The Semantic Level in HMS Design: Constraints, Scale Types and Representational Forms

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ABSTRACT

Motivation – A conceptual analysis of the semantic level in Human-Machine Systems (HMS) design is suggested and a revision of the approach of Cognitive Systems Engineering (CSE) is outlined. Specifically the role of scales and representational forms in Ecological Interface Design (EID) as well as the principles of information integration should be reconsidered.

Research approach – Conceptual analysis of theoretical and methodological issues in CSE and EID.

Findings/Design – Although EID is justifiably seen as the most advanced theory and methodology within CSE, it has a limited focus on direct perception of affordances and constraints in the work domain – leaving aside other issues such as e.g. representational forms in general and the role of scale types and scale transformations.

Research limitations/Implications – The semiotic framework for analysing the semantic level in Human Machine Systems design needs to show its impact on actual design methodologies, i.e. through cases on integrated design of processes, automation, and HMS.

Originality/Value – Clarification of conceptual issues in CSE-based HMS design is attempted and it is sketched how a semiotics of representation design could be an addition to the conceptual foundation of CSE.

Take away message – A shift in conceptual orientation of design for safety can be obtained by elaborating the implicit semiotics of CSE and EID into an explicit semiotics of representation design.

Keywords

INTRODUCTION

The semantic level in the analysis and design of Human-Machine Systems (HMS), i.e. the level of representation, meaning and intentionality, has been a recurrent problem in theories and methodologies of HMS design. Although the problem have been recognized for at least 30 years there is still no coherent theory and methodology for HMS design that resolves the issues involved. The problem was addressed – but not resolved – as part of the initial conceptualization of Cognitive Systems Engineering (CSE) in the 1980-ies (Norman and Draper 1986). The “ecological turn” of CSE in the early 1990-ies was followed by a tendency to avoid semantic issues in favour of design for direct perception of affordances and constraints in the work domain (May 2010). Recently a number of approaches within HMS design have introduced semiotics, i.e. general theories of meaning and signification, as relevant to automation and control (Lind 2001), design of human-robot systems (Sawaragi 2008) and Human-Machine Interaction in general (Petersen & May 2006 a, b). We might expect a “semiotic turn” in CSE with a focus on Joint Intelligent Systems (Norros & Salos 2009). In recent years semiotics have already been applied to the analysis and design of Human-Computer Interaction (de Souza 2005) and to multimedia systems (Purchase and Nauman 2001, May and Petersen 2007, O'Neill 2009). As discussed in this paper there was, paradoxically, a semiotic inspiration behind the models proposed by Jens Rasmussen for CSE (Rasmussen 1983), and this has recently been used constructively to reframe CSE and EID within semiotics (Flach 2009).

An underlying reason for the reluctance to address problems of representation, meaning and intentionality in HMS design might be found in the theoretical foundation of regulation and control, since design intentions, human goals and meaningful actions cannot easily be seen as part of theories expressed through mathematical analysis (e.g. differential equations). In that sense the problem of semantics in HMS can be traced back to the conceptualization of cybernetics as a theory of control and communication (Wiener 1965) and to the conceptualization of information theory (Shannon and Weaver 1963) – both theories expressed through the analysis of signals excluding intentions and meaningful relations between signs.

FROM EID TO CSE: BACK TO BASICS

The semantic level in HMS design concerns the nature of the design knowledge that is required to support the integrated design of processes, automation systems and supervisory control of safety-critical complex systems, e.g. power systems, process plants, and transportation systems. In these domains the design of information, interfaces and procedures should be subsumed under an integrated design of processes, automation systems and
HMS (Lind 2009). Since we do not yet have the full picture of how an integrated methodology will look like, the strategy in this paper is to look in detail at simple instrument displays to clarify the semantic level, specifically with regard to information integration, one of the key issues in EID. This can appear to be a step back to previous design paradigms based on individual instrument displays (cf. traditional control rooms), but we do need to understand the semantic level in simple cases before proceeding to the complex issues of overview displays, and complex interfaces will also maintain a number of simple displays as component parts of overview displays (May and Petersen 2006).

