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Collaborative model-based matching of heterogeneous models

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Abstract—Design of complex systems implies various points of view expressed by stakeholders with different areas of expertise. Each stakeholder describes his model in a Domain Specific Language, according to his point of view. Ensuring the consistency of the global system and building a cross view is a challenging task. It requires the involvement of all stakeholders to produce intermodel correspondences that satisfy their concerns. In this paper, we first introduce a metamodel of collaboration that formalizes collaborative work, then we use this metamodel to define a collaborative process for heterogeneous design models matching. This approach establishes semantic links at metamodel level by following a group decision-making process, then it refines those links semi-automatically at model level by exploiting their semantics.

Keywords—heterogeneity, collaborative matching, correspondence, group decision-making process, semantic link

I. INTRODUCTION

Design of complex systems involves several stakeholders having different expertise. To describe the whole system they produce partial models that are naturally heterogeneous (i.e. conforming to different metamodels) and complementary. To ensure the consistency of the system, various techniques are proposed in the literature such as model matching, mapping or alignment. In this paper, we use the term of matching as defined in [1].

In previous work [2], we proposed a centralized matching approach - performed by a coordinator playing the role of domain expert - to define correspondences between distinct points of view. We experimented it in several case studies [3], [4] and concluded that the domain expert can hardly manage alone the matching process. Indeed, he does not necessarily grasp the real concern of each point of view. The collaboration of the involved stakeholders is therefore a key feature to satisfy the various visions. Hence, in this paper, we present a new matching approach based on a group decision-making process. This approach allows communication and coordination among stakeholders from several business areas in order to establish

semantic links between concepts of their models. For example, in the case of a Conference Management System (see section V), the process model's element "*Task:EditReview*" should be associated to the "*Operation:ReviewPaper*" from the Software Design model with an "*induction*" as type of semantic link.

This paper is structured as follows: section II presents related work, section III summarizes the core of the centralized matching approach previously proposed, section IV introduces our conceptual approach for collaborative matching of models. Section V describes a preliminary application on a Conference management System (CMS) while section VI presents the architecture of our developed tool. A conclusion and an outlook of future work are drawn in section VII.

II. RELATED WORK

As our paper mainly targets the collaborative matching of design models, we discuss below some approaches for both model matching and collaborative work formalization.

A. Model Matching

We do not consider approaches for physical composition of models, since they deal only with models having common (or related) metamodels. Moreover, we focus on establishing rich semantic links (not only similarity or equivalence). Hence, next we present three representative approaches.

Openflexo [5] federates models coming from different technical spaces (EMF, OWL, XLS) into the same conceptual space realized as a virtual view. Until now, there is no dedicated language to define relationships. So it is almost always done manually by a tooling expert which may be error-prone and time consuming in case of large systems.

Bräuer [6] defines a semantic model connector that creates semantic links between different domain-specific models using an ontologic knowledge base. Relationships are defined at the level of this ontology, then they are propagated to the

metamodel and model levels. This approach supports a limited set of semantic relationships and it has no supporting tool.

EMF Views [7] allows to build a view on a set of interrelated heterogeneous models using various types of link. However, this view is read-only.

Collaborative matching approaches mainly concern ontologies matching and thus establish primarily similarity links [8], [9]. Since we already have a centralized matching approach, we outline in the next subsection, some approaches that formalize collaborative work in order to ensure the transition from the centralized approach to a collaborative one.

B. Collaboration modeling

Collaboration modeling includes both communication flows and tasks sequencing as described in [10], [11]. As a collaborative process comprises tasks where stakeholders take initiatives or suggest modifications, it should offer a group decision-making procedure allowing contributors to raise issues, provide details and take decisions.

Collaboro [12] proposes a decision-making metamodel that describes the building of group consensus around a proposal. It allows representing both static (e.g. change proposals) and dynamic (e.g. voting) aspects of collaboration. Compared to our objectives, this metamodel offers only a consensus-based group decision-making policy.

Molina et al. [13] define a metamodel that, in addition to static collaboration aspects, represents concepts describing users interactions and group awareness. However, this metamodel does not support the group decision-making process.

Other approaches propose some trust-based decision-making models [14], [15] but we currently omit the question of trust as we consider that stakeholders have levels of expertise known in advance and that no one intends to harm the collaborative matching.

