Context Separation Using Structured Knowledge Models For Reusable Interactive Computer Assisted Learning Resources

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Abstract. In this paper, we describe a novel approach to the generation of reusable computer-based assets to support the production and customisation of learning materials for user and environment constrained learning scenarios. We present a framework for learning which proposes that navigating within a space of many models overcomes limitations inherent in mono-model approaches to learning contextualised knowledge. The approach is based on work carried out by the authors in knowledge base research, user modelling, training systems for industry, and learning environment development. Work is now under way on a project to develop both the technological solution and the pedagogic strategy necessary to produce an adaptive learning system based on this approach. How part of a professional's knowledge, for industrial process control, can be structured for use by a learner for one particular approach to learning is discussed to illustrate different elements of context. This combination of different knowledge types allows a variety of learning situations to be accommodated.

Keywords

Material reuse, learning environments, learning scenarios, knowledge structuring, context analysis

1. INTRODUCTION

There has been a significant change in the development of educational materials that has been taking place over the past few years. Specifically, we have seen a move from the *traditional* cohort-based, classroom-delivered, teaching driven model of development, to an individual, computer-delivered, learning centred model. Pedagogically, this can also be seen as a move from an instructivist approach to a more constructivist model. A number of factors, such as greater access to education, flexible work practices, governmental policy, overseas markets for educational products, and the ubiquity of the Internet, can be identified as drivers for this change. In order to facilitate the development of learning materials for on-line delivery a large number of tools, predominantly derived from the considerable body of research in CAL, CBT, CAI, etc., have been developed. However, the material developed using these tools is highly context specific, predicating against the possibility of reuse outwith of that immediate context, which means different groups of learners learning about the same domain require completely different training systems. It may only be a change of context or situation that is required for all the groups to use the system.

The focus of the research described in this paper is to address the issue of reuse, and thereby the capability of developers and authors to produce generic models, tools and materials customisable to specific learning scenarios.

2. RESEARCH OUTLINE

The core feature of this research is the development of a novel approach to the generation of reusable computer-based assets to support the production and customisation of learning materials for user and environment constrained learning scenarios. It will test the hypothesis that knowledge about a specific task or area of learning can be decomposed into acontextual content and layers of context-specific information, building on work carried out in knowledge-base research in projects such as Cyc [Lenat 90] and more recently in MIPS [MacKinnon 98] and MOBIT [Brown 99]. The purpose of this decomposition of knowledge is to facilitate the development of a recombination strategy which will enable the reuse of the acontextual content with different layers of context-specific information, supporting different learning scenarios. The recombination strategy will be driven by the user profile [MacKinnon 96], which could refer to an individual user or the characteristics of a cohort-based group of users, combined with the rules and heuristics governing the mechanisms for the delivery of material to support the particular learning scenario. The rules and heuristics identified will be drawn from the existing body of research in the area of cognitive architectures, particularly ACT* (with reference to earlier models, HAM and ACTe) [Anderson 83] and SOAR [Laird 87], [Newell 90]. A key element will be to investigate and adapt cognitive architectures, which are capable of describing human information storage, knowledge acquisition and integration, and *knowledge* manipulation. Other cognitive architectures will also be examined (e.g. THEO and ICARUS which were originally designed to account for human cognitive tasks but have also been applied with some success to robotics and computational problems). How this approach to learning systems could be integrated with the adaptive hypermedia environments such as PaKMaS [Suss 00], InterBook [Eklund 98] and AHA [Wu 00] will be investigated to permit the advances developed in these systems to be extended with these ideas. The test vehicle for the project will be material currently under development as distance learning modules for the Computer Science degree at Heriot-Watt, based on existing classroom-based modules. Control information will be gathered from the classroom-based module, and three scenarios of learning will then be investigated: on-campus, cohort-based, with local tutor support; off-campus, small group-based, with local tutor support; and off-campus, individual user, with internet-based support.

The project will involve the development of both the technological solution and the pedagogic strategy necessary to produce an adaptive learning system based on the approach outlined above. The outcomes of the investigation of the three scenarios will validate the approach and provide information for the further development/refinement of the tool(s) and strategy thus developed. Successful outcomes will also offer the opportunity for further research project work to produce an IT framework, and allied tool(s), for learning scenario support in other teaching areas. This could, in turn, lead to the development of a generic methodological approach supporting the more efficient reuse of material developed for computer-assisted learning systems. Additionally, individual learners should be able to gain an improved learning experience over traditional approaches, as it will be possible to produce a system that tailors the learning experience specifically for each individual user.

