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Marian Ursu
Brunel University

Peter Hammond
University of London

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Marian F. Ursu
Department of Information Systems and Computing
Brunel University

Peter Hammond
Department of Dental and Medical Informatics
Eastman Dental Institute for Oral Health Care Sciences
University of London

Abstract

The performance gap between expert and novice designers motivates the enhancement of design systems with expressed design knowledge to produce critiquing Intelligent Design Assistants. This paper focuses on the need for generic languages for representing expressed design knowledge for animation and flexible reuse in different design domains and in different design environments.

Expressed Design Knowledge

The absence of theoretical foundations (Bahrami and Dagli, 1994) encourages the view of the design process as an “imprecise art” (Dagli and Kusiak, 1994), with the individual designer's experience and expertise playing a determining role. Therefore, the differences in background, formal training, experience and awareness of external influences are very relevant to the design activity itself.

Brown (1991) classifies design, with respect to the *known* knowledge, as varying from routine to creative — “*known*” meaning directly accessible, available in the needed format and requiring no transformation. At one extreme, a design task is completely routine if all the knowledge needed for its completion is available at the outset; at the other, a design task is entirely creative. The position of a design activity along the routine-creative axis can only be determined relative to the designer’s experience and expertise, “routine is in the brain of the beholder” (Brown, 1991, p. 7). The more experienced a designer, the more routine the design process becomes for them. The novice designer may also be characterised in two ways; firstly, as the budding specialist designer and secondly as an individual whose main activity is not design but whose occupation requires occasional design tasks to be undertaken.

Design know-how is acquired in a variety of ways. Here we are concerned with the deliberate formulation of information that encourages best design practice. We refer to this as *expressed design knowledge*. Expressed knowledge can be published as informal guidelines (Building Research Council, 1994) or internal company standards (Xerox, 1987), as the accumulated expertise of key practitioners (Davenport, et al., 1988), as the consensus of a large group of professionals (Davenport, et al., 1996) or as formal, regulatory standards enforceable by legislation (Building Regulations, 1992; Arya, 1994). The descriptions of best design practice can be extensive and their assimilation and specification may take years. They can be used to disseminate design expertise and enable the novice or inexperienced designers to become better. On the other hand, the standards and regulatory design knowledge can often be used to discourage unsafe or harmful design practices. Both forms, though, can be decisive in helping novice designers achieve performance levels closer to that of experts.

Intelligent Design Assistants

On the basis that they are already expressed in written form, design regulations are suitable for incorporation in software systems that assist designers - Intelligent Design Assistants (IDAs). However, in most cases, regulations are used more to restrict unacceptable design rather than support creative design. Therefore, an appropriate architecture for a regulation centred IDA is that of a critic. In a critiquing IDA, the developing design is constantly checked against the embedded regulations. The same approach can also be taken with the animation of expert design knowledge. In this latter case, though, it is more likely that the design expertise can be put to use in an automatic or semi-automatic fashion.

The main function of a critiquing IDA is to react when a design does not conform with the expressed design knowledge it contains. This can be achieved through a wide spectrum of behaviour, which is strongly influenced by the type of assistance the (novice) designer desires or is thought to require. Critiques of design operations can be simple warnings or comprehensive explanations of errors. Negotiation of error correction can have the dual benefit of improving design quality and educating the novice designer. Conformance checks can be made automatically or initiated by the user when and where desired. However, problems arise from inappropriate assessment of intermediate stages of design when it is unfair to apply some design constraints.

Although a variety of expressed design knowledge is available, especially of the regulatory kind, there is the problem of its representation in a form amenable to computerised animation within an IDA. Standards and conventions for graphical depictions and APIs (application program interfaces) are available or forthcoming (Middleditch, et al., 1998), but they currently do not support the transition of expressed design knowledge from paper to electronic form. In particular, the absence or lack of support of the following is notable:

- a communication medium for designers and implementors of IDAs
- fine-tuning of expressed design knowledge by designers
- portability of expressed design knowledge from one IDA to another
- application of IDAs to different bodies of expressed knowledge.

In order to provide for these, generic representation formalisms are needed for describing expressed design knowledge. The rest of the paper describes an empirically based approach to the development of such a language.

Toward A Generic Language for Expressed Design Knowledge

In configuration design, the unspecified structure of the design involves the composition of pre-defined parts and connectors (Tong and Sriram, 1992). Common characteristics of associated expressed design knowledge are the use of: spatial representations (extensively); qualitative descriptions and vague reasoning; modalities (obligations, preferences, alternatives); type hierarchies; as well as necessity of existence and cardinality. For an illustration, consider the examples in Figure 1.

The design domains referred to in the figure were considered in an empirical study with the objective of defining elements suitable for a generic representation language for representing expressed design knowledge. The first stage of the study involved exhaustive analysis of a particular body of design knowledge. From this a domain specific, but jargon independent, language was refined. It was felt important to have at least one complete body of design knowledge thoroughly analysed, as the consideration of isolated examples might be misleading. The availability, the number and variety of design constraints and consensus support of 70 or so experts suggested the use of a design knowledge base in prosthetic dentistry (Davenport, et al., 1996).

The second stage consisted of an iterative investigation of other design domains, during which the elements of the language refined in the previous stage were abstracted and generalised. The principle of parsimony was repeatedly applied throughout this process — each component of the representational vocabulary was generalised only to the extent that was sufficient to represent the extract of expressed design knowledge. Because of their predominant role in the regulations' specification, spatial representation mechanisms were given particular attention.

