A Methodology of Collaborative Synthesis by Artificial Intelligence

-- JSPS Research for the Future Program: Science of Synthesis --

Riichiro Mizoguchi, Yoshinobu Kitamura, ISIR, Osaka University
Eiji Arai, Graduate school of Engineering, Osaka University
Masahiko Onosato, Graduate school of Engineering, Osaka University
Koji Kawakami, Graduate school of Engineering, Kyoto University
Tadataka Konishi, Faculty of Engineering, Okayama University

Abstract

This project aims at establishing basic theories and fundamental methodologies for synthesis through knowledge systematization by exploiting the artificial intelligence technology, especially Ontological Engineering. The concrete objectives of the project include development several kinds of ontologies for knowledge systematization and development of a multi-agent collaborative synthesis framework. The formers mainly concerned with the domain-independent design object knowledge and the latter with domain-independent design process knowledge. This paper report on the intermediate results in the middle of the project term(five years) as well as on the future plan.

Keywords: Knowledge systematization, ontology, multiagent,

1. Objectives

Humans have made a great progress in industrialization by inventing the mass-production paradigm. While it has worked extremely well until recently, there have appeared non-negligible difficulties such as green house effect, resource limitation, industrial waste processing, etc. these days. This is partly because engineering has developed within each domain with little interaction among different domains and because the fact has prevented global optimization of production across the domain. By Synthesis, we mean all the activities performed during the course of producing artifacts. The key issue here is in spite of the fact that all the domain engineering implicitly share *Synthesis* we have no theory or technology of it. Science of synthesis, the parent project managing the four subprojects one of which is the project the paper is going to overview, has been established intended to investigate synthesis as a domain-independent science. Our project inherits the core of the objectives of the parent project.

Table 1 shows our understanding of the current state of the art of Theory of synthesis. The important dimensions for classification of related knowledge include domain-dependence and static/dynamic, and the dynamic knowledge has subdimensions such as logical/mathematical/system. The conventional engineering knowledge has been independently systematized in each domain such as Electrical engineering, Mechanical engineering, Chemical engineering, etc. The issue here is the knowledge of common activity across these domains, Synthesis of artifacts, is hidden in each domain in spite of that we could uncover the common knowledge about synthesis. One of the key claims Science of synthesis makes is to uncover such hidden knowledge for future advancement of knowledge-intensive design support systems by getting rid of the sectionalism of knowledge systematization.

	Static knowledge（Knowledge about design objects ）	Dynamic knowledge(Knowledge about design process)		
		Logical aspects	Mathematical aspects	System aspects
Domain dependent	Conventional domain-oriented engineering	NA	NA	Ad hoc system
Domain independent	**None**	Tomiyama project	General Design Theory	**None**

Table 1 The current state of the art of “Theory of synthesis”.

General design theory proposed by Yoshikawa[Yoshikawa 80] has initiated such research that investigates the domain-independent knowledge of the activity of design from the mathematical point of view. And, it has made a substantial contribution to a better understanding of design in general. However, it does not deal with the real dynamic aspects of synthesis, that is, “Process of synthesis”. Tomiyama has noticed some rooms of improvement in the general design theory and established his own project on “Model of Synthesis” in the Project of “Science of synthesis”. He in fact adopted a logic-based approach to come up with an executable model of synthesis.

Our project has two major objectives concerning the above classification of knowledge systematization. One is to try to systematize synthetic process knowledge from system building point of views to come up with more concrete knowledge usable for building knowledge-intensive design systems. The other is to try to systematize domain-independent knowledge of design objects. The key technology employed in our project is Ontology engineering[Mizoguchi, 97] which gives us a theory and guidelines for modelling knowledge. To describe more concretely, we have the following five objectives:

(1) **Design of an ontology of basic concepts such as agent(of operation), object(of operation), behavior, function which are key concepts common to all the static and domain-dependent knowledge of synthesis**: The major target here is to design a functional ontology. Our challenge includes in-depth understanding of the differences of domains through explication of those between the basic concepts across domains. This provides us with an infrastructure of systematization of synthesis knowledge.

(2) **Description of a set of design knowledge in terms of functional ontology for a concrete innovative design problem to evaluate the systematization**: The value of functional knowledge is truly exhibited when it is grounded onto behavior and structure. The functional ontology[Sasajima 95] we develop is carefully designed so as to capture such grounding by defining relations between behavior and function and physical state modelling system gives us a firm foundation for knowledge systematization.