To sum up this overview of related work, we note that most matching approaches only consider a limited set of links with frozen semantics. Besides, rich semantic links definition requires domain specialized knowledge so it is often a manual task that entirely falls on the domain expert. This can be a complex and tedious task, even for a small system: an expert can hardly grasp the concerns of all the partial models. So, it is necessary to involve their designers.

III. OUR PREVIOUS WORK

As a response to the model matching issues highlighted above, we have proposed a centralized matching approach that establishes semantic links among partial models.

El Hamlaoui et al. have proposed a **metamodel of correspondences (MMC)** [2] that describes correspondences among heterogeneous (meta) models. Each correspondence links at least two referenced (meta) elements by a relationship of type **DIR (Domain Independent Relationship)** or **DSR (Domain Specific Relationship)**. **DIRs** represent relationships that are common to all application domains (namely *Similarity*, *Aggregation*, *Dependency and Generalization*), while **DSRs** are relationships valid for a particular area. We distinguish

two levels of correspondence: **meta-correspondences (MCs)** between metamodels elements and **correspondences** between models elements. For each relationship, a semantic expression is proposed to verify whether a set of elements may or may not be linked through the given relationship.

Model matching in this centralized approach is performed solely by a domain expert using a dedicated tool called *HMCS (Heterogeneous Matching and Consistency management Suite)*. As prerequisites, the expert is supposed to be familiar with the features of each partial model and able to define links at metamodel level. The HMCS tool reproduces HLCs automatically at model level, then it keeps only LLCs that satisfy the semantics associated to their relationships. As mentioned in the introduction, it is challenging for one person to apply this approach especially when dealing with large systems, and the expert may need help from the partial models designers.

IV. COLLABORATIVE CONCEPTUAL MATCHING APPROACH

In this section, we present a Metamodel of Collaboration (section A) and a collaborative matching process that instantiates the proposed metamodel (section B).

A. Metamodel of Collaboration (MMCollab)

MMCollab, the Metamodel of collaboration, defines concepts needed in each collaborative session as illustrated in Fig. 1. This metamodel may be used in several application domains where a stakeholder initiates proposals and other contributors have to evaluate them and come to a group decision-making.

The **Collaboration** concept is the focal point of this metamodel. It is a specialization of the concept **Activity** of SPEM (Software & Systems Process Engineering Metamodel). A **Collaboration** is therefore a collaborative activity that implies a *moderator* and a set of *involvedUsers*. It is composed of a set of **Proposals** that may be composite or elementary. A composite proposal gathers a set of elementary proposals. Each proposal comes from a user (*initiator*) and may have associated **Solutions** and **Comments** that are provided by other users. A proposal may be in conflict with other ones. The *moderator* of the collaboration chooses the **DecisionPolicy** to be adopted in the session in terms of involved users (a democratic strategy in which all stakeholders participate, or a delegated one where only a subset of them participate), type of approval (building a consensus or performing a vote) and weighting factors associated to each user. The **SelectedSolution** is chosen according to the **DecisionPolicy** adopted and users evaluation. A proposal may produce or consume **CollaborativeWorkProduct(s)** while the **SelectedSolution** modifies those latter to take into account the group's decision.

Notice that MMCollab is inspired by Collaboro [16] for the change proposal part, but supports other common decision-making policies in order to meet various situations.

B. Collaborative Matching Process

We have instantiated MMCollab and defined a process for the collaborative matching session. Each team of designers