Another reason why we need to go back to basics in CSE is the need for a coherent theory. A case in point is the role of representations in the HMS design. As pointed out by David C. Woods we should understand CSE as a kind of representation design, but looking at EID as the most advanced design methodology for CSE, we do not find any systematic theory of representational forms nor any methodology for choosing between them. Woods defined representational forms in terms of how domain data “is mapped into the syntax and dynamics of visual forms in order to produce information transfer to the agent using the representation given some task and goal context” (Woods 1991). He also pointed out, however, that what is important is not the visual forms as such, but the representational forms involved in the mapping, but these were often confused in the Human Factors community. We should therefore investigate representational forms and different mapping principles. This point was made in the context of Jens Rasmussen’s work, i.e. that we need a better understanding of the different types of representations and the cognitive support they provide (Bainbridge 1988). This seems like the research program of semiotics and distributed cognition (i.e. the “other branch” of cognitive systems research), but never the less CSE and EID have remained relatively isolated from these traditions. In a recent textbook on EID (Burns and Hajdukiewicz 2004) important design dimensions are outlined as part of a “language of interface design”, but despite the reference to semiotics (through Woods) the semiotic framework remains implicit.

EID has developed general principles for supporting affordances and constraints in the work domain through direct perception and manipulation. Additionally EID has been applied in case studies demonstrating the benefits of EID displays over more traditional displays, but when it comes to the representations employed, the specific design choices often seem to rely on ad hoc inventions and creativity rather than mapping principles. An important breakthrough in the branch of cognitive systems research known as distributed cognition (Zhang and Norman 1994, Hutchins 1995, Zhang and Patel, 2006) was the discovery that it is possible to give specific arguments for the cognitive support provided by alternative work practices and their use of cognitive tools. “Artefacts shape cognition and collaboration” (Woods 1998) and the choice of representations to support work practices will affect the efficiency of the tasks performed by human operators (Zhang and Norman 1994). A contribution to systematic mapping principles for representation design was proposed for Relational Information Displays (DIDs) (Zhang 1996). A revision of the RID theory through the concept of flexible scale transformations have been suggested in the context of CSE (Petersen & May 2006 a, b), including an extension to media types and sign types (representational forms) to describe the design space of instrument displays (May & Petersen 2007).

MEASUREMENTS AND SCALE TYPES
Semiotics and control theory have a common ground in key concepts shared by both theoretical domains (Lind 2001, Flach 2009). One of these key concepts is the concept of measurement. Formally a measurement is an assignment of real numbers to observable states of a system, but any actual measurement also depends on causal mechanisms of artefacts that realize the physical measurements. In the following we will examine the implicit semiotics of instrument reading as implied in CSE (Rasmussen 1983, Vicente 1999) as a background for the analysis of measurement and display mappings.

Signals, Signs and Symbols: the flow-meter case
An important intuition expressed in the early Skills, Rules and Knowledge (SRK) framework (Rasmussen 1983) was the idea that the same instrument display can be interpreted in a number of different but prototypical ways. In describing these interpretations, conceptual distinctions between signal, sign and symbol were introduced in what constitutes an implicit semiotics. The concepts are not made explicit within a coherent semiotic theory, but are rather pasted together from different sources including Whitehead’s discussion of symbolism and reflex actions, Cassirer’s dualistic distinction between physical “signs” and meaningful “symbols”, and the concept of signals developed within cybernetics and engineering. The SRK framework should be understood as a classification and not as a model of cognition (Vicente 1999). Within this framework the genuine semantic issue (interpretation) is turned into a psychological issue (e.g. generic types of human performance, subjective preference of individual operators): the human operator can relate to a display through each of the performance modes (skills, rules or knowledge) and will thereby perceive the information as signals, signs or symbols respectively, cf. the flow-meter example (Rasmussen 1983, Vicente 1999).

