Intelligent Information and Engineering Systems' Vol. 3684 (pp. 221-227). Melbourne, Australia, 14-16 September 2005

Knowledge Sharing Between Design and Manufacture

Sean D. Cochrane, Keith Case, Robert I. Young, Jenny A. Harding, and Samir Dani

Wolfson School of Manufacturing Engineering, Loughborough University,
Leicestershire, LE11 3TU, UK
`s.d.cochrane@lboro.ac.uk`

Abstract. The aim of this research is to develop a representation method that allows knowledge to be readily shared between collaborating systems (agents) in a design/manufacturing environment. Improved mechanisms for interpreting the terms used to describe knowledge across system boundaries are proposed and tested. The method is also capable of handling complex product designs and realistic manufacturing scenarios involving several parties. This is achieved using an agent-architecture to simulate the effects of individual manufacturing facilities (e.g. machine tools and foundries) on product features. It is hypothesised that knowledge sharing between such agents can be enhanced by integrating common product and manufacturing information models with a shared ontology, and that the shared ontology can be based largely on The Process Specification Language (PSL).

1 Introduction

Manufacturability analysis allows cost/performance optimisations to be made early in the design process with minimum rework; and many organisations have deployed Knowledge Based Systems (KBS) to improve the consistency of this analysis. Typically KBS work well in isolation. There is however, a growing requirement to share knowledge between systems. This is driven in part, by a need to do more than move problems along a supply chain. Such holistic analysis requires intimate knowledge of all the processes used to manufacture a product, and with the growing use of subcontractors, no single party is now likely to provide this. The development and maintenance of knowledge bases can also be expensive, and knowledge sharing distributes these costs between collaborating parties.

Knowledge sharing is not however straightforward. Existing systems typically use bespoke models of entities and relationships, and implied terms for stating rules, constraints and objectives. These make it difficult for knowledge to be mapped between systems. Recent research tackles these issues by formally defining lexicons of terms, referred to as *ontologies*. An explicit ontology provides a starting point for the mapping process. Ontology mapping has however proven difficult to achieve on an industrial case scale. Ontologies often use different terms to describe similar concepts and similar terms to describe different concepts. Different taxonomies and conflicting definitions add further complexity. Mapping techniques include shared ontologies which define terms relevant to multiple systems. Shared ontologies are however difficult to define beyond generic concepts. The specific terms used to describe actual products and processes (e.g. nuts, bolts, milling, and drilling) still need to be defined; and their inclusion leads to large lexicons, with complex taxonomies that are difficult to apply and adapt to specific application. The question arises as to whether specific

R. Khosla et al. (Eds.): KES 2005, LNAI 3684, pp. 221-227, 2005.

terms can be fully defined by instantiating generic concepts? A set of generic concepts (and associated models) for manufacturability analysis would be required for this purpose.

The aim of this research is to develop representation methods that improve knowledge sharing between collaborating systems in design/manufacturing environments. Improved mechanisms for interpreting the terms used to describe knowledge across system boundaries are required. The method should also be capable of handling complex product designs and realistic manufacturing scenarios involving several parties. Section 2 discusses the research literature relevant to knowledge sharing, and section 3 describes the knowledge sharing approach proposed by this research. Conclusions and further work are discussed in section 4.

2 Information Models and Ontologies

The use of object-oriented models to structure shared information in design environments is widely discussed in the research literature. Proposed models include separate product and manufacturing hierarchies [1], where classes represent entities such as product features and manufacturing processes. These structures have also been extended for knowledge representation. The Factory Data Model (FDM) [2] for example, extends the Manufacturing Model [1] with a strategy hierarchy for manufacturing rules, constraints and objectives. Even the FDM however, does not specify the terminology used to describe rules. This is left to bespoke extensions of the basic model. The interpretation of rules will therefore be specific to the model deployed by each KBS. This makes it difficult for systems to directly apply knowledge from other systems.

Ontologies have been proposed as a way of overcoming these issues. Ontologies are *"a formal description of the entities within a given domain: the properties they possess, the relationships they participate in, the constraints they are subject to, and the patterns of behaviour they exhibit"* [3]. Explicitly defining the terms used by a KBS to describe rules makes it easier to map between systems (figure 1: left). There are however, significant issues involved with mapping ontologies, including: extraneous clauses (e.g. synonyms), and conflicting inferences. Techniques such as combinator logics [4] have been demonstrated as a means of resolving conflicting inferences under certain conditions. These techniques are rigorous, but potentially difficult to scale to industrial case examples involving several collaborating parties.

Shared ontologies have been proposed as a way of simplifying ontology mapping (figure 1: right). This is analogous to using English to communicate across national boundaries, even when no native English speakers are present. In practice however, establishing a shared ontology is difficult when several parties are involved. Ideally, a pre-existing ontology would be available, and several have recently emerged. These include: *The Process Specification Language* (PSL) [5], and the Suggested Upper Ontology (SUO) [6].

