Construals to Support Exploratory and Collaborative Learning in Medicine

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Abstract. Research into learning environments naturally emphasises the positive merits and benefits of technologies upon which their very existence depends. As learning environments mature, it becomes ever more important to examine the full impact of the underlying technologies critically. We argue that exploratory and collaborative learning is not well-served by the predominantly symbolic protocol-driven basis for communication that computing technology promotes. To address this issue, we apply Empirical Modelling (EM) principles to make *construals*: interactive environments that can be co-constructed by collaborating human agents so as to reflect their fluid understanding and developing knowledge of a subject domain. This approach is particularly well-suited to the medical domain, where reasoning draws on scientific knowledge and evolving human experience and judgement, and learning is not based on theory alone. We illustrate this via a proof-of-concept collaborative case study in which we draw on our technical and medical expertise to develop construals of malaria. To this end, we exploit a web-enabled variant of the principal EM tool that enables many agents to participate in exploratory learning activity.

1 Introduction

Intelligent support for collaboration activities in exploratory learning environments (ELEs) typically takes its inspiration from topical existing software technologies. Two important influences are tools for social networking, and collaborative development on an 'open source' model. In assessing the benefits of using these technologies, it is natural to consider the extent to which (a) human communication can be made more effective by developing suitable computer-based representations and exploiting automation, and (b) the limitations of individual judgement can be overcome by drawing on resources developed by a community of experts. In this paper, we argue that these benefits depend critically upon the conceptual framework within which computer support is developed. Specifically, computer support based on software developed on traditional lines is liable to lead to automation that displaces rather than emancipates

human judgment – cf. (a), and that inhibits rather than liberates the unique creative contributions of the individual – cf. (b). And whilst both of these characteristics have a valuable role to play in the development of future software applications, they also constrain the expressive power of such applications – especially where explorative and collaborative activities are concerned.

Our critique of traditional computing support for human communication is well-aligned with the views expressed by Jaron Lanier in his provocative book *You are not a gadge*t [1]. Lanier highlights the way in which software development can lead to *de facto* standards when initially adequate but subsequently limiting design decisions become 'locked-in' – as in MIDI-based music software [1:7]. He argues that – in a similar fashion – the computer-based representations for people that feature in our present social networking and communication technologies may compromise the notion of personhood, and make it harder to do justice to the depth and richness of human experience in digital communication [1:4]. In modern trends towards automating activities where human experience and judgement have previously been deemed essential, and towards privileging knowledge that is built anonymously by consensus, Lanier cautions against the dangers of 'cybernetic totalism' [1:24] – cf. (a) and of exaggerating the capabilities of the 'hive mind' [1:4] – cf. (b). He concludes by identifying the need for 'post-symbolic communication', and for new concepts that will make it possible to develop 'software that rejects the idea of a protocol' [1:190].

Empirical Modelling (EM), a conceptual framework for computing first explored in 1985 [2], has many characteristics that are highly relevant to Lanier's agenda. Whereas a traditional computing system is conceived as a 'program' that reflects a paradigm of 'computational thinking' based on protocol-driven interaction between agents, EM proposes a broader perspective on computing based on the more primitive notion of 'construal'. A *construal* is an interactive environment in which a human interpreter can experience metaphorical counterparts of the different states and transitions between states they encounter in a phenomenon or field they wish to understand. EM demands a shift in emphasis from an abstract algorithmic and functional specification of the computer's role towards the broader notion of computing technology as giving unprecedented support for metaphorical expression of state. This is entirely consistent with Lanier's concern with exploiting the computer as an instrument for making and communicating meaning in a way that is not necessarily mediated by language [1:190].

The remaining sections of our paper discuss the role of EM construals in relation to learning with special reference to exploratory and collaborative learning and to medicine. This is followed by a brief introduction to EM and an illustrative example in the form of a construal of malaria that we have developed in an exploratory and collaborative manner. Our conclusions are summarised in the final section.

2   Construals in support of learning

Central to Lanier's critique of current software development is the distinction between implementing protocols that are based on well-established scientific principles, and

inappropriately or prematurely introducing representations and protocols where there is no satisfactory scientific basis in our understanding [1:51]. It is precisely in the latter context that exploratory and collaborative learning are most critical. In the first instance, exploration is necessary for an individual person to develop assured knowledge about a domain. In establishing the objectivity that then makes it possible to exploit this knowledge in protocols, collaboration is subsequently essential.