3. BACKGROUND

This approach has been developed over a number of years. It is based on the development of training systems for industry and some generic approaches to these problems developed in the MOBIT [Brown 99] and EXTRAS [Khan 97] projects, and work on the use of learning environments for process-based industries in the ASTEP [Ferreira 98, 99] project. This is further supported by work on reuse of learning materials in the MANTCHI project [Newman 99], and on user modelling for information presentation [MacKinnon 96]. This has led to the concepts of

modeling dimensions and knowledge decomposition, involving the identification of base content and contextual information layers, for training systems.
Developing multimedia, computer and net-based Learning Methodology products involves a design process which is essentially similar to others in which there are defined end products. However, despite considerable development and research effort over the past 20 years into learning technology, through CAL, CBT, CAI, etc., no widely accepted, far less standardised, development model and/or methodology has emerged for the development of multi-media learning material.
Those materials that have been developed are both context and scenario specific, with limited or no generic applicability. While there is considerable research stressing the importance of providing information in context to support the appropriate construction of learning, the development of

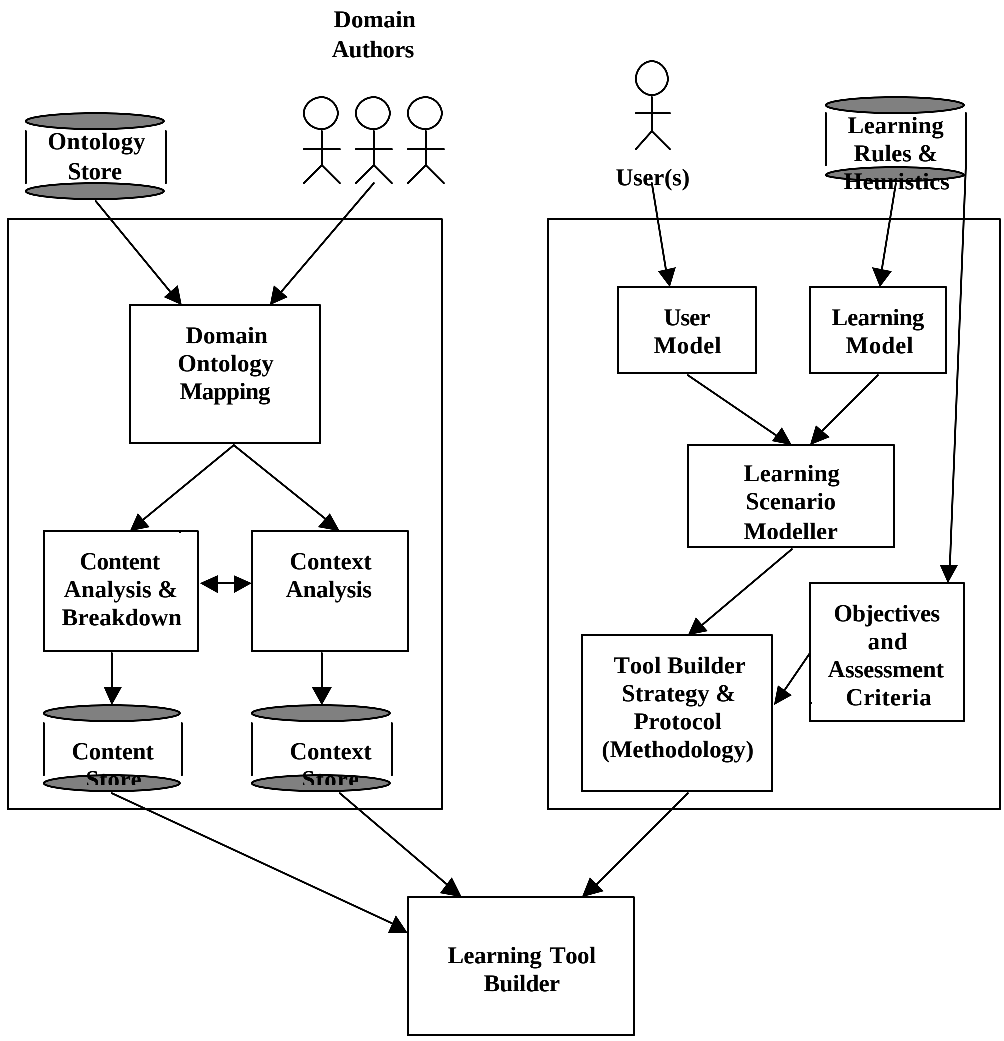

Figure 1 – Design of Advanced Learning Methodology Systems (ALMS)