If the operator relates to the flow-meter on a skill-based level of cognition, the information available from a deviation from a set point will, according to Rasmussen, be used as an error signal within a situation of manual control. Here the operator is assumed to be acting directly on some physical objects and events in the environment, and indicators of system states and variables (flow measurement) are tracked continuously. The signal picked up by the human operator will “have no meaning or significance except as direct physical
time-space data” (Rasmussen 1983). In CSE this conception of the skill-based level was later supported by the concept of “direct perception” of affordances (Rasmussen, Pejtersen & Goodstein 1994). If, however, we reconstruct the example from the point of view of cognitive artefacts and their support for distributed cognition, it becomes clear that any reading of an instrument display will imply external representations as well as their interpretation, i.e. “meaning”. The conceptualization of cognitive artefacts and external representations were important parts of the foundation of CSE (Norman and Draper 1986), and in the present paper it is suggested that we need to reinterpret CSE to include principles of cognitive distribution as well as a revision of EID based on semiotics.

If the point of the signal relation to the instrument (in the skill-based mode) is that the operator acts on continuous variables like flow rate through manual control actions, the instrument reading will have to be interpreted as an indexical sign of the causal processes (of e.g. fluid flow in a pipe) in which the measurement device participates. The reading will be minimally meaningful as a reading of the measured flow rate. Without this minimal meaning objectively anchored in how the measurement device and its display component have been constructed, we would in fact have failed to construct any measurement at all. This is a semantic issue and it should not be confused with a psychological issue of whether the operator in any given situation actually pays attention to this meaning or not. The operator will know that the flow-meter represents fluid flow rates and this (background) knowledge is not dependant on any specific performance mode, although it will of cause depend on education and training.

The focus on the deviation from a set point, however, is an additional level of meaning, where the graphical distance of the pointer from the set point is taken as an iconic sign since the distance of the actual reading from the set point on the graphical scale is understood through a similarity relation: distances on the numerical graphical scale is seen as similar to (homologue to) differences in measured flow rates. In so far as the operator needs to evaluate the size of the deviation from the set point, the cognitive support for this evaluation could in fact be improved by adding a dynamic bar graph representing this deviation graphically on the scale (Fig. 1, right). This would constitute a secondary dynamic graph (right). This would constitute a secondary dynamic graph (right).

To complete the semiotic analysis of the signal based flow-meter example, we should also consider the role of the set point. The set point is a fixed value set by the system or the operator to express the desired value of a measurement relative to the purpose of the subsystem in question and relative to current situations and relevant actual goals within these situations. In semiotic terms the set point constitutes a symbol: a sign expressing a law, regularity or a social norm in reference to the future (e.g. the desired future state of the flow).

As suggested by the semiotic reconstruction any instrument reading, even in the signal case, will have a meaning, and it will rely on three types of sign relations: indexical relations to the causal dynamics of the measurement, iconic relations of the mapping from measurement data to the graphical presentation (pointer-scale in this case), and symbolic relations to a desired future state (as indicated by the set point) and to the law-like interpretation of component parts and the instrument as a whole (e.g. numerical symbols, labels).