The virtues of a broad view of knowledge and learning are well-illustrated in medicine. Medicine has developed a language and understanding that is universally shared, together with established guidelines at both a national and international level. The practice of medicine in many aspects lends itself to an account based on protocols which has proved valuable and effective. The aspiration to use computing technology to reinforce this scientific perspective on medicine is reflected in topical initiatives (e.g. [3,4]). There is however a complementary perspective with a greater role for more tacit knowledge, experience and the development of judgment. In the spirit of Lanier, it may be feared that an account of medicine that is too narrowly rule-based will fail to reflect the richness of a given situation, clinical scenario and possibility, and that simple protocol-based practices, if taken to extremes, may limit knowledge and undermine future effective, individualised care. Medical education should reflect this, and modelling with construals provides an opportunity for more holistic learning experiences, facilitating the development of judgment as well as theory. Even in territories that are considered to be well-mastered, medicine is a field in which revisions to what we have previously considered known are frequently made.

Traditional approaches to software development are therefore well-suited to supporting medical education where presenting what is established and certain by way of terminology, factual information and standard protocols is concerned. But both clinicians and researchers can also benefit from complementary learning resources that help them to exercise, develop and share ideas under construction. Medical learning and learning environments in particular ideally emphasise exploration of what is not known, or what is understood more fully by others, rather than simple exposition of established ideas,. A construal fulfils this role by inviting engagement from learners with many different goals, levels of expertise, and varieties and degrees of experience. Rather than immediately supplying definitive answers, accessing this activity provokes questions, and in the process forces the learner to reflect upon their knowledge and experience in context with others. EM supports exploratory learning by stimulating discussion, enabling participants to represent speculative knowledge, postulate and rebut arguments through interactive model redevelopment with accountable contributions dependent on individuals' backgrounds and expertise.

3 The principles of Empirical Modelling

The principal goal in using Empirical Modelling to support collaborative exploration is to develop an interactive artefact (a 'construal') that reflects and communicates a team of modellers' understanding of – or 'intelligence about' – a current situation.

Figure 1 depicts the key ingredients in making a construal using EM: the **construal**, its **referent**, and the **context** within which a modeller interacts with both. The construal takes the form of an interactive artefact constructed on the computer. The figure is intended to represent a 'live' correspondence that a modeller experiences whilst interacting with the construal and with its referent. The key idea behind making construals in EM is that we make sense of phenomena by thinking about putative causes - what acts in the situation to make changes (*agents*); what these actors are deemed to 'sense' and respond to (*observables*); and how agents' actions immediately affect several observables simultaneously in predictable ways (*dependencies*).
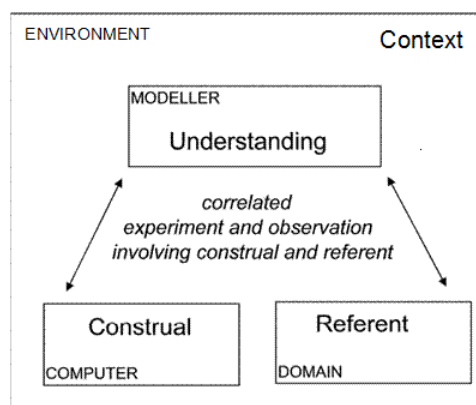

Fig. 1. Empirical Modelling for making a construal: a modeller's perspective

Intelligence about the current situation is tacit in the construal in much the same way that intelligence is tacit in a spreadsheet. This intelligence embraces 'what if?' knowledge: "what would happen were I to act in the following way in this situation?". Being more primitive than a spreadsheet and having no standard structured interface, a construal invites free open-ended interaction with broad potential for interpretation.

In the construal, the current situation as perceived by each modeller is reflected by a family of *observables* that have counterparts in the referent. An observable is an entity to which an identity and current status can be attributed. The observables within the construal are subject to *dependency* relations, whereby changing the value of one observable leads directly and 'instantaneously' – or at any rate without any possibility of interruption – to the updating of other observables. All state-changing actions made by the modellers in essence take the form of modifying the current values of observables and/or the dependencies to which they are subject. Dependencies, like observables, have direct counterparts in the referent. They reflect the ways in which changes to observables are characteristically synchronised in the current situation.