material which is highly context-specific predicates against the possibility of reuse outwith of that immediate context. Likewise the development of learning tools and environments to support learners in specific learning situations or scenarios have not resulted in the development of truly generic models for such tools and environments, together with the rules and heuristics necessary to customise them for specific learning scenarios. This presents practical difficulties for those developing new products. We would argue that there is a pressing need to address the issues of reuse of learning material and customisation of learning scenarios to permit the definition of generic development models and/or methodologies.

It should be possible to bring together existing knowledge to develop a generic decision support aid to help Learning Methodology developers. Figure 1 above shows a model of the process underlying the Design of Advanced Learning Methodology Systems, which provides the basis for a generic decision support aid (learning tool builder). The projects in adaptive hypermedia including InterBook [Eklund 98], PaKMaS [Suss 00], and AHA [Wu 00] have developed approaches to presenting hypermedia courses to learners. The work described here is consistent with these approaches, by providing a structure for the analysis, breakdown and storage of the domain knowledge, separated into content and contextual components. A conceptual structural model such as that used in AHA could also be utilised in defining the structural relationship between these knowledge components, to avoid the structure being defined by an ontological model which is in itself domain, and thereby context, related. The particular learning scenario being used by a learner would determine how the interface would navigate around the knowledge to provide the adaptive learning experience, as in InterBook and PaKMaS.

Modelling the knowledge that is to be used in a learning system allows the knowledge to be separated in ways that will mean that it may be used in a variety of scenarios. A weak situationist perspective on learning is anticipated, which proposes that a set of descriptive models overcomes the failings of mono-model approaches to teaching contextualised knowledge. How descriptive (symbolic) models have been used in expert systems and tutoring systems does not extend to supporting many aspects of expertise, such as metacognition, affective skills and subconscious skills, although descriptive models can be used effectively in new ways to support development of expertise. Clancey's intention in claiming that "detecting when a model is inadequate and adapting it in subtle ways to the nuances of each new setting cannot be fully automated by using models alone" [Clancey 92] was to draw attention to alternative research directions to overcome the limitations of mono-model architectures. In response to this call for alternatives, this project proposes the use of multiple models as an approach for supporting computer-assisted learning. Our proposed approach to learning recognises the importance of flexible meta-level knowledge for decision making, and the influence of social structures on judgements and action. By using a well chosen set of domain models, a learning environment can be constructed to encourage learning in particular contextual situations, reusing a core set of models of knowledge in differing context.

A space of possible descriptive models is created by specifying values for a set of modeling dimensions. Learning these decontextualised models is valuable because some knowledge may be learned acontextually [Anderson 96]. By treating descriptive models as particulars (described theories, rules etc.), exposure to them helps develop abilities to attend to practical skills [Polanyi 66]. Descriptions of knowledge are important for the meta-level cogitation essential for learning and evolving affective skills and other elusive elements of expertise. Hence, multiple descriptive models have a significant role to play in supporting computer-assisted learning. Below activities of process workers who require training in a particular domain are discussed. The domain the workers are in is the same but the context and therefore appropriate training is different.

If we accept Anderson's contention that some knowledge may be learned acontextually, we also have to accept that it should be possible to separate contextual knowledge and acontextual knowledge, or neutral content. It is core to this project to identify and develop mechanisms by which that separation can be achieved, and a recombination model by which different combinations of content and contextual knowledge can be created. As already described, the concept of "layering" of information, widely used within information technology, has been identified from our previous research as an appropriate focus for this part of the project.

Activities of Industrial Workers

Here we describe the kinds of activities that industrial workers typically engage in, and the different kinds of knowledge described previously that are relevant to those activities. The main conclusion we lead to is: the particular context of a situation determines the different demands on the different kinds of knowledge. No one knowledge kind takes highest importance exclusively, rather the work environment (system, organisation and co-workers) and the nature of the task (mundane, complex and stressful) have a significant influence on the makeup of skills and knowledge needed to be a practitioner of the community. Therefore, *flexibility* and *communication* are both paramount pedagogic 'goals' as well as pedagogic 'tools', and must be focal issues of computer assisted learning environments.