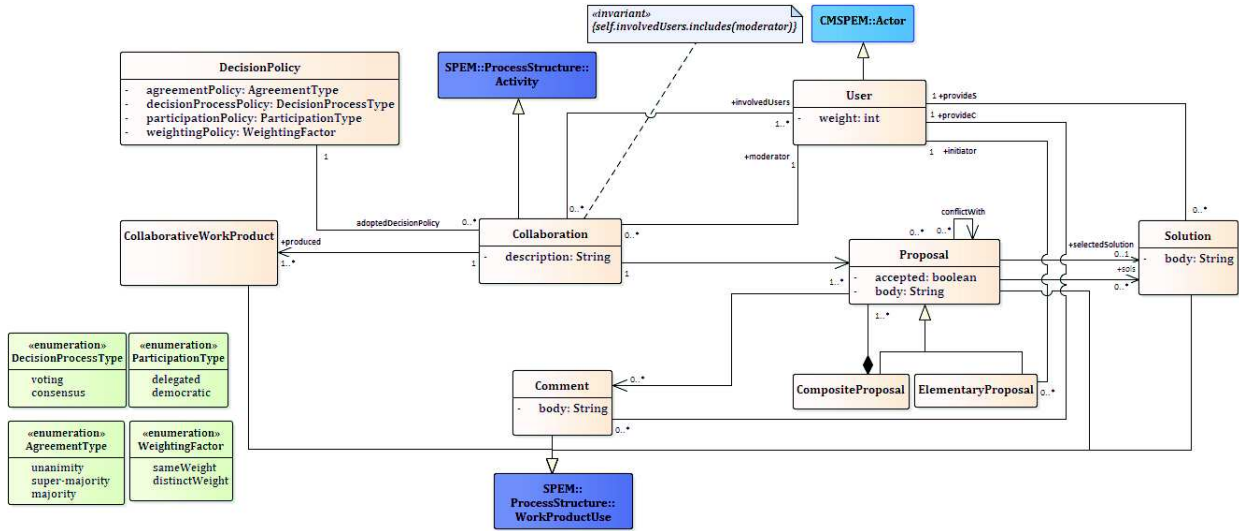


Fig. 1. MetaModel of Collaboration (MMCollab).

designates a **Local Coordinator** (LC) who will participate in this process. The session **moderator** is chosen by LCs via consensus. This collaborative matching process involves also a **semantics expert** who defines the semantics of newly added DSRs.

Proposals, in this context, consist in DSRs and meta-correspondences definition. For each collaborative activity, the moderator chooses the DecisionPolicy to be adopted. According to this DecisionPolicy, a proposal may be seen as (1) an individual action which is then evaluated collaboratively in case of a voting policy or (2) a collaborative action where a stakeholder initiates a change and the others refine it by brainstorming to build a consensus.

Fig. 2 illustrates our collaborative matching process. It produces a model of correspondences (MIC) between elements of heterogeneous models through four main activities. In this global workflow diagram, we show the main Collaborative-Workproducts produced and consumed by each activity, and engaged actors. Next, we detail these four activities.

1) Activity 1- Verify MMC Adequation:

The local coordinators of the system's points of view verify individually the adequation of the generic MMC to the studied application domain.

2) Activity 2- Extend MMC:

If the generic MMC is not enough to describe possible correspondences for the studied domain, its specific part (DSRs) is specialized according to the adopted DecisionPolicy. Local coordinators propose relationships specific to this studied system. Once a relationship has been proposed and validated, its semantics is implemented by the semantics expert in case a formal semantic expression could be associated to it.

3) Activity 3- Produce M2C:

Each local coordinator (LC) may propose potential meta-correspondences (MCs) that involve meta-elements of his metamodel. Using MMC and the business domains metamod-

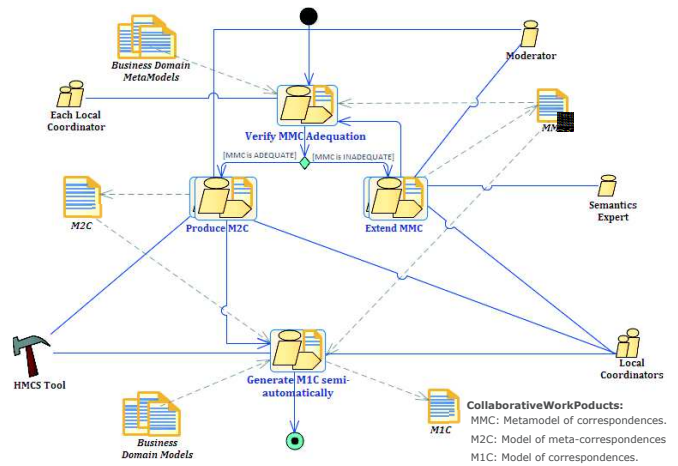


Fig. 2. Collaborative matching process.

els, he specifies the meta-element(s) involved in the meta-correspondence (meta-elements from his metamodel and the other ones) and the type of relationship that links them. Once these MCs are validated by the other involved LCs by vote or consensus, the HMCS Tool combine these evaluations to generate Model of Correspondences between Meta-elements (M2C). Fig. 3 shows the diagram of this activity. It contains 2 specific types of CollaborativeWorkProduct (the one with index *P* designates the list of proposed MCs while the one with index *S* designates the result of these proposals' evaluation).