(3) **Systematization of knowledge related to synthetic process by investigating synthetic process from task ontology and collaboration among agents perspectives**: The concept of task ontology proposed by the project leader, Mizoguchi [Mizoguchi 95][Ikeda 97b], has been accepted as a powerful

methodology world wide. Design task ontology which we are going to develop is an ontology consisting of domain-independent concepts appearing in “design” as an innovative problem solving process.

(4) **Model development of synthetic process at the system behavior level in terms of collaborative behaviors among multiagent**: The agents are located in the grids of the two dimensional space spanned by the abstraction hierarchy and the time of the process. The former consists of the three conceptual levels such as physical states, behavioral and functional levels and the latter consists of design time and manufacturing time. Each agent negotiates with each other following the negotiation protocol based on a negotiation ontology we develop. The negotiation protocol together with the ontology specifies the collaborative behaviors of agents domain-independently, which in turn contributes to specifying dynamic aspects of the synthetic process.

(5) **To develop a methodology for developing collaborative synthesis systems**: On the basis of the framework of the collaborative synthesis we build and the systematized knowledge together with ontologies, we reveal the way to build such a knowledge-intensive design support system.

The project started in 1997. This paper overviews of the project and reports on intermediate results obtained thus far.

2. Overview of Research Plan

2.1 Knowledge systematization for synthesis

The goals of the research consist of ontology development for knowledge systematization and realization of an innovative redesign system using the systematized knowledge.

As a basic theories and tools for knowledge systematization, we develop five kinds ontologies:
(a) Basic ontology
(b) Functional ontology
(c) Design task ontology
(d) Redesign strategy ontology
(e) Negotiation ontology

Basic ontology covers concepts such as *agent, object, state, behavior, function*, etc. Functional ontology covers various types of concepts related to function such as **domain function** *like warm, cut, remove*, etc. **types of functions** like *attain, maintain, sustain*, etc. and **meta-function** like enable, *drive, provide, control,* etc. Each type has its own role. Further, domain functions are organized in terms of ***is-achieved-by*** relation. Domain functions are grounded onto behavior.

Design task ontology provides us with a vocabulary for explaining and building the design process domain-independently and includes verbs such as *select, connect(components), generate(solutions), evaluate, etc*. and role concepts which domain object play in the design process as well as design specific concepts such as *requirement, cost, constraint*, etc. Redesign strategy ontology covers concepts specialized for redesign task such as *inconvenience, cut the causal chain, replace the* *function, etc.* The fifth ontology is one for negotiation among agents. Contrary to the common understanding that communication ontology necessarily becomes domain-dependent, we believe we can design domain-independent ontology for negotiation [Ikeda 97a] on top of communication performatives provided by, say, KQML[Finin, 94]

These ontologies collectively specify problem(search) space necessary for performing design tasks and enable us to systematize knowledge of synthesis.

The other goal is to design and develop a redesign system which needs an innovative architecture. The first step done by the system is to understand the given artifact, which requires the functional ontology and sophisticated methods for mapping behavioral and structural information onto the functional space. A lot of and various inference should be done in the functional space to come up with many possible candidate solutions which are free from the inconvenience given. While the new solution proposing process, the system exploits the redesign strategies described in terms of redesign strategy ontology. We plan to implement the candidate solution proposing module using the SOAR architecture in which the redesign strategy ontology plays a key role.

In order to build a higher level communication infrastructure for agents collaboration, a negotiation ontology is developed. A negotiation protocol is specified in terms of the ontology. Finally, we investigate knowledge systematization for synthesis which enables us to talk about synthesis in terms of well-designed vocabulary which can be understood also by computers.

2.2 Collaboration mechanisms of design and production

(1) Collaborative Tasks between Designers and Production Planners

At the design and production stages, both designers and production planners need to get the reciprocal exchange and transfer of information related to the manufacturing processes and product specifications. Actually, CAD/CAM systems are required to achieve high quality design and production. In order to realize smooth cooperation between designers and production planners, the designer's intention plays a very important role, since production planners must know it to understand the design. Fast decision making can be achieved using the designer's intention in a cooperative design/production environment. For this purpose, we develop a new CAD/CAM system which can handle the designer's intention as an additional information with the product model.