A similar analysis can be made of the rule-based and the knowledge-based cases, i.e. all three types of sign relations (indexical, iconic and symbolic) will be involved in the semantics of the instrument display. It is therefore misleading to frame the signal case as involving only human perception and as “having no meaning” as opposed to instrument readings in the context of rule-based and knowledge-based behaviour. The semantic requirement for a human agent to relate rationally to the instrument display does not change across the three cases of the flow-meter example, but the control situation assumed is changed significantly and this changes the context of interpretation and the focus of human actions. Vicente argues that: “Despite the fact that the object being observed is exactly the same in each case, the information from the environment is being interpreted in three different ways” (Vicente 1999, 284-285). The object being observed is, however, not really the same since the underlying control situation assumed in the three cases are different and so are the illustrations supporting the argument. In the rule-based case Jens Rasmussen changes the assumed situation by focussing on a valve that can be closed or open and this will of cause change the interpretation of the instrument reading and the relevant actions (adjusting flow or recalibrating the device). In the knowledge-based case the assumed situation is now extended to include the control situation after a calibration where the instrument reading might still show a low flow rate. The argument now is that the human operator in this case needs to reason (e.g. diagnostic reasoning about a possible leak), whereas “no reasoning is required” within the rule-
based and the signal-based categories of human performance (Vicente 1999, 82). It is quite appropriate – with Rasmussen and Vicente – to avoid the mistake of reifying sign categories as different types of physical objects: “whether something is a signal, sign or symbol ultimately depends on how workers decide to interpret information in the environment” (Vicente 1999, 286). It is however problematic to frame the semantics of information presentation as a matter of free choice, individual preferences and selective attention.

We need to avoid psychological distortions of the semantic and control theoretic issues in supervisory control work: from the point of view of design we should be concerned with the objective control situations that can arise relative to the controlled production systems and their superimposed automation systems (Lind 2009), and we need to consider the flow of information and interaction between subsystems and through the human-machine interface as required for safe and efficient operation. Consequently we need to consider the task allocation and cognitive distribution between automated and human agents. We should be concerned with the content, the form and the timing of information that needs to be presented to human operators, as well as the content, form and timing of supervisory control actions. In short we should be concerned with how to support team situation awareness and how to design for safety, flexibility and transparency of the different forms of cognitive distribution and cognitive support provided by artefacts, decision support systems and automation systems. All these statements are common objectives for CSE and EID. It is argued here, however, that the interest in framing the human operator through a taxonomy of performance categories inspired by levels of control within the nervous system of an organism (cf. the reference to reflexes and sensory-motor patterns on the skill-based level, perceptual cues for direct action at the rule-based level etc.) is not the best perspective for design. In design for safety and support for team situation awareness (Endsley, Bolte and Jones 2003) it seems like a strange choice to assume that human operators in the control room do not need to maintain reasoning within major performance categories or to assume that instrument readings within certain behavioral modes have “no meaning or significance”.

**Power Systems: a SRK framework example**

A brief meta-analysis of an application of the SRK framework to the analysis and design of an industrial scale system can be useful to clarify the conceptual issues discussed above. A well documented example is the design of EID-based control room overview displays for the electrical power distribution for the city of Athens (Drivalou and Marmaras 2009, 2003; Drivalou 2005). EID analysis and design will generally be based on the SRK framework as well as on the Abstraction Hierarchy (AH) for decomposition of the work domain into part-whole hierarchies (systems, subsystems, and components) and functional hierarchies based on means-ends relations. The overall framework is usually referred to as Cognitive Work Analysis (CWA). An observation to be made about the methodology in the case study is that CWA had to be extended with other methods in order for designers to obtain enough information about the power system and its operation (e.g. ethnographic analysis, task analysis, analysis of Critical Operational Conditions, COC) and in order to establish a mapping from the outcome of CWA to the actual design of interfaces. The latter extension has been proposed as a semantic mapping complementing EID (Reising and Sanderson 2002). The semantic mapping is where we could expect to find an explicit semiotics of representation design, and COC is where we could expect to find an analysis of control situations.