PSL targets process-centric environments (e.g. manufacturing and construction), and defines generic terms for most (if not all) processes. PSL has been used to exchange project planning information [7], describe process inputs and outputs [8], and model process flows, e.g. painting [9]. The need for a shared set of terms for interpreting product/manufacturing models, and the potential application of PSL to this issue has also been recently highlighted [10]. SUO defines a large lexicon, which incorporates PSL, and more specific concepts for manufacturing (and other) environments, e.g. material removal and cutting. The more detailed concepts needed to describe specific environments are not included in SUO (e.g. casting cylinders, and drilling holes). These invariably require bespoke augmentation for specific applications.

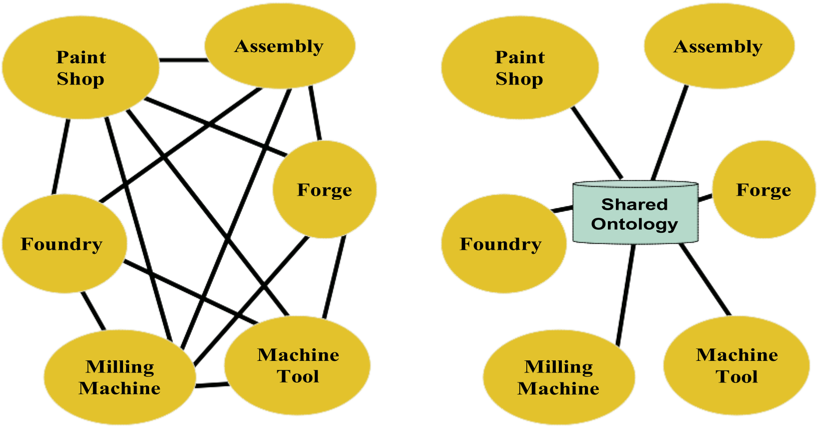

Fig. 1. Ontology Mapping Approaches

PSL and SUO highlight a limit of shared ontologies. Agreement on generic concepts may be achievable, but the specific customised concepts required by all applications are unlikely to be included. A "one-size-fits-all" approach would be highly cumbersome, and so ontologies such as PSL and SUO are recommended as starting points for more detailed, application specific ontologies. Customisation however, leads to the previously described issues of synonyms and conflicting inferences. Point to point mappings (figure 1: left) will also be required, as bespoke terms fall outside the operation of the shared structure.

3 Multi-agent Systems

Agents are software modules capable of applying knowledge to a particular task (essentially a form of KBS). Agents (in simplified form) support goals (i.e. an idea of what they are trying to achieve), have a defined perception of their environment and the information they receive from their environment, hold beliefs about how they should behave and interact with their environment, and be capable of executing actions or action sequences (i.e. plans) that meat goals [11]. An agent's perceptions, goals, beliefs and actions will usually be expressed in terms of rules; and ontologies can be applied to expressing the rules deployed by agents. Multiple Agent Systems address a number of inter-related tasks through the operation and interaction of several agents. Such architectures have been applied to many environments, including product design, and are supported by bespoke ontologies for detailed design tasks, materials, and quality standards [12].

Returning to our manufacturability analysis problem; figure 1 can be seen as several agents representing facilities (e.g. machine tools), collaborating in the manufacture of a product. Each agent can be owned and developed by participants in the supply chain, and the problem of knowledge sharing (as previously described) can be seen in terms of agent communication and interaction. The knowledge bases of each agent may use terms that have similar or conflicting meanings. These issues have been tackled using a mediator agent [13] to manage the mapping of terms between systems.

4 Hypothesis and Research Platform

This research sets out to share knowledge between several parties in a manufacturing supply chain. This is achieved using an agent-architecture to simulate the effects of individual manufacturing facilities (e.g. machine tools) on product features. It is hypothesised that knowledge sharing between agents can be enhanced by integrating a common information model with a shared ontology, and that the shared ontology can be based largely on PSL. Specific terms can also be modelled by instantiating entities and relationships defined by the shared-generic ontology. This allows specific terms to be interpreted by other agents. The questions that need to be addressed in developing this hypothesis include: what PSL concepts are relevant to manufacturability analysis, and what additional shared concepts are required? Mechanisms for handling the specific terms are also required.

Figure 2 shows the research platform designed to explore these issues. The Manufacturability Analysis Platform (MAP) uses agents, called Process Agents, to simulate the behaviour of manufacturing facilities. Each process agent manipulates the shared product and manufacturing information models according to the processes they are capable of performing. Higher level controlling agents referred to as Strategy (or Complex Process) Agents create and match manufactured features as closely as possible to the required features of a product. Strategy agents hold beliefs relating to how processes should be combined (e.g. drilling precedes boring), and a perception of the whole product being manufactured (not just individual features). Strategy agents effectively simulate the effects of multiple processes, and these simulations can (and should) include a final comparison of required and manufactured features.