(2) Cooperative Actions among Manufacturing Elements

The concept of "Auction" is important in distributed manufacturing system architecture. "Auction" is an interaction between a computer system and machining cells, in which active database assigns certain jobs to the cells, and the cells judge their ability to achieve the assigned jobs with estimation of machining time. The final decision is made by the computer system according to the selection of minimum machining time. It is efficient to derive the maximum performance of the cells, and the total manufacturing system acts more flexibly.

In fact, an interaction between a scheduling system and machining cells has been achieved in conventional manufacturing systems, but the scheduling system have predominated over the machining cells. In those systems, job information has been provided by the computer system and the machining cells have remained subordinate. However, recent advanced cell controller has enabled to administer intelligent information. It means that the cell controllers may judge possibility to accomplish assigned jobs and estimate machining time. Therefore, the distributed manufacturing system architecture based on "Auction" plays a key role in re-scheduling to maintain high potential and performance of the total manufacturing system.

A qualitative simulation agent for 2D motion is developed. It locates at the behavioral level and check feasibility of the motions of intermediate model of artifact.

2.3 Intelligent information processing platform for cooperative synthesis

The aim of this sub-project is to design and develop "Intelligent Information Processing Platform", which will be a core technology for "Cooperative Synthesis by Artificial Intelligence".

The intelligent information processing platform(I2P2) should be designed to include following functions:

(1) I2P2 stores the descriptions about the physical world including design objects and their environment, provides intelligent agents with the design object data and related concepts for their knowledge processing, and records the design results by agents.
(2) I2P2 plays the role of the communication media for distributed agents.
(3) I2P2 manages the constraints in the physical world and maintains their consistency by using logical inference and simulation.

The research group of the sub project has been doing several research projects related to I2PS functions mentioned above.

(1) Development of the State Modeling System (SMS) handling a set of state primitives each of which composes a spatial region, a time interval, and a set of physical properties.
(2) Development of an integrated product modeling system which supports life-cycle product management.
(3) Formalization of cooperative task processing by introducing the concept of the OTP(Organization-Time-Process) structure and development of a modeling system.
(4) Development of virtual manufacturing systems simulating shopfloor activities in factories on the level of behaviors or physical phenomena.

Based on these results of previous research, the research group are currently developing the prototype system of I2P2 in order to support advanced cooperation among intelligent agents.

2.4 Knowledge acquisition and utilization in synthesis

In order to synthesize artifacts based on Knowledge Engineering techniques, a lot of knowledge of synthesis is indispensable. This sub-project aims to develop a method for acquiring such knowledge from artifacts that is utilized when designers synthesize physical systems. We also intend to develop a framework for supporting synthetic problem solving by making use of acquired knowledge based on human-computer interactions through multilateral channels. In order to construct such methods as knowledge-based systems, we focus our effort on developing:

(1) A scheme for representing not only intended but also unexpected phenomena by designers, especially focusing on artifacts which functions with the help of physical effects.
(2) A framework for acquiring some pieces of knowledge of synthesis which are utilized by designers at the design process of artifacts based on analyzing artifacts how they avoid interference which spring from attaining functional requirements simultaneously.