In discussing design for skill-based behaviour within the EID display for power distribution a number of significant contradictions with the underlying SRK framework can be observed. According to the theory operators working in the skill-based mode utilize cue-response patterns based on their expertise and operator actions can be released effectively without reasoning. Direct perception of affordances should be supported by organising the information in the display as isomorphic to part-whole structures of eye and hand movements. Actions are understood as movements rather than meaningful interventions and operators are supposedly looking for cues for direct action rather than meaningful information: “Neither any conscious analysis of the situation nor any sort of deliberation of alternative solutions is required” (Drivalou and Marmaras 2009, 951). So far the presentation of the case follows the SRK framework. When describing the interface, however, the authors have to introduce representations, meanings and intentions in order to make sense of the design and explain their design choices. An example is the grouping of semantically related display objects: supervisory control work in the power distribution domain relies on information about objects of control such as transformers, busbars and interconnection lines. In the engineering tradition of mimic displays the layout and structure of interfaces are often based on a diagrammatic representation of the physical structure of corresponding objects in the domain. According to EID (and classical Gestalt psychology) spatial proximity can be used to display semantically related information, e.g. quantitative information about busbar voltage loads is displayed as bar graphs within or close to the graphical container of the busbar object, and busbar levels that can meaningfully be compared are aligned graphically. It is stressed that this grouping of display objects allow operators to perform inferences about relations among actual and desired values, but this constitutes reasoning as well as support for meaningful understanding (e.g. situation awareness). The fine cognitive support provided by the design thus contradicts the theoretical framework for the associated skill-based behaviour. Furthermore the EID methodology seems to ignore other advanced proposals for visualization of power systems (Overbye 2002).
Yet another problem with the application of the SRK framework is that the separation of performance modes can impose misleading assumptions on the suggested design solutions. In the context of skill- and rule-based behaviour it is suggested that the constraints and affordances of interconnection lines can be supported through a “graphical puzzle” where the connectivity of matching lines can be directly seen (Drivalou and Marmaras 2009). Considering alternative connections between transformer busbars in a power distribution network should, however, involve causal reasoning about the potential consequences of a reconfiguration of the system (May 2008). Displaying the connectivity of the network as a graphical puzzle could be misleading, because it suggests that reasoning is not required by operators for safe operation and supervision.

**Semantic mapping as a missing link**
In his review of progress and challenges in EID Kim Vicente stressed the issue of “choice of visual form” in deriving interface specifications from the constraints of the work domain as given by an AH analysis (Vicente 2002). Detailed design choices are left to individual creativity rather than theoretical principles, and this means that the practice of EID in some ways is like an art rather than a science. In this regard the detailed case study provided by (Reising and Sanderson, 2002 a, b) is very important because it suggest several extensions to EID methodology. One extension concerns the sensor-based measurements that will be used to derive higher-order functional information utilized by configural display components. Another extension concerns the mapping of relations and constraints discovered in the domain into graphical relations in display components and interfaces. This is explicitly seen as a semantic mapping in line with earlier foundational work (Bennett and Flach 1992, Woods 1991). Even though the concept of semantic mapping addresses human factors issues, it remains undeveloped as a theoretical conception of the representational forms available for HMS interface design, i.e. it is not recognized as a semiotic problem. This is partially due to the restricted approach to representation design within EID. It is assumed in advance that EID will exploit configural displays and look for mappings from constraints to geometric shapes. Given this generic solution it is therefore difficult to address representational design through a more elaborated conception of the design space within a semiotics of representational forms, media types and scale types. It is symptomatic that the design choice issue is addressed as a problem of selecting a visual form (Vicente 2002): the focus on the visual form of a graphical object hides the underlying semiotic question of its representational form (e.g. image, graph, diagram etc.) and presupposes that the object is expressed in the graphical media in the first place (rather than in a haptic or an acoustic media). Auditory displays constitute a further extension to EID suggested by (Sanderson, Anderson, and Watson 2000).

EID is restricted by its focus on comparing EID interfaces with “traditional displays” and by its preference for configural displays, but it is also restricted in the other end of the semantic mapping, since the domain ontology implied by WDA focus mainly on constraints of the work domain and often ignores the role of automation in supervisory control work. Higher-order properties have been analysed in the context of AH (Reising and Sanderson 2002 a).

