by a corresponding DLOP, providing details on the properties of the device. The devices are combined to model the resulting system. The characteristics of the selected devices now become characteristics of the resulting system. Additionally the resulting system may have new characteristics. Mostly these new characteristics may be derived from the characteristics of the system elements, but sometimes new characteristics evolve, that cannot be derived from characteristics of the system elements alone. If for instance a capacitor C and an inductor L are integrated to create an LC circuit, the capacitor still has the characteristic 'capacitance' and the inductor still has the characteristic 'inductance'. But, the system together has a new characteristic 'resonant frequency'.

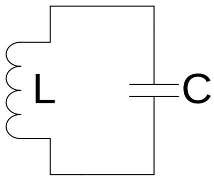

Figure 11 – LC Circuit

An important criterion during selection and integration of system elements is that the characteristics defined in the requirements ("RequirementCharacteristics") are met by the characteristics of the SystemElements and of the resulting system ("SolutionCharacteristics"). For instance, if the requirements define specific operation conditions (e.g. process temperature), the devices need to be able to operate within these environment conditions – the corresponding minimum and maximum values should define a range.

4 Functional composition and relation between characteristics

An interface is described by a property block as described in section 2. – For example consider the “nozzle” in Figure 7. For each “nozzle” type, a set of properties (block) is defined and for each actual nozzle a set of property values describes the actual nozzle.

For the example “Electropump” (see Figure 3) it is possible to describe the interfaces by their properties (see Table 1 and Table 2).

Table 1 – Examples for properties of interfaces

System element	Interface	Property
Electrical drive	Electrical terminal	Min Voltage
Electrical drive	Electrical terminal	Max Voltage
Electrical drive	Electrical terminal	Max electrical current
Electrical drive	Torque output	Min Torque
Electrical drive	Torque output	Max Torque
Electrical drive	Torque output	Rotation direction
Rotary pump	Torque input	Rotation direction
Rotary pump	Torque input	Min Torque
Rotary pump	Torque input	Max Torque
Rotary pump	Fluid inlet	Inlet suction
Rotary pump	Fluid inlet	Pump head
Rotary pump	Fluid outlet	Outlet pressure
Rotary pump	Fluid outlet	Flow rate

Table 2 – Examples for properties of a device interface (level device)

Bezeichnung	Identifier	Beschreibung	Datentyp	Wertebereich	Einheit
Hilfsenergie elektrisch	PROLIST-AAA805-004	Angaben zur Energie, welche der Einrichtung zum Aufrechterhalten ihrer Funktion zeitweise oder ständig zugeführt werden muss und nicht einem Messsignal entnommen werden kann.	Block		
Versorgungsart	PROLIST-AAA520-002	Angabe, ob das Geräte mit einem eigenen Hilfsenergieanschluss oder über seinen Signalanschluss mit Hilfsenergie versorgt wird.	String	<limited>	
Spannung	PROLIST-AAA098-002	Nennspannung der Hilfsenergie elektr., bei der das Gerät spezifikationsgerecht betrieben wird.	Real		V
Spannungsart	PROLIST-AAB870-002	Die Art der elektrischen Spannung wie z. B. Gleichspannung, Wechselspannung oder alle Spannungsarten (Universalspannung), mit der ein Gerät betrieben werden kann.	String	<limited>	
Versorgungsspannung min	PROLIST-AAB871-003	Die minimale Spannung der Hilfsenergieversorgung, mit der ein Gerät betrieben werden muss, so dass es spezifikationsgerecht arbeitet.	Real		V
Versorgungsspannung max	PROLIST-AAB872-003	Die maximale Spannung der Hilfsenergieversorgung, mit der ein Gerät betrieben werden darf, so dass es spezifikationsgerecht arbeitet.	Real		V