4) Activity 4- Produce MIC:

HMCS tool produces automatically MIC by propagating meta-correspondences to models level. It generates for each meta-correspondence, the Cartesian product of instances of meta-elements involved in it. Then, it only keeps correspondences that respect the semantics associated to their relationships.

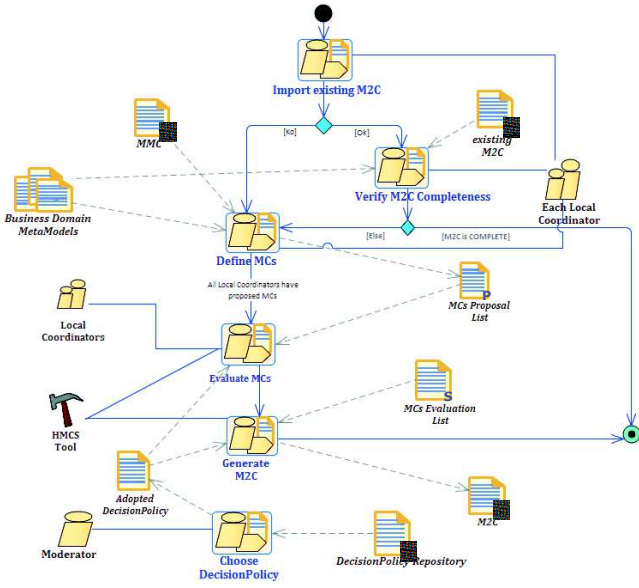


Fig. 3. Detailed activity diagram of Produce M2C.

V. APPLICATION EXAMPLE

A. Presentation of the case study: CMS

We illustrate our approach on a Conference Management System (CMS) as it is a well-known system. The design of this system involves stakeholders from different business areas. We assume that 3 partial models have been built by separate teams (groups of PhD students). These models are heterogeneous in the sense that they conform to different metamodels covering 3 business domains: Software design, Processes and Data Persistence. The 3 partial models are:

- Software Design (SD) model: represents classes, their attributes and methods;
- Business Process (BP) model: describes roles, activities and products;
- Persistence (PS) model: describes a relational database with tables for data storage.

Each team of designers delegate the matching task to one local coordinator. **LC1**, **LC2** and **LC3** refer respectively to SD, BP and PS models local coordinators. Fig. 4 presents an extract of these models (see [16] for more details).

B. Collaborative Matching Process applied to CMS

Fig. 5 shows the stakeholders involved in the matching process of the CMS, their respective models and metamodels.

1) Extend MMC for CMS:

The three local coordinators individually verified the generic MMC adequation. They founded it incomplete. So, they agree (brainstorming) in adding two DSRs, namely "deduction" and "induction". The first one expresses the process of deducing a concept from another, while the second one indicates the action of implicating something.

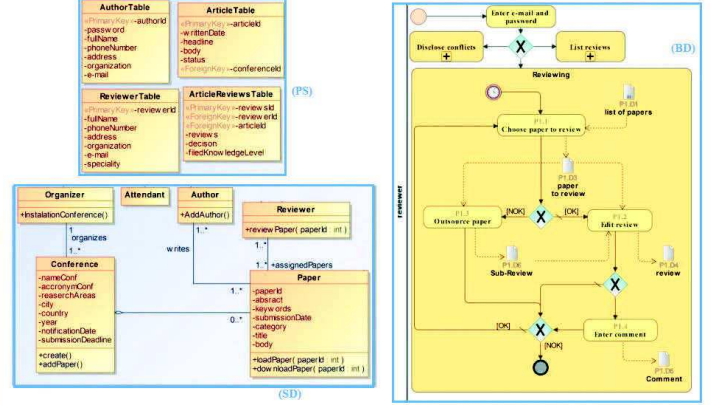


Fig. 4. Extract of the three partial models.

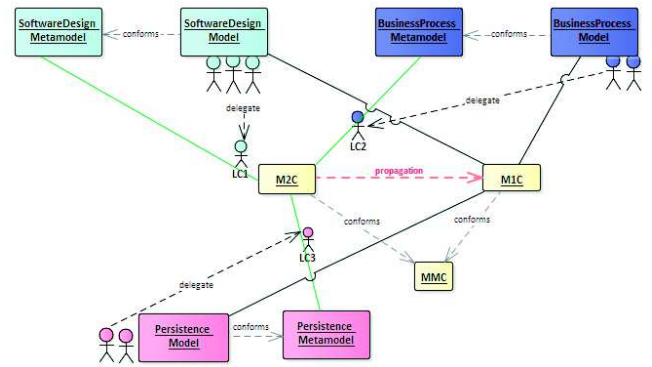


Fig. 5. Overview of CMS models, metamodels and matching enactment.