Constraint and object-centred representations give rise to complementary representations of the work domain (Rasmussen, Peitersen and Goodstein 1994). Designing HMS interfaces will eventually require an elaborated theory of representation design and comprehensive domain ontologies in order to account for different layers of information integration, different perspectives on control situations in the domain and different roles of human and automated agents. The fixed AH is inadequate for the required modelling (Lind 2003).

According to the three layer model of data interpretation and integration (Petersen 2004) supervisory control work will demand representations designed for three types of content:

- representations expressing relations among objects (e.g. causal relations)
- representations expressing constraints (i.e. relations between variables)
- representations expressing variables.

This model can be used to define a set of generic inference steps in the integration and interpretation of data (see fig. 2). The inference steps involve data at all three layers of representation: (1) integration of variables into higher-order variables, (2) derivation of higher-order variables from the values of measured variables (using constraints), (3) state identification of a variable on an ordinal scale (e.g. low, normal, high) from interval-based constraints, (4) state identification of a constraint (e.g. violated, non-violated) based on underlying variables, (5) state identification of functions (e.g. failed, realised) at the object-centred level based on the state of constraints specifying proper function, (6) reasoning about object relations (e.g. causal reasoning) in the domain based on an object-centred model.

In EID a lot of emphasis is put on the direct perception of constraints and especially on their violation. According to the SRK philosophy of human operators implied by EID it is assumed that operator behaviour should be supported at “as minimally demanding a level of cognitive control as practicable” (Reising and Sanderson 2002b), if possible at a skill-based level. Accordingly there is a tendency to ignore that operator judgments of the implications of violated constraints requires support at an object-centred level in the form of explicit representations of goals and functions of the work domain. In unfamiliar situations in particular it is crucial that operators know what a violated constraint actually means in terms of disturbed goals and functions at the object-centred layer. Only at this layer of system
representation will it be possible to reason about causes and consequences at a plant wide level (Petersen 2004).

Fig.2. Generic inference steps according to the three layer model. After (Petersen 2004).

The semantic mapping in EID appears to be a matter of choice of geometry to support the “direct perception” of affordances and constraints. The geometry of a configural display figure for the integration of variables should not be confused with the geometry of a graph or diagram since different representational forms each have their own intrinsic semantics (May and Petersen 2007). In representation design the primary issue is not the choice of visual form or geometry but the choice of media types, representational forms and scale types to express a given type of information and to provide required forms of cognitive support. The choice of geometry is a secondary issue arising if graphical media and configural displays have been selected.

**Scale transformations and representational forms**

Recent presentations of EID can include references to representation design and the systematic description of available digital media channels and representational forms, but usually without recognizing the potential of a fully elaborated semiotics. According to (Burns and Hajdukiewicz 2004) one of the earliest design choices is “how to refer to a piece of data”, and this is seen as a semiotic issue. Within the ecological tradition (Woods 1991; Vicente and Rasmussen 1992; Bennet and Flach 1992) the classification of representational forms is, however, limited to propositional forms, iconic forms, and analogical forms. Within semiotics and cognitive linguistics propositional forms of referring to data would be conceptualized as symbolic forms. These can take on a linguistic form or a diagrammatic form, i.e. diagrams in engineering design are often systematically expressed as Diagram Modeling Languages and they are therefore also propositional. The so called iconic forms of (Burns and Hajdukiewicz 2004) are simply graphical symbols (interface “icons”), whereas analogical forms seems to include everything else, i.e. including quite different representational forms with iconic properties such as images, maps, graphs and (overlapping with propositional forms) diagrams. The conceptual structure and taxonomy of representational forms is a complex theoretical problem, and the analysis has to include other dimensions of information presentation and interaction e.g. media types and scale types (Petersen and May 2006 a, b; May and Petersen 2007), cf. also the problems addressed by the extension of EID to auditory displays (Sanderson, Anderson and Watson 2000).