Bezeichnung	Identifier	Beschreibung	Datentyp	Wertebereich	Einheit
Restwelligkeit	PROLIST-AAA165-003	Unerwünschte periodische Abweichungen der Versorgungsspannung, bezogen auf den Durchschnittswert, bei Frequenzen, die in Beziehung stehen zur Netzversorgung (gemäß IEC-Wörterbuch)	Real		%
Frequenz min	PROLIST-AAB874-003	Die minimale Frequenz der elektrischen Hilfsenergieversorgung mit der ein Gerät betrieben werden kann, damit die Spezifikationen eingehalten werden.	Real		Hz
Frequenz max	PROLIST-AAB873-003	Die maximale Frequenz der elektrischen Hilfsenergieversorgung mit der ein Gerät betrieben werden darf, damit die Spezifikationen eingehalten werden	Real		Hz
Leistungsaufnahme max	PROLIST-AAB875-003	Die maximale aus der Hilfsenergieversorgung entnommenen Leistung, wie sie z. B. beim Einschalten aufgenommen wird.	Real		W
Leistungsaufnahme normal	PROLIST-AAB876-003	Die typische aus der Hilfsenergieversorgung entnommenen Leistung bei bestimmungsgemäßem Betrieb.	Real		W

When the relations between system elements are created, a number of conditions must be considered. The interfaces of system elements need to be connected to each other. This includes as a first condition, that the interfaces must complement each other. For instance the mechanical interface of the drive cannot be connected to the fluid inlet of the pump - a functional relation cannot be created.

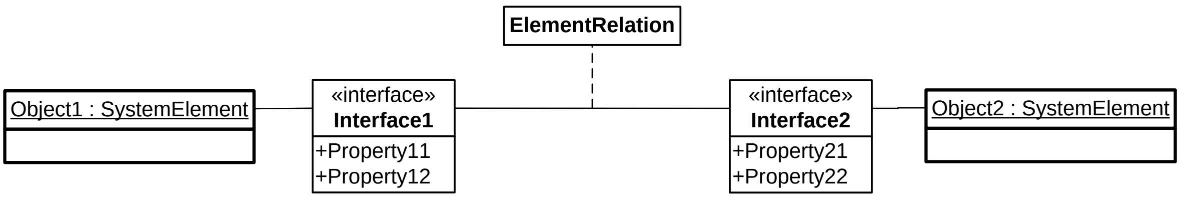

Figure 12 – Interfaces with properties

The second condition is that the interfaces are dimensioned in a way that they may fit to each other. For instance if a power supply shall feed the electric drive, it must be dimensioned in a way that it may provide sufficient power to the drive. – This means that the properties of each interface must have values that fit to each other.

The functional relations of the system elements define the relations between the properties of the system elements. Such property relations are not intuitive, they must be defined explicitly.

Example: Electric Drive and rotary pump:
If the rotor of the electric drive is connected to the mechanical drive of a pump, then it is important that the mechanical drive of the pump may accept the driving force provided by the electrical drive. The torque provided by the electrical drive must correspond to the acceptable torque of the pump.

Such property relations are different from the property relation represented in “relation to other characteristics” (intra-relations), because they describe relations between different system elements. Such relations to external properties are named “extra-relations”.

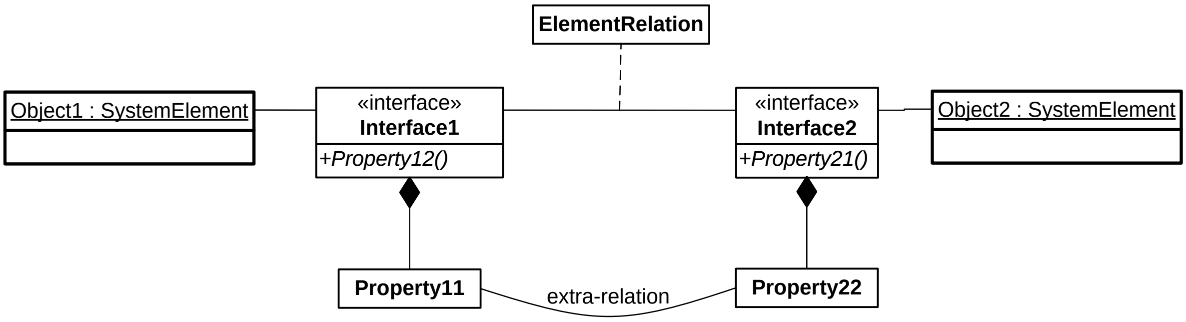

Figure 13 – Extra-relation

Definition: An extra-relation is a property-relation between characteristics of different CharacterizedEntities.