In the process industries learners can adopt several identities during their progress from peripheral to full participation: operator, technician, engineer. Workers must engage in navigating about a model space to alter how they perceive the physical world. This metacognitive process is affected strongly by the identity workers adopt while solving a problem. An operator identity, for instance, is unlikely to formulate complex theories. Instead, an operator's chosen model is oriented towards directly executable procedures—possibly interacting with the physical system at different levels of precision, with minimal attention to the particulars of the tacit skills. When adopting an engineer identity, in contrast, the worker encounters novel situations and potentially must consider all available models and strategies for switching between them. The kinds of knowledge needed by a worker can be demarcated into a hierarchical arrangement based on the significance of each kind to the worker's identity, or more generally, to the particular social structure [Gurvitch 71].

As highlighted by [Rasmussen 94], the division of work for an operator is determined by several criteria ranging from: norms and practice; load sharing; functional decoupling; competency; information access; and safety and reliability. They describe the nature of the process industry worker's activities as: "Activity under varying conditions will depend on continuous adaptation and improvisation, on the ability to reconfigure patterns, to modify effective routines, to combine elementary routines into new patterns, and to generate new work procedures on demand".

In the process industry, for example, the worker must engage in a host of different activities—each one making different demands on the worker's knowledge. These tasks range from real-time operations involving monitoring the progress of the plant and interweaving this with thinking about the tasks to perform, and assessing the situation and engaging in higher-order analysis and conceptualisations [Zuboff 88] as well as longer term planning. Additionally, sometimes the worker must cope with especially complex dynamic tasks: dealing with various information uncertainties (unreliable cues, delayed cues, unfamiliar cues); managing dynamic and independent devices working under high cognitive workload predicting problems and reacting in real-time to unpredictable and emergency events. It is at these times, particularly more so than when engaged in mundane and cognitively undemanding activities, that flexibility, spontaneity and reflection are demanded of the worker to devise new working methods and solutions.

It is clear that the activities of the worker are more complex than following and performing standard operations and techniques all the time; so there will be varied requirements for learning. Gaining full membership into the community of process industry workers means exhibiting all of the following knowledge and skills in various proportions: meta-level reasoning; communication, introspection and reflection; social norms, values and rules; and be familiar with natural laws, repertoires, exemplars, paradigms, instrumentation, media and language. Because the combination of various knowledge and skills depends on the peculiarities of different work systems, 'direct social interaction' with colleagues, for example, has variable importance in different professional settings; and the forms of knowledge consequently learned have similarly variable utility for enculturating the learner as a practitioner of the profession. The multiple models methodology presented here can readily accommodate the varying demands of situations and contexts on workers; from which appropriate learning methods can be developed for different work situations, such as re-framing and changes in identity. A learning environment developed from multiple models, therefore, can manage interaction between learners and practitioners to create a realistic environment in which necessary situated skills can be exercised in different work settings. This kind of learning environment will have the capability to target each kind of knowledge as an identified pedagogic objective.

4. KNOWLEDGE STRUCTURE

Leitch proposed a comprehensive set of properties for physical systems, called modeling dimensions [Leitch 95], that allow a rich representation of knowledge, and supports both contextual and acontextual knowledge. Each dimension is a fundamental characteristic associated with perception of a physical system and how to interact with it. The dimensions proposed by Leitch will have to be extended to deal with the more general problems being examined here. The approach of multiple modeling tackles a similar problem to [McCarthy 93] but uses an alternative formalism to the logical based one. McCarthy's work on formalizing context presents the idea of adding context to a logical view to permit a logical proposition to be true in different contexts. This allows axioms to transcend their original limitations. In our proposed work, the ideas of context can be mapped to navigation around the multiple model structure using different representations of different kinds of knowledge.
If a model is considered a representation of an observer's perception of the world, multiple models produce a space of possible viewpoints. Each of these can be held by an observer acting different roles to produce a unique identity. Learning can be encouraged by designing interaction between a learner and a professional, which consists of a dialectic of two identities. This can be arranged by associating different models of a situation with each actor,