If we go back to the basic issues raised by the display of measurement data, cf. the example of the flow-meter in the early days of CSE, it should be noted that the branch of CSE known as Distributed Cognition (DC) have since developed detailed accounts of the use of artifacts and external representations in complex work domains. DC accounts of the mapping of measurement data in information displays are largely ignored by EID in spite of the common CSE background of both traditions.

Jiajie Zhang proposed a theory and methodology of information mapping under the name of Relational Information Displays (RIDs) (Zhang 1996). The point of departure for (Zhang and Norman 1994) was the role of external and internal representations in distributed cognitive tasks. Human culture in general depends on the use of artifacts and external representations to provide different forms of cognitive support in performing different tasks and activities. The kind of cognitive support provided will depend on specific properties of the representational systems and forms used. In order to describe these properties Zhang made use of the concept of measurement scales introduced by (Stevens 1946).

Stevens distinguished four types of scales: nominal, ordinal, interval, and ratio scales. The operations that can be legitimately applied to data, i.e. the operations that lead to meaningful statements about the property it is referring to, determines the scale type of data. The ratio scale is the “strongest” scale as it allows the entire set of operations, i.e. determination of equality, determination of greater than or less than, determination of equality of differences, and determination of equality of ratios. The nominal scale (the “weakest” scale), on the other hand, only allows the determination of equality, i.e. classification.

A scale type is not an intrinsic property of a dimension, but a feature of the measurement mapping from a property dimension to a formal relational system (e.g. a number systems) (Petersen and May 2006a). Different measurements can therefore impose different scales types for the same property and construct data in different ways. In the case of temperature, data can be on an interval scale (when measured in degrees Celsius or Fahrenheit) or on a ratio scale (when measured in degrees Kelvin). Equality of different temperature ratios can only be determined when the temperatures are measured on a ratio scale (with an absolute zero). It is therefore not meaningful to claim that 80 degrees is twice as hot as 40 degrees when measured in degrees Celsius, whereas it is meaningful on the Kelvin scale.
The levels of abstraction in data specified by the three layer model (variables, constraints and object relations) can be combined with the scale types in a state space describing possible operations on data (vertical axis) and possible scale transformations (horizontal axis) (Petersen and May 2006a). On a ship, for instance, regular measurements performed by an echo sounding device is used as data samples to be integrated and further used in a derivation of data for water depth. This data is at first constructed on a ratio scale. Zhang here introduce a plausible hypothesis about the semantic mapping of measurement data into dimensions of display components: in order to be accurate and efficient the representing dimensions of the display component and the represented dimensions of the domain measurement should match in scale types (Zhang 1996), cf. the grey diagonal in fig. 3.

This can seem like a plausible principle for semantic mapping, but on a closer look something is wrong. The tailoring done by human operators in complex work domains reveal that they often attempt to need to change the scale type of presented data (scale substitution) or add a secondary scale of another type (superimposition) in order to make it more informative or easier to interpret in the different dynamic situations. In the case of water depth, for instance, ratio scale data can be important for ship officers when manoeuvring in harbour areas and coastal water, but on the open sea during ordinary navigation ratio scale water depth data becomes irrelevant. A weaker presentation on an ordinal scale or even on a nominal scale (e.g. classification of water depth as “normal” or “shallow”) will be more informative and more useful. In the latter (nominal) case an additional shift in representational form could be called for, i.e. an auditory alarm indicating when the constraint of normal water depth is violated and ship bridge officers should again pay attention to the ratio scale data, i.e. in shallow water. As shown in fig. 3 Zhang’s principle of matching scale types has to be modified according to the need for tailoring and scale transformations. Data on a “weaker scale” (ordinal or nominal) can be more informative and useful than the full ratio scale information.

A semiotic theory and methodology of representation design should be developed as a systematic description of the design space made available by scale types, representational forms and media channels for information presentation and interaction (May and Petersen 2007). EID might then be seen as a special case with regard to principles of information integration and configural displays within such a broader theory and methodology, but the role of the AH and the SRK framework will have to be reconsidered.

REFERENCES