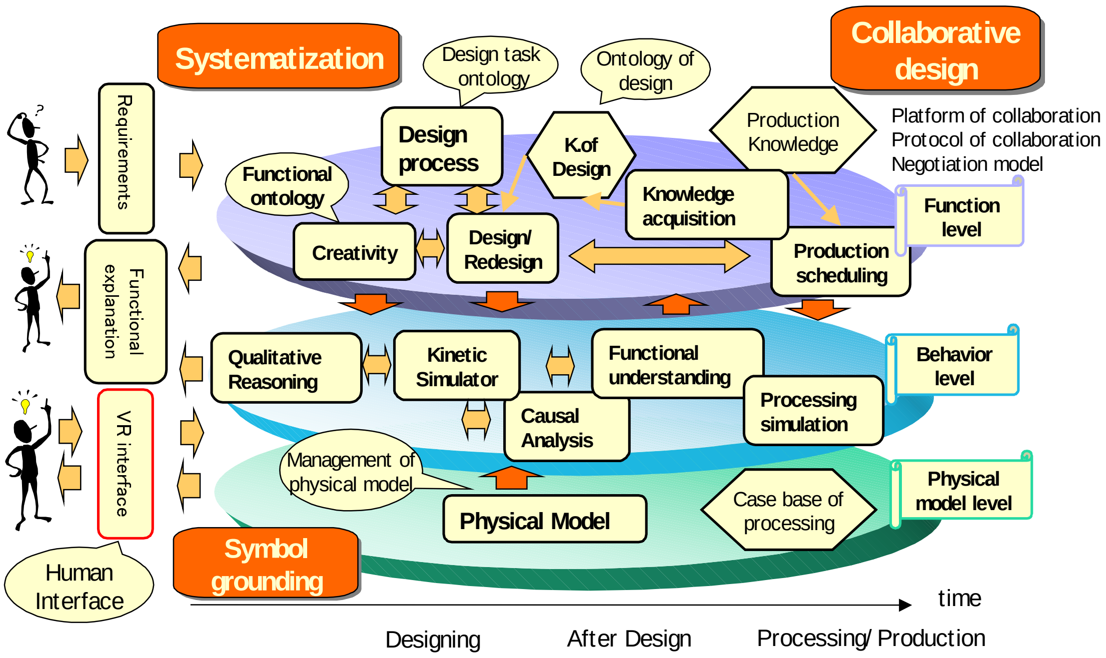

Fig. 1 Framework of multiagent system

(3) A scheme for representing knowledge of synthesis which can be available to symbolic processing systems.
(4) A framework of computer aided design system where knowledge of synthesis are utilized based on human-computer interactions.
(5) A way for organizing a lot of knowledge of synthesis, which enables human-computer interactions through multilateral channels.

3. Results Obtained Thus Far

Fig. 1 shows a framework of our multi-agent system. The horizontal axis represents the lifecycle of products such as design, processing, manufacturing, etc. The vertical axis, on the other hand, represents abstraction hierarchy, such as structural or physical level, behavioral level and functional level. Several agents are located at this two-dimensional space and collaborate with each other to attain a common goal, that is, to produce an artifact satisfying requirement given. Each agent has its own responsibilities which some times overlap and it some times meets a conflict during the course of performing its functions. This is why we need a sophisticated collaboration/negotiation mechanism.

We have implemented an agent responsible for managing physical state of the artifact being designed. One of the main role of this agent is to ***Ground symbols*** in the higher layers onto those on the physical layer which corresponds to the real world. Thus, it enables to constrain the higher level model within physically feasible models. Concerning the behavioral level, we plan to build qualitative simulators, a qualitative motion simulator in the two-dimensional space and a virtual processing simulator. Among them, the motion simulator was thus far implemented for two rectangular parallelepipeds: one is in a linear motion and the other in rotation. This simulator is used to check if the current physical configuration has any difficulty in motion. One of the key issues in function level processing is that how to keep the correspondence between functional and behavioral levels. We developed a language for representing functional model and designed an agent which understands functional structure of a given behavioral and structural model. In order to include human designers into the system, a virtual 3D interface which allows designers to virtually use the computer model of artifacts, 4D design review interface and lifecycle information browsers embedded in the artifacts are developed.

At the functional layer, designer’s intention representation scheme has been designed in order to transfer it to process designers. Another knowledge representation language for design and manufacturing management has also been developed. A legacy of designs has a lot of design know-how in it. Its explication will contribute to in-depth understanding of design knowledge. A method for extracting a causality network from a design by causality analysis has been designed to achieve the goal. Meaningful subnetworks are elicited from the network to identify know-how for reuse in similar situations by storing them in a case base.

Research on functional ontology for knowledge systematization and redesign support system are summarized as follows: As a fundamental stand point, we decided to adopt a device ontology rather than process ontology. Device ontology has several key concepts which should be investigated in-depth. We extracted basic concepts such as agent, object, goal, behavior, function, etc. and build a network of these concepts. Then, we attacked “method” and “way”. By the former, we mean a sequence of actions to achieve a goal and by the latter, we mean a conceptualization of hidden rationale for justifying the method to work. An example of “way” is “external heat source way” of a heater and that of a “method” for the “way” might be “generate heat and transfer it to the target”. The labels of “way” and “method” might not perfectly appropriate, but we believe the definitions of the two make sense. We built a hierarchy of functional decomposition using “is-achieved-by” relation based on the above idea. Before starting this project, we already had a preliminary functional ontology and a language called FBRL: Function and Behavior Representation Language for representing a functional model grounded on behavior and structural model. In this project, we introduced a new idea of meta-function which is a role of a function to another function, that is, a conceptualization of dependency between functions. We identified several key meta-functions and developed an identification algorithm. As a result, we identified four types of categories of function and designed four taxonomies collectively form a functional ontology.