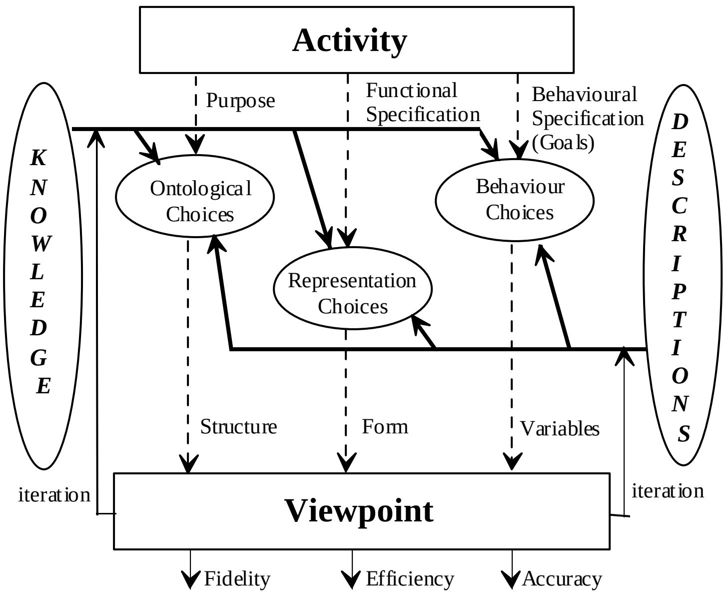

Figure 2 **A unified modeling process: generation of viewpoints from descriptions of knowledge**

and enabling communication in terms of the models.

The view of modeling dimensions presented here is of the modeling process, which consists of several modeling choices. These in turn involve the definition of many model properties. First, the Ontological choices reflect those aspects of knowledge being modeled, such as where the knowledge comes from. Next, the Representational choices dictate how the selected knowledge can be best represented. Also inherent in this dimension is Generality, which specifies how widely applicable knowledge is in problem solving across tasks. Finally, the Behavioural choices consider aspects of the variables of a model. The entire set of modeling dimensions enables a model to be described so that differences between models are apparent along significant aspects, and it is clear which properties of the model are retained or replaced in switching. Figure 2 above shows how these dimensions interact in formulating a model/viewpoint.

When a learner participates in the community's practices, a particular viewpoint is adopted by the learner that reflects how he or she perceives the situation. This may be different from the way more experienced members of the community perceive it. Several properties combine to specify these perceptions of the situation. An important property of knowledge is its Source, which may have a theoretical grounding, e.g. currently accepted scientific principles, or may be based in observations, e.g. rules-of-thumb. Source carries connotations of acceptability and conformity because theoretical bases intimate greater acceptance of behaviour by the community of practice (at least in the scientific communities (e.g. [Kuhn 70])) than more personal and subjectively oriented knowledge (that is, match between a learner's and a professional's viewpoints). Some choices involve adopting component- [de Kleer 84] or process-based viewpoints [Forbus 84], which are examples of Ontology

Based on this background, the aim is to develop a model for knowledge decomposition, using in this instance a constructivist definition of knowledge as "information in context". The model to be developed would therefore investigate an ontological filtering approach to separate the information content from the contextual aspects of the representation and presentation. This would provide a store of contextually independent information and a separate store of contextual information, which could then be reused through a recombination protocol that would also be defined as part of the model.

This would lead to the development of an outline specification for a generic learning tool/environment. From this outline specification the focus would be on the development of learning scenario models by which to customise such tools to specific learning situations. This would involve the identification of the rules and heuristics which govern selection of approaches to learning, and can incorporate consideration of the appropriate use of metaphor underpinning the learning process. An approach such as this permits a completely system specified learning scenario to be developed, or the use of input from the user to help specify the most appropriate learning path. The research would show whether the idea of knowledge decomposition into context independent and context dependent information could be combined with adaptive approaches to learning, to successfully reuse material for different user groups.

5. EXAMPLE

In order to demonstrate how our domain modelling based on structured knowledge can be used to aid learning in context, we show an example.

Here we have a physical system, a boiler plant (containing a water system detailed below), Figure 3, which can be represented in many ways by altering the dimensions of a model. Figure 7 shows a visualization of how the knowledge can be structured as both knowledge of the system and knowledge about the system. This hierarchical structure permits navigation around the domain knowledge keeping base content separate from the layers of context. Different users have differing perceptions of the boiler plant; each perception can be described by a model that differs along certain dimensions [Leitch 95]. By separating out the models of the system (as illustrated in Figure 7) from the context, whilst maintaining the knowledge structure, the different learning requirements of the learner and expert can be accommodated.