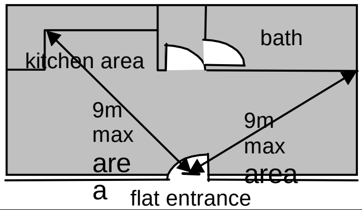
A characteristic for configuration design is the specification of relations *between* design objects, viewed as pre-defined design components. Putting aside the aspects related to the shape of the individual design objects, the relations between objects and the complementary specification mechanisms required in their expression (such as form features or design guides) were an early focus. Thus, the developed language is situated at a level of abstraction where the shapes of objects are irrelevant. The spatial relations defined within the generic language were characterised in seven major classes: overlapping, contact, distance apart, vicinity, location, orientation and enclosure.

The elements of the language are described using a combination of mathematical and logical notations, augmented with natural language and depictorial representations.

The specification of the language comprises polymorphic definitions (Figure 2), multiple definitions (Figure 3) — using different primitives — useful for accommodating different graphical representation schemes and axioms describing properties of and interactions between the elements of the language (Figure 4). An example of how the language is used for expressing

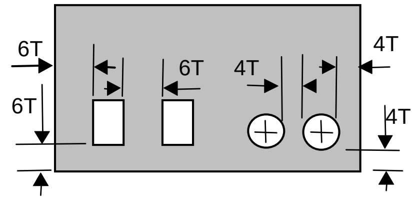
"an acceptable approach when planning a flat which has a floor at more than 4.5m above ground level is to plan the flat so that the travel distance from the entrance door to any point in any of the habitable rooms does not exceed 9m and the cooking facilities are remote from the entrance door and do not prejudice the escape route in the flat."

(Building regulations, 1991)



"Minimum distance from edge of part and between holes
non-circular holes
preferred min = 6T
absolute min = 3T but not less than 3.5mm
circular holes
preferred min = 4T
absolute min = 2T but not less than 1.5mm

(Sheet metal design criteria —Xerox, 1987)



"a free end saddle (distal extension) should have a retentive I-bar clasp whose tips contacts the most prominent part of the buccal surface of the abutment mesio-distally"

(RPD regulations — Hammond and Davenport, 1995)

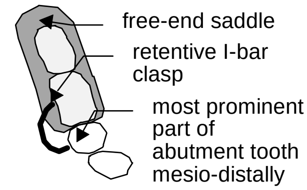


Figure 1. Examples of Expressed Design Knowledge

design knowledge is given in Figure 5 — the representation of the dental prosthesis rule described in Figure 1 (*remotest_point*, *tip* and *contact* are part of the language for spatial representations, whereas *free-end*, *abutment* and *i_bar* are domain specific).

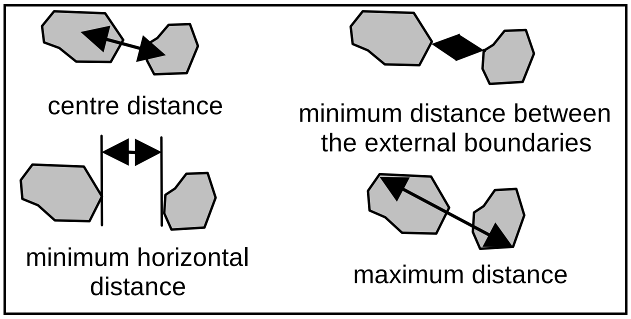


Figure 2. "Distance Apart" Relations

remotest_point(RP, Obj, Dir) ↔
∃ LINE L • L ⊥ Dir ∧ RP ∈ L ∩ boundary(Obj) ∧
¬ ∃ LINE L' • anterior(L', L, Dir) ∧
L ∩ boundary(Obj) ≠ ∅

remotest_point(RP, Obj, Dir) ↔
RP ∈ boundary(Obj) ∧
(¬ ∃ POINT P1, P2 | P1, P2 ∈ boundary(Obj) •
between(pr(P1, Dir), pr(P2, Dir), pr(RP, Dir))) ∧
∃ POINT P | P ∈ bounday(Obj) •
anterior(pr(RP, Dir), pr(P, Dir), Dir)

Figure 3. Definitions of a Relation Using Different Primatives

overlapping(Obj1, Obj2) ↔
overlapping(Obj2, Obj1)
included(Obj1, Obj2) →
overlapping(Obj1, Obj2)
included(Obj1, Obj2) ∧ included(Obj2, Obj3) →
included(Obj1, Obj3)

Figure 4. Axioms for Overlapping Relations

<for any> SADDLE Saddle **<with properties>**
free_end(Saddle) ∧
abutment(Saddle, Tooth) ∧
remotest_point(RP, Tooth, mesio-distally)
<there is a> CLASP Clasp **<with properties>**
i_bar(Clasp) ∧
tip(Clasp, Tip)
<such that> contact(Tip, RP)

Figure 5. Representation of Design Rule from Figure 1

The final stage involves the validation of these generic language features against as many and as diverse bodies of expressed knowledge as possible.

Even though the specification of the generic language employs mathematical and logical structures, a complete formalisation has not been attempted owing to the experimental iterative method employed in its development. Only when more thorough validation has taken place does a more thorough formalisation become worthwhile.

Conclusions

The availability and animation in computer software of expressed design knowledge can help bridge the gap between novice and expert designers. Moreover, the flexibility of this paradigm, reflected in the possibility of tailoring the behaviour of the IDA according to the designer's needs, confers the IDA with the quality of a knowledge transfer tool. Inexperienced designers will need firm supervision and comprehensive explanations in case of errors, but as they become more experienced, the active role of the IDA can diminish. However, before this can be achieved, much more remains to be done in defining generic languages for representing expressed design knowledge.

References

References available upon request from Marian Ursu (Mariam.Ursu@brunel.ac.uk).