Process agents (guided by messages from strategy agents) manipulate the resource usage profile and initial process plan (via the shared model). These outputs directly support manufacturability analysis, and are monitored by the shared model for conflicting inferences, e.g. errors in the logic of the process plan, and insufficient resource allocations. Errors will also be reported if manufactured features (in the final comparison) fall short of requirements.

Process agent perceptions include required and manufactured features (e.g. holes) and their attributes (e.g. diameter tolerances). An agent's goal will be to improve the correlation between required and manufactured feature attributes. In the case of a "drill-hole" process, this includes the creation of the manufactured feature itself. Alternatively a "bore-hole" process would search for a pre-existing manufactured hole, with the aim of improving its diameter tolerance. Beliefs include the relationship between facility parameters and manufactured feature attributes, resource demands, and how process durations relate to product features (e.g. milling rate * surface area). The actions supported by an agent include the manipulation of manufactured features, process plans and resource profile. A process agent will also interpret messages from a strategy agent, e.g. "bore-hole (list-of-holes)", and "ream-hole (list-of-holes)".

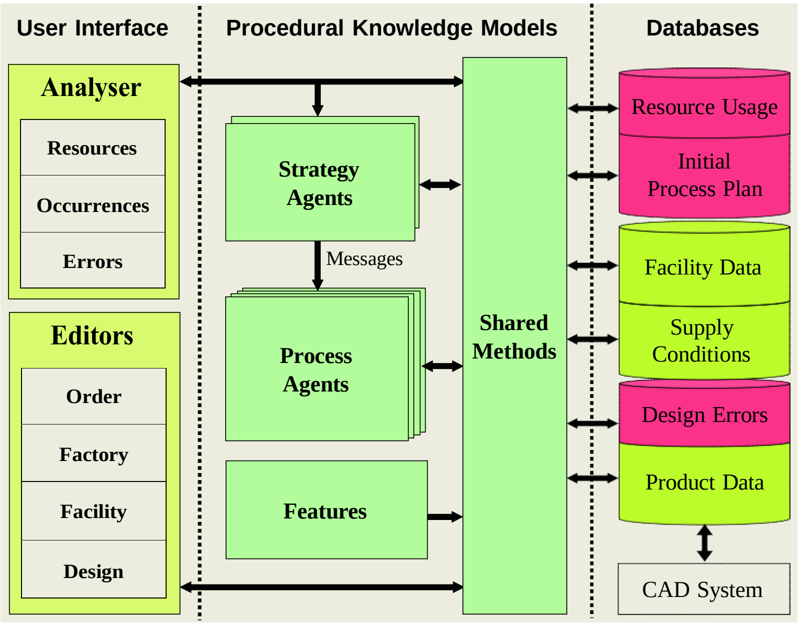

Fig. 2. The Manufacturability Analysis Platform (MAP)

5 The Shared Ontology

This section discusses the requirements of the shared terms, and how they can be derived (where ever possible) from existing ontologies and standards. A distinction is drawn between the shared-generic concepts relevant to all systems and the bespoke lexicon that only needs to be shared between agents in a particular environment.

As agents need to manipulate a common process plan, terms for describing processes, and their inter-relationships are required. PSL supports this extremely well. Processes can be modelled as "activity-occurrences"; and process hierarchies can be described using PSL terminology, e.g. "boring_hole15" is a "sub-activity-occurrence" of "machining-my-product". PSL also allows sequencing rules to be applied, e.g. "drilling" is "possible" after "drill-setting", and for process durations, beginnings, endings, and resource demands to be described in a consistent (shared) manner.

The naming of processes and resources requires consideration, as this falls outside the PSL ontology, and forms part of the bespoke-shared lexicon. Parent process names almost certainly need to be interpreted across system boundaries e.g. "machining-my-product", as these form part of a Strategy Agent's perception, and are likely to use multiple process agents to achieve their goals. Individual sub-process names will also need to be shared if two or more agents need to declare rules relating to each other. Drilling-Hole15 and Boring-Hole15, may for example, be performed by different machine tools. Process names can be handled within the shared model and enforced in a consistent fashion across all systems.

As multiple agents are likely to process the same features, a shared set of concepts for describing features is required. This should include numerical representations (e.g. real numbers and integers), along with geometries (e.g. m, m2, m3, and gram), and enumerated properties (e.g. colour: blue, red, and green). A shared understanding of the features themselves is also required. Each feature includes a set of attributes (e.g. a holes diameter and associated tolerances), and rules for setting attributes (e.g. a hole must be associated with a solid structure such as a block or cylinder). The basic concepts of numbers and geometries are included in SUO, and many detailed feature definitions are provided by STEP AP224 [14]. A shared understanding of Blocks, Cones, Cylinders, Holes, Taps, and Countersinks can therefore be defined according to existing standards. The names of individual features (e.g. Hole15), are however an additional part of the bespoke/shared lexicon. The shared model can be used to enforce the consistent use of feature names across all connecting agents (reporting errors if different names are used by different agents).