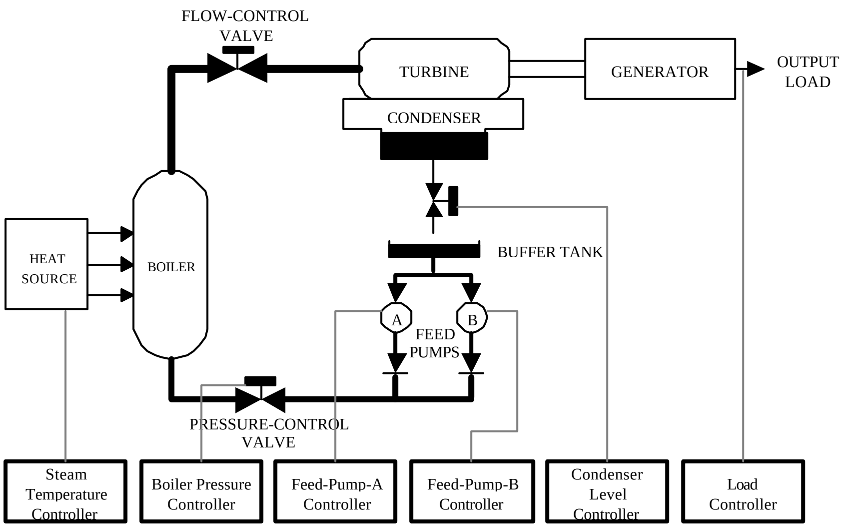

Figure 3: Structural representation of boiler plant

The learner is free to experiment in the environment to "get a feel" for the expert's viewpoint. It is intended that through questioning and experimenting, the individual can experience alternative perspectives on the same problem domain. In a similar manner, other skills and knowledge can be learned by using appropriate context, with different viewpoints, facilitated by manipulating structured models.

When a learner and the community interact, we assume particular viewpoints are adopted to reflect the context. Several properties combine to specify these perceptions of the situation. An important property of knowledge is its *Source,* which may have a theoretical grounding, e.g., currently accepted scientific principles, or may be based in observations, e.g., rules-of-thumb. Figure 6 illustrates the base layer for three tanks in a system. It is this base layer which is built upon with the layers of context. Figure 4 shows a three tank subsystem of a boiler plant at a certain scope, where layers of context have been added compared to the base layer shown in figure 6. Figure 5 gives an example of a change in scope in which only the Hot Tank is considered; here the context has been layered on the base level model of a single tank. Similarly, either of the other tanks in isolation can be considered.

The water system, which is shown in differing forms in Figures 4, 5 and 6 will have other related contextual information. This related contextual information could be found by navigating to the appropriate point in the knowledge hypercube, as shown in Figure 7. A boiler plant operator who is learning to control the boiler power output will use contextual knowledge for water supply into the boiler. The trainee operator will not require the full detail of the water system, but will need to have a qualitative ‘feel’ for the system. This can be done with the model shown in Figure 6 taking the learner through the input output relationships. However, a designer working on the same system but wanting to update the controller characteristics will need to have a more detailed knowledge of the water supply system as his context is the detailed control of the water supply system. For this application he would look at one tank at a time as shown in Figure 5. Using this layered approach to context the same knowledge may be used for different learning scenarios for different users. The choice of learning scenario will govern the navigation around the domain knowledge and hence the learning experience. This separation of knowledge allows a variety of tasks and skills to be supported by a unified framework.