The range of state-changing actions that can be effected by a modeller is broad. Modifying the current values of observables or the dependencies might reflect a change of state of the referent. It might alternatively be refining the correspondence between the construal and the referent. Such refinement could involve introducing a 'new' observable relating to the current situation. It might also entail improving the

way in which observables are realised visually or can be changed via an interface. It may be a corrective action – revising an incorrectly specified dependency, or correcting a misapprehension about the nature or even the identity of the referent.

Modelling activity of this broad nature is not normally conspicuous in the use of spreadsheets, but features in exploratory modelling with spreadsheets and is typically what setting up a standard spreadsheet from first principles entails. In making an EM construal, modellers exploit the breadth of the state-changing mechanism to interact as if in the role of other state-changing *agents* that can act in the current situation. This makes it possible to explore the nature of the potential agency latent in a situation. The scope for making several modifications to observables and dependency simultaneously also allows multi-agent interaction to be simulated.

In EM, the semantic relation that links the construal to the referent is informal in character. It is a relation that is experienced by the modeller because of the way in which observables and dependencies have been configured and agency is enacted. Like its referent, the construal presents itself to the modeller in a particular state that may or not be familiar. Though some aspects of the current state are explicit in what is directly observed, some are latent, and are only elicited through interaction. What the modeller recalls from previous interactions is highly significant in this process of elicitation, and shapes what Figure 1 refers to as the modeller's **Understanding**.

4   Characteristics of EM construals in relation to ITSs

The principles discussed in §3 are practically supported by several EM tools. This is illustrated in Figure 2 by an embryonic construal of infection with Plasmodium Vivax we have developed using an online variant of the principal EM tool [5]. As documented via the 'HTML Output' tab, this construal is based on tracing stages in the development of malaria, from health to overwhelming parasitaemia and haemolysis.

Observables of many different kinds are associated with understanding malaria. These can be classified according to the role of the modeller (e.g. malaria patient, a clinician, medical researcher etc.), the nature of their observation, and the other agents relevant to the modelling context (e.g. the Plasmodium parasites and associated hosts in their many different forms, the mosquitoes that carry and transmit the infection). For the patient and clinician, key observables are the symptoms and clinical consequences of malaria – relapsing fever, small vessel ischaemia, splenic pain, haemolysis and anaemia etc. For the medical researcher, observables might relate to parasitic load, cell-signalling, pathogen-host interactions at the cellular level, or statistical data derived from epidemiological studies.

In making malaria construals, metaphorical counterparts of relevant observables have to be devised. This is illustrated in the PVMI construal shown in Figure 2, and explained in more detail in the model documentation. Although it does not represent the circulation itself, the red annulus in the construal metaphorically represents the blood within it. Each pink circle in the annulus represents a population of red blood cells and the blue circle within it the number of infected cells. The level of parasitaemia is reflected in the observables **bcinfnum** and **freeinblood**, which estimate the

proportion of infected red blood cells and the number of parasites in the bloodstream respectively. Several key observables in the construal depend on these two observables. They determine the estimated total number of parasites in the blood which in turn determines the point at which the modelling of the infection process terminates. The radii of the pink and blue circles depend logarithmically on **bcinfnum**. The background colour of the annulus also depends in a logarithmic fashion on **freeinblood**.
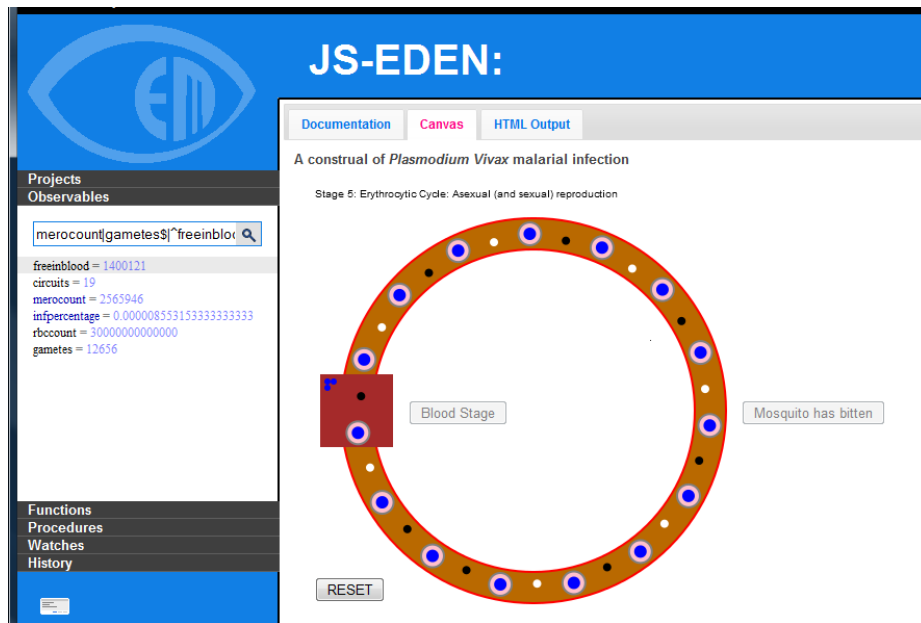