Parallel to that, the semantics expert implements the semantics of the *induction* and *deduction* relationships on the HMCS tool using internal relationships from some knowledge bases (Wordnet [17] and ConceptNet [18]).

2) Produce M2C for CMS:

Using the 6 relationships of MMC (*Similarity*, *Aggregation*, *Dependency*, *Generalization*, *Induction*, *Deduction*), the 3 LCs define meta-correspondences (MCs). In this activity, a majority-based voting policy was adopted to validate the proposed MCs where voters have the same weighting coefficient.

Fig. 6 summarizes the validated MCs. We adopt the notation *Metamodel : metaElement* to identify a concept. For example *PS : Column* refers to the meta-element *Column* from the *Persistence* metamodel (PS). The first 3 MCs were proposed by LC1, the 7th one by LC3 and the rest by LC2.

From a *PS : Column*, we can deduce the value of a *SD : Property*. *PS : Table* is similar to *SD : Entity* and *SD : StereotypedEntity*. A *BP : Task* implicates several *SD : Operation*, thus they are linked through an Induction link. This link also applies between *SD : Property* and *BP : Task*. Designers have proposed other MCs, but they haven't been validated, for example the proposed meta-correspondence (Induction, *BP : Process*, *SD : Operation*) has been rejected because it is less expressive than the 5th MC

which directly links operations to their associated task.

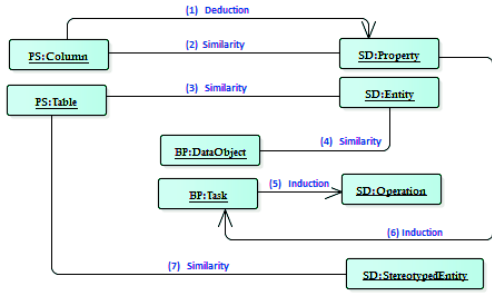


Fig. 6. M2C of the CMS.

3) Produce MIC for CMS:

First, HMCS tool reproduces each meta-correspondence to the model level. From the 7 MCs previously described, it generates 1393 correspondences. Next, a refining is automatically performed to keep only correspondences that satisfy the semantics of their relationship. For example, the propagation of MC2 (Similarity, $PS : Column, SD : Property$) to the model level produces 528 correspondences. We cite 2 of them (Similarity, $PS : phoneNumber, SD : phone$) and (Similarity, $PS : e-mail, SD : phone$). To verify the accuracy of each correspondence, HMCS tool applies the semantics of *Similarity* to each pair of concepts and keeps only 21 correspondences concerning MC2 (15 correct and 6 false positives).

4) Evaluation:

In a centralized matching, it is too cumbersome for one person to come up with a correct alignment between several metamodels. In fact, this person has to deal with various points of view that he is not necessarily familiar with. Whereas in a collaborative matching, local coordinators focus on defining meta-correspondences that involve concept(s) from their meta-models which ensures that: (1) each person has to do a very small amount of work, (2) each person can improve on what has been done by others.

To validate the contribution of our approach, 2 evaluations are necessary: (1) collaboration efficiency and (2) accuracy of matching in terms of semantics. In terms of collaboration efficiency, the PhD-students expressed their satisfaction with the results of the collaborative matching and the ease of the task compared to dealing with the whole matching process individually. However, we could not provide metric evaluation for the collaboration in this paper since the collaborative module is not completely implemented. For the evaluation of the accuracy of the relationships semantics, local coordinators checked manually the produced MIC. LC1, LC2 and LC3 checked the 48 correspondences kept after the refinement step. As in this example, there is only binary correspondences, if a LC considers a correspondence incorrect, he notifies the other concerned LC and they both build a consensus. Fig. 7 shows the MIC produced for the CMS and Table I evaluates the tool performance in terms of precision, recall and f-measure of each relationship. The *precision* metric is the ratio of

correct correspondences retained (by the tool) over the total number of retained correspondences. The *recall* presents the ratio of correct retained correspondences over the number of correspondences validated by the local coordinators, and the *f-measure* is the harmonic mean of precision and recall.