6 Conclusions and Further Work

This work focuses on knowledge representation for manufacturability analysis in design. This was chosen due the perceived benefits of sharing knowledge between several parties involved in the manufacture of a product (e.g. holistic analysis). The work has demonstrated the integration of a product and manufacturing information model, with a shared ontology based on PSL. The resulting "shared model" acts as a platform for sharing knowledge between problem solving agents collaborating in the manufacturability analysis of complex products. A structure for building process agents (based on perceptions, goals, beliefs, and actions) has also been proposed and tested. Obvious extensions of the work include the sharing of costing and failure effects knowledge. These use much of the same knowledge of manufacturing processes, and could be represented using similar methods.

Acknowledgements

This work is part of the "Knowledge Representation and Reuse for Predictive Design and Manufacturing Evaluation", project, funded under EPSRC GR/R64483/01. Further information can be found on: http://www-staff.lboro.ac.uk/-mmsdc.

References

1. Molina A, Bell R, 1999. A Manufacturing Model representation of a flexible manufacturing facility. Journal of Engineering Manufacture: Proceedings of the Institution of Mechanical Engineers, Vol 213, Part B, pp.225-246.
2. Harding J, Popplewell K, 2001. Enterprise design information: the key to improved competitive advantage. Int. J. Computer Integrated Manufacturing, 2001, V. 14, No. 6, 514-521.
3. Uschold, M, Gruninger M, 1996. Ontologies: Principles, Methods, and Applications. Knowledge Engineering Review, 1996, Vol. 11, pp. 96-137.
4. Correa da Silva F, Vasconcelos W, Robertson D, Brilhante V, Melo A, Finger M, Agusti J, 2002. On the insufficiency of ontologies: problems in knowledge sharing and alternative solutions. Knowledge Based Systems 15 (2002) 147-167.

5. Schlenoff C, Gruninger M, Tissot F, Valois J, Lubell J, Lee J. The Process Specification Language (PSL) Overview and Version 1.0 Specification. Accessed 03/Oct/03: http://ats.nist.gov/psl
6. Niles I, Pease, A, 2001. Towards a Standard Upper Ontology. In Proceedings of the 2nd International Conference on Formal Ontology in Information Systems (FOIS-2001), Maine, October 17-19, 2001. Accessed 03/Oct/03: http://suo.ieee.org
7. Gruninger M, Sriram R, Cheng J, Law K. Process Specification Language for Project Information Exchange. Int. J. of IT in Architecture, Engineering & Construction, 2003**.**
8. Bock, C., Gruninger, M., 2004. Inputs and Outputs in PSL NISTIR 7152, NIST, Gaithersburg, MD, 2004. Web Accessed 17th Feb 05: www.nist.gov.
9. Bock, C., Gruninger, M., 2004. PSL: A Semantic Domain for Flow Models. Software and Systems Modeling Journal, 2004. Web Accessed 17th Feb 05: www.nist.gov.
10. Cutting-Decelle, A, Young R, Anumba C, Baldwin A, Bouchlaghem N. The Application of PSL in Product Design across Construction and Manufacturing. CERA Journal, Vol. 11, No.1, March 2003.
11. Arazy O, Woo C, 2002. Analysis and design of agent-oriented information systems. The Knowledge Engineering Review, Vol. 17:3, 215-260.
12. Chira O, Chira C, Tormey D, Brennan A, and Roche T, 2004. A Multi-agent Architecture for Distributed Design. Lecture Notes in Computer Science. Volume 2744 / 2004 Title: Holonic and Multi-Agent Systems for Manufacturing. ISBN: 3-540-40751-0. Chapter: pp. 213 - 224. Online Date: January 2004.
13. Zhang J, Zhang A, Chen C, Wang B, 2003. Semantic Interoperability Based on Ontology Mapping in Distributed Collaborative Design Environment. Lecture Notes in Computer Science. Volume 2663 / 2003 Title: Advances in Web Intelligence: First International Atlantic Web Intelligence Conference AWIC 2003, Madrid, Spain, May 5-6, 2003. Proceedings Chapter: pp. 208 - 217. Online Date: August 2003.
14. Sharma, R, Gao J, 2002. Implementation of STEP Application Protocol 224 in an automated manufacturing planning system. Proceedings of the Institute of Mechanical Engineers, Vol 216 Part B: Journal of Engineering Manufacture.