Another achievement is a redesign system based on knowledge described in terms of functional ontology. Redesign requires in-depth understanding of the artifact given as well as inconvenience to improve. The understanding must be done at the functional level and hence we need well-designed functional concepts provided by functional ontology and the inference mechanisms to properly understand artifacts. After understanding, the system tries to diagnose the artifact with the help of other agents such as qualitative motion simulator and 3D virtual interface to allow designers to virtually use the intermediate product. One of the key issues is how to control the search space for a devising innovative functional structure of the artifact free from the inconvenience. The redesign system has a set of strategies for getting rid of the inconvenience with some heuristics. We also have a plan to reanalyze the knowledge in the [TRIZ 99] to make them operational by introducing functional ontology.

4. The next steps

4.1 Informal assessment

We could summarize that the past two year activities include basic investigation on knowledge systematization, design of the multi-agent architecture in the two dimensional space and prototype development of each agent. As stated above, one of the key technology we employed is ontological engineering for systematization of domain-independent and static knowledge. Under this goal, our results on functional ontology is promising because it suggests us the possibility of building functional understanding system of artifacts. The other important goal is systematization of dynamic knowledge, that is, design process knowledge. For this purpose, the framework we designed is just a first step. We need to make a lot of advancement in this direction. That is, the framework is used as a testbed of the dynamic knowledge systematization. What we need is to provide an ontology for specifying the communication among the agents in the framework which in turn specifies a macroscopic synthesis process performed by collaboration of the agents. The good things of this approach is that the systematized knowledge are evaluated by running the multi-agent system. Such an evaluation is also necessary for static knowledge systematization. In fact, we understand the necessity of implementing systematized knowledge and run a system using the knowledge. This observation suggests us the following research plan:

4.2 Research plan

On the basis of the above observations, we have the following six research objectives for the rest of our project period:

(1) Augmentation and evaluation of the ontologies developed
(2) Development of a collaboration model and ontology
(3) Development of a representation language of the systematized knowledge as well as cases and its use in the multiagent framework
(4) Augmentation of each agent
(5) Systematization of system-view-based knowledge

4.2.1 Knowledge systematization

(1) Augmentation and refinement of the ideas of meta-function and functional decomposition hierarchy based on “way” and “method” and development of a representation language for them
(2) Systematized knowledge representation for a specific task of redesign of a domestic use printer
(3) Development of task ontology and redesign strategy ontology of design tasks considering a design/redesign process as a target
(4) Negotiation ontology design for modeling collaboration by agents

4.2.2 Model of collaborative synthesis by multi-agent

(1) Development of organization of the knowledge for evaluation of design system based on multi-agent.
(2) In order to realize an explicit processing of shared understanding among agents about the world they work, we develop a systematic representation scheme for fundamental knowledge about the physical(real) world.
(3) Modelling of knowledge about collaborative design process, design output, communication, et al. to come up with various quantitative evaluation methods of collaboration.

4.2.3 Case base and case-based reasoning

(1) Case description in terms of vocabulary in the ontology designed.
(2) Development of a causality analysis method cooperating with physical structure management system
(3) Establish case-based method as a complementary way of knowledge systematization.

4.2.4 Development of collaboration framework between design and production planning

(1) Development of a product information model and management system of design process for smooth transfer of the design rationale to the production phase.
(2) Refinement of qualitative motion simulator
(3) Development of a negotiation model between design and manufacturing agents based on process simulation.

4.2.5 Summary

The main efforts should be put on the knowledge systematization through the ontology and system development. This is to be done with the help of all the project participants, rather than individual activities described in the above.

5. Conclusion

We are still in the middle of the five year project. Nevertheless, some of the results look promising. Functional ontology, physical state management system, design rationale representation, case analysis/description based on causality tracing, etc. enable us to realize the collaborative design framework through design knowledge systematization. Our hidden intention includes to materialize the Yoshikawa’s General design theory by introducing ontological engineering. Design knowledge systematization is going to be done for that purpose. Mathematical stuff in the general design theory could be materialized in terms of task ontology and functional ontology together with the multiagent framework.