Fig. 2. A simple construal of *Plasmodium Vivax* malarial infection

The process by which the construal is developed and can be elaborated can be illustrated by looking in more detail at the definitions that mediate these dependencies. In Figure 2, the red, green and blue components of the background colour of the annular region are respectively defined by the formulae:

> **rb is 255 - 10 * ntodecls(freeinblood)#;**
> **gb is 15 * ntodecls(freeinblood)#;**
> **bb is 0;**

where **ntodelcs()** calculates the number of decimal digits – ranging from 1 to 12 - in **freeinblood**. The effect of this dependency is to make a significant change to the background colour, initially pure red, whenever the number of parasites free in the blood increases tenfold. Aesthetically, it might be considered more appropriate to use crimson (RGB components 220, 20, 60) rather than red (RGB components 255, 0, 0) to depict a colour to resemble blood. From a clinical viewpoint, it may seem inappropriate to depict the impact of an increase in the number of parasites in the bloodstream from 10 to 100 in just as visually emphatic a way as an increase from 10^6 to 10^7. Taking these considerations into account suggests the alternative definitions:

rb is 220 - 110 * freeinblood/600000000000;
gb is 20 + 10 * freeinblood/600000000000;
bb is 60 + 30 * freeinblood/600000000000;

These give quite different experiential characteristics to the construal.

Making construals can be compared and contrasted with the development and use of Intelligent Tutoring Systems (ITSs), especially those targeting ill-defined domains. The account of advances in ITSs in Nkambou et al, 2010 [6] provides a most helpful context for this comparison, which is elaborated in more detail in [7].

Making construals can be interpreted in two ways - as an activity that serves an educational purpose resembling that of a conventional ITS, and as a potential basis for developing a conventional ITS. The primary and most distinctive feature of the process of making construals is the emphasis placed on capturing meaning through experiential connections, and not in the first instance through formalism. This is significant both in methodological and epistemological terms.

The sample interaction above illustrates key differences between making a construal and conventional software development. The focus at all times is on what potential interactions the construals can sustain in its current state and what potential meanings can be ascribed to these by different agents. The integration of agent perspectives that can be achieved in this way is close enough to allow agents to interact in parallel, thereby blurring the conceptual distinctions between roles and phases that are so prominent in design and development. The aspiration is to co-construct a construal that can be given interpretations in many different ways through what is conceptually one and the same kind of interaction, whatever the status, expertise and interest of the initiating agent. This is in sharp contrast to the speculation in [6:§18.4.3] that the challenge to integration presented by Woolf's proposed framework of intelligent tutor building blocks must be met by first devising a suitable ontology to capture each agent perspective.

From an epistemological perspective (cf. [6:§2.2]), making construals is concerned with the sense-making activities that might precede the specification of such ontologies. This can be illustrated by considering how understanding of malaria has informed the development of the PVMI construal through the eyes of a learner who – like the first author – initially had only rudimentary knowledge. A useful first source for such a learner might be the diagrammatic depiction of the life cycle of a malaria parasite (taken from [8]) on the left of Figure 3. The informal semantics of this diagram is highlighted by problematic aspects of its interpretation. For instance: only one human body is shown; there are pictorial elements that simultaneously suggest blood circulation and schizogony; there is no sense of the number of parasites or time-scale involved. Construals inherit the semantic ambiguities inherent in metaphorical representations of this kind. Elaborating construals cannot eliminate these at a stroke, but can support the sense-making activities that enable us to exploit such representations interactively in communication and comprehension. A key aspect of this is identifying stable and coherent contexts within which to interpret a construal as in Figure 1.