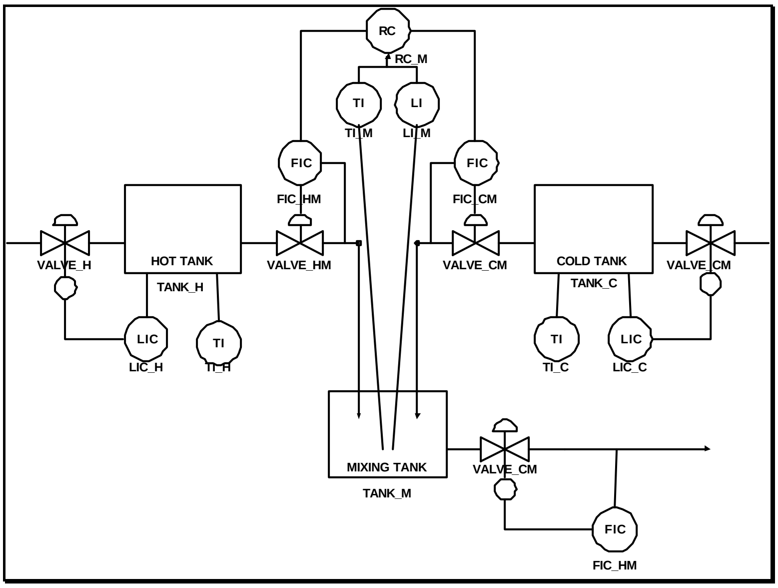

Figure 4: Three tank water system at a certain scope.

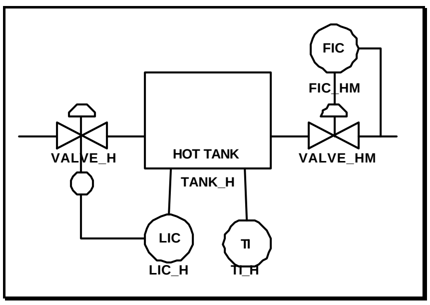

Figure 5: Three tank system at a reduced scope to focus on a single tank

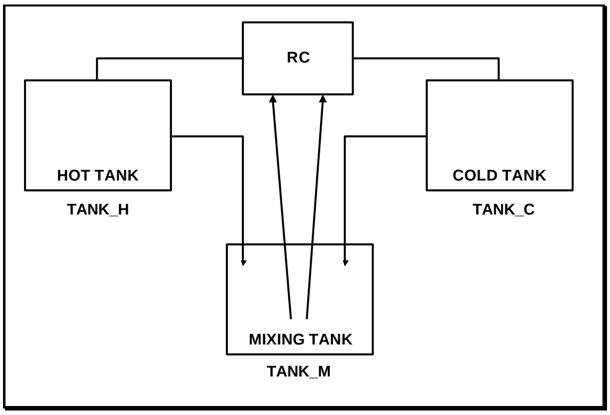

Figure 6: Three tank system remodelled at a different resolution

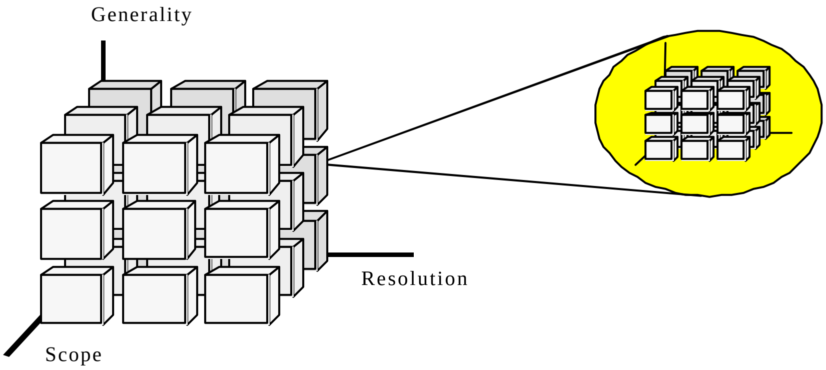

Figure 7: Hierarchical Model Cube–each cube comprises smaller cubes, the hierarchy holds the relations for the heterogeneous knowledge types

6. Conclusion

We have proposed a novel approach to the generation of reusable computer based assets for producing individually tailored computer assisted learning. The hypothesis is that knowledge for teaching a specified task can be decomposed into a multiple model form and then used in a selection of situations for supporting individual's specific learning requirements. The approach allows the development of both the technological solution and the pedagogy required to make a useful adaptive learning system. We believe this approach can be developed for production of computer assisted learning systems for any subject domain and facilitate the re-use of the learning assets for a range of different user types. Using this approach the reuse of acontextual material and layers of additional contextual information will be made possible permitting the more efficient use of material developed for computer assisted learning systems. Additionally the learner should be able to gain an improved learning experience over traditional approaches, as it will be possible to produce a system that tailors the learning experience specifically for each user. That is, each user will, using the same basic set of resources, be able to use them in the most efficient manner for their preferred learning style.

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