Our approach is different from conventional design support expert systems in many respects. It employ few heuristics. Most of the knowledge comes from carefully designed ontologies. Most of the search spaces are spanned by the well-designed knowledge specialized to the particular tasks we identified. All the functional concepts are grounded onto the physical states and are nicely constrained by the physical laws. Various major functional modules are built as autonomous agents which are loosely coupled each other to allow maximally flexible collaboration with a powerful negotiation protocol. Thus, the project is expected to produce a milestone of knowledge-intensive design systems with a prototypical knowledge systematization.

Acknowledgments. This research is supported in part by the Japan Society for the Promotion of Science (JSPS-RFTF97P00701).

Reference

[Finin, 94] Finin, T., Fritzson, R., McKay, D., and McEntire, R, “KQML as an Agent Communication Language”, in Proceedings of the Third International Conference on Information and Knowledge Management (CIKM'94), ACM Press, 1994.

[Ikeda 97a] Mitsuru Ikeda, Shogo Go and Riichiro Mizoguchi, Opportunistic Group Formation - A Theory for Intelligent Support in Collaborative learning -, Proc. of Artificial Intelligence in Education, pp.167-174, 1997

[Ikeda 97b] Mitsuru Ikeda, Kazuhisa Seta and Riichiro Mizoguchi, Task Ontology Makes It Easier To Use Authoring Tools, Proc. of IJCAI-97, pp.342-347, 1997

[Mizoguchi 95] Mizoguchi R. and J. Vanwelkenhuysen and M. Ikeda. Task Ontology for Reuse of Problem Solving Knowledge. Building & Knowledge Sharing 1995 (KB&KS'95) (2nd International Conference on Very Large-Scale Knowledge Bases), Enschede, The Netherlands, pp.46-59.

[Mizoguchi 97] R. Mizoguchi and M. Ikeda, Towards Ontology Engineering, Proc. of PACES'97, pp.259-266, 1997

[Sasajima 95] Sasajima, M.; Kitamura, Y.; Ikeda, M.; and Mizoguchi, R. 1995. FBRL: A Function and Behavior Representation Language. In *Proc. of IJCAI-95*, 1830-1836.

[TRIZ 99] Manual of TechOptimizer 3.0J, Invention Machines Corporation, Japan, 1999.

[Yoshikawa 80] Yoshikawa, H., General Design Theory and a CAD System,l In Man-Machine Communication in CAD/CAM -- Proceedings of the IFIP Working Group 5.2-5.3 Working Conference 1980, eds. T.Sata and E. A. Warman, 35-53, 1980.

Research results(English papers only)

[Functional ontology and QR]

Yoshinobu Kitamura and Riichiro Mizoguchi, Meta-Functions of Artifacts, The Thirteenth International Workshop on Qualitative Reasoning (QR-99), Scotland, pp.136-145, June, 1999.

Yoshinobu Kitamura and Riichiro Mizoguchi, An Ontological Analysis of Fault Process and Category of Faults Tenth International Workshop on Principles of Diagnosis (DX-99), Scotland, pp.118-128, June, 1999.

Mizoguchi, R., and Kitamura., Y., Methodology of Collaborative Synthesis by Artificial Intelligence, - An innovative redesign method based on functional understanding -, Proc. of The Third IFIP Working Group 5.2 Workshop on Knowledge Intensive CAD (KIC-3), pp.329-336, Nov. 1998.

Kitamura, Y. et al.: Towards Redesign of Manufacturing Processes based on Functional Understanding, Poster Proceedings of Artificial Intelligence in Design '98, p.14, 1998.

Mizoguchi, R. et al.: Methodology of Collaborative Synthesis by Artificial Intelligence--JSPS Research for the Future Program: Science of Synthesis-- Workshop on the Methodology Emergent synthesis-WMES, (1998), 37-40.

Kitamura, Y. and Mizoguchi, R., Functional Ontology for Functional Understanding, Working Papers of Twelfth International Workshop on Qualitative Reasoning (QR-98), pp.77-87, 1998

Kitamura, Y., Ikeda, M., and Mizoguchi, R., A Causal Time Ontology for Qualitative Reasoning, Proc. of the Fifteenth International Joint Conference on Artificial Intelligence (IJCAI-97), pp.501-506, 1997

Kitamura, Y., Ikeda, M., and Mizoguchi, R., An Ontological Consideration of Causal Time in Qualitative Reasoning Systems, Proc. of The Eleventh International Workshop on Qualitative Reasoning (QR-97), pp.277-285, 1997.