The problem with extra-relations is, that they are not a static attribute of any property. Extra-relations depend on the ElementRelations, they are created dynamically when an ElementRelation is created. Also extra-relations depend on the type of ElementRelation. Depending on what type of ElementRelations is created between 2 Elements, different extra-relations may be created. Also depending on the type of ElementRelation different properties may be involved in the extra-relation. For instance if one system element is a threaded pipe (which may be characterized by an inner-diameter and an outer-diameter) and the other system element is a reducer fitting, it depends on which side of the reducer fitting is used, whether the inner diameter or the outer diameter of the pipe may be relevant in the extra-relation.

A possible solution for this problem is to consider the extra-relation as a property of the ElementRelation and to manage the ElementRelation like an element of the system. Each type of ElementRelation together with their extra-relations may be managed within a library. If an ElementRelation is created, the definition of that relation type may be pulled from the library and used for checking the extra-relations. The type of ElementRelations that need to be stored in the relation library depends on the used SystemElements and their expected use cases.

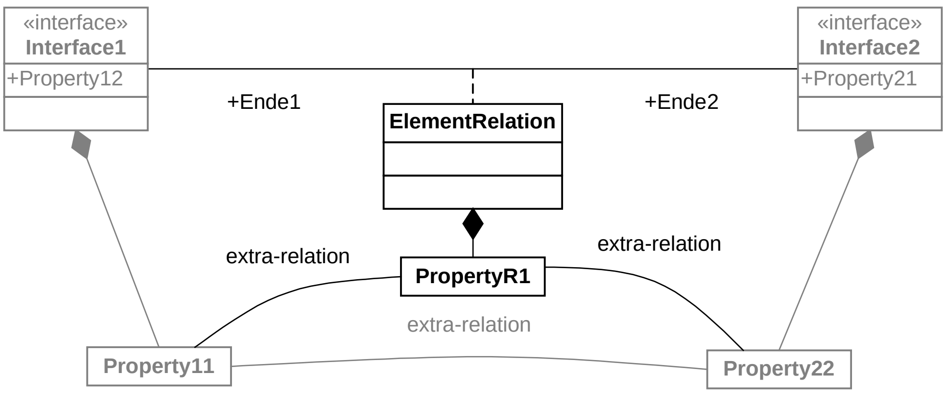

Figure 14 – ElementRelation and the respective relation property with its extra-relations

Since an extra-relation by itself cannot be considered as property, the property of the ElementRelation should be a ‘matching capability’. The value of the ‘matching capability’ is determined by setting the values of the external properties into ratio. Again the type of ratio depends on the type of extra-relation.

Such a property ‘matching capability’ of the ElementRelation describes the quality of the relation. Often the ElementRelation may depend on more than one ‘matching capability’.

Since it is not possible to manage fixed relation to SystemElements within a relation library, it is of advantage to use placeholders in the description of the property ‘compatibility’. Such placeholders ‘End1’ and ‘End2’ indicate the SystemElements (CharacterizedEntities) that are connected by the ElementRelation. Thus the ratio is indicated by “End1.Property11’ to ‘End2.Property22’.

In the example “Electro pump” the connection between electrical drive and rotary pump depends on the rotation direction and the torque that can be provided by the drive and that can be consumed by the rotary pump. Table 3 shows how the properties of the system elements are set into a ratio.

Table 3 – Extra-relations for example ‘rotary pump’

SystemElement-property	Rule	Relation Property
RotationDirection	End1. RotationDirection == End2. RotationDirection	RotationDirection.compatibility
Value range	End1. MinTorque >= End2. MinTorque End1.MaxTorque >= End2. MaxTorque	Value range compatibility

Literature

[IEC60050-351] IEC: IEC 60050-351: International Electrotechnical Vocabulary Part 351: Control technology. IEC, Geneva, 2006.

[IEC61360-1] IEC: IEC 61360-1: Standard data element types with associated classification scheme for electric components - Part 1: Definitions - Principles and methods. IEC, Geneva, 2004.

[IEC61987-10] IEC: IEC 61987-10: Industrial-process measurement and control - Data structures and elements in process equipment catalogues - Part 10: Lists of properties (LOPs) for industrial-process measurement and control for electronic data exchange - Fundamentals. IEC, Geneva, 2009.