Figure 3 depicts a simple construal in which components from the webpage at [8] have been used to make an interactive environment where the value of a single observable **stage** determines which parts of the diagram and of the account of the life

cycle are highlighted. This is a first step to creating the state-for-state correspondence between the construal and its referent that features in Figure 1. A variant of the PVMI construal that makes use of metaphor in a manner similar to that featuring in Figure 3 to represent a generic malarial infection has also been developed [5]. Elaborating thematically-related construals of this kind to sustain richer and more precise modes of observation, interaction and communication illustrates the potential for using EM to give computer support to the identification of ontologies and methods for ITSs. The technical devices represented in this revision and refinement of construals (adding new observables, specialising the context, adapting the metaphors) make it possible to develop construals that remain consistent and "backward compatible" as our under-standing of a phenomenon deepens. It is these same mechanisms that allow one-and-the-same construal to support different agent views and interventions.
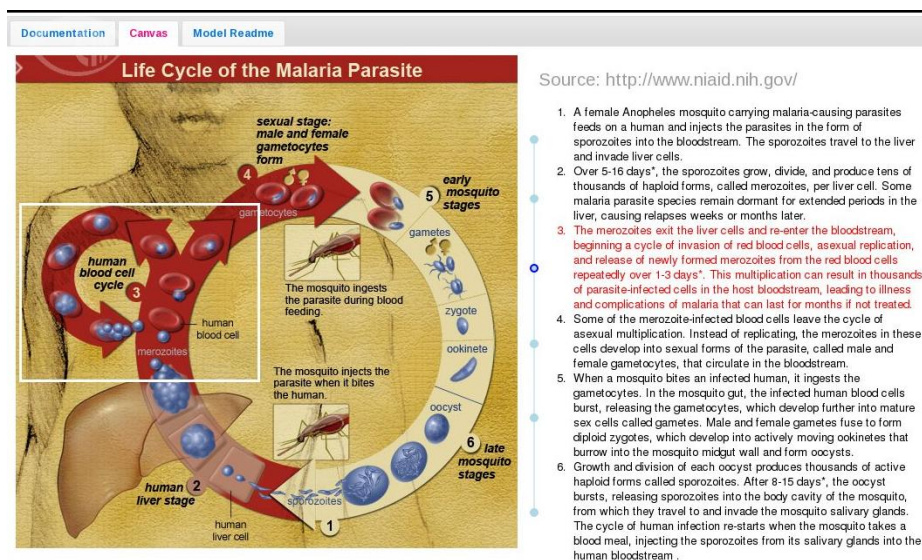

Fig. 3. Animating the NIAID depiction of the life-cycle of a malaria parasite at [8]

5 Conclusion

Our experience of co-developing construals and study of ITS research has led us to a number of preliminary informal and subjective findings that will inform future work.

Making construals can not only bring new techniques to bear on the problems of developing ITSs for ill-defined domains but also offers a unifying perspective on standard approaches to constructing ITSs (cf.[6:§5.3]). Agent interaction orchestrated using networks of dependencies is closely connected with the rule-based activities that feature in Model Tracing, and makes links between syntactic and semantic view-points. Like Constraint-Based Modelling, EM exploits higher-level observables such

as relate to integrity constraints within the domain. The integration of manual and automated activities that EM affords is highly relevant to Partial Task Modelling.

In addition to potentially contributing to the development of conventional ITSs, making construals also has promise as a means to support learning in its own right. Developing construals serves as an engine for learning because of the way in which understanding or enquiry is integral to the EM process. Learning is implicit in appreciating the collaborative construal, which of its nature cannot be meaningfully used without either refining or reflecting upon and challenging established understanding. Trying to frame appropriate observables and dependencies with a construal inevitably provokes questions that probe the limits of what is known by the participants or by science. This provocation to explore beyond current understanding is to the best of our knowledge unique to the EM process.

Work on EM construals for medical education is still immature. Our collaboration has shown that EM principles for making construals are a powerful means of stimulating domain learning that is not necessarily task-specific but it has also exposed limitations in current EM tools. The learning activity would give more efficient support for sharing if non-technical participants could readily acquire the 'programming' literacy needed to modify the construal directly independently, rather than having to rely on a facilitator skilled in EM. Our experience as computer scientist and physician with very different knowledge and background but complementary skills suggests that, with more investment in development, EM tools may be a useful collaborative vehicle for bringing together the perspectives of many participants in the learning context, helping them to communicate, critique and share their mental models. They may also help to address Lanier's concern for using computing technology before and beyond established methods and ontologies, as is essential in fields such as medicine.

6 Acknowledgements

7 References

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