[Cooperation mechanisms of design and production]

E.Arai, K.Shirase, and H.Wakamatsu ; CAD with use of Designers' Intention, Proceedings of The Third IFIP Working Group 5.2 Workshop on Knowledge Intensive CAD, pp21-30, 1998.

Y. Murakami, E. Arai, K. Shirase, H. Wakamatsu, F. Kimura ; Development of CAD System for Die Production of Car Forging Crank-shaft on The Basis of Product Model － Rule Based Die Molding Process, Proc. of the 1998, JAPAN-U.S.A. Symposium on Flexible Automation, pp.701-706, 1998.

K. Shirase, H. Narita, H. Wakamatsu, E. Arai, K. Iwata ; PC Based Virtual Machining Simulator for Autonomous and Intelligent Machine Tool, Proceedings of the 1998 JAPAN-U.S.A. Symposium on Flexible Automation, (1998), pp.1281-1288.

N.Uchiyama, S.Takagi, and E.Arai, A Non-linear Programming Approach to Testing Gravitational Stability of Mechanical Subassemblies, Proc. of the 8th intl. conf. on production engineering, (1997) pp.435-444

E.Arai, K.Shirase, H.Wakamatsu, Y.Murakami, M.Takata, and N.Uchiyama, Role of Production Simulation for Human Oriented Production Systems, Proc. of 14th intl. conf. on production Research, (1997), pp.758-761.

Hidefumi Wakamatsu, Takumi Matsumura, Shinichi Hirai, and Eiji Arai, Dynamic Analysis of Rodlike Object Deformation towards Their Dynamic Manipulation, Proc. of the 1997 IEEE/RSJ International Conference on Intelligent Robots and Systems, (1997), pp.196-201.

[Intelligent information processing platform for collaborative synthesis]

Suppen, N., Onosato, M., and Iwata, K., A Life-Cycle Maintenance Methodology with Environmental, Health and Safety Considerations, Proc. of EcoDesign'99, pp. 875-879, 1999.

Onosato, M., Osaki, S., Nitao, M., Teramoto, K., and Iwata, K., Working in a Digital Factory: Interface between Human and Virtual Manufacturing Systems, Proc. of 31st CIRP Int. Seminar on Manufacturing Systems, pp. 282-287, 1998.

Naka, Y., Onosato, M., Sumioka, S., and Iwata, K., A Modelling Method of Organization-Task-Process Structures for Collaborative Works, Proc. of Int. Conf. on Manufacturing Milestones toward the 21st Century (MM21), pp. 273-278, 1997.

[Knowledge acquisition and utilization in synthesis]

H. Kawakami, O. Katai, N. Fujisawa and T. Konishi, An Agent-based Framework for Supporting Functional Design of Artifacts: Proc. of the 4th World Conf. on Integrated Design & Process Technology, 1999.

Toba, O., Katai, O., Sawaragi, T., and Kawakami, H., Designing Artifacts via Amalgamation of Information principle and Physics, Proc. of 2nd International Conf. on Engineering Design and Automation, 1998.

Kawakami, H., Ikemoto, F. and Konishi, T., An Evolutional Method for Generating Candidates for Conceptual Design of Physical Systems, Proc. of The Australia-Japan Joint Workshop on Intelligent and Evolutionary Systems, pp.120-125, 1997.

Appendix: Project participants

Leader:

Riichiro Mizoguchi
Institute of Scientific and Industrial Research, Osaka University

Core members with research topics:

Collaboration mechanisms of design and production
Eiji Arai, Professor, Graduate School of Engineering, Osaka University

Intelligent information processing platform for cooperative synthesis
Masahiko Onosato, Associate Professor, Graduate School of Engineering
Osaka University

Knowledge acquisition and utilization in synthesis
Tadataka Konishi, Professor, Faculty of Engineering, Okayama University
Kouji Kawakami, Associate Professor, Graduate School of Engineering,
Kyoto University

Knowledge systematization for synthesis
Riichiro Mizoguchi, Professor
Yoshinobu Kitamura, Research Associate
Institute of Scientific and Industrial Research
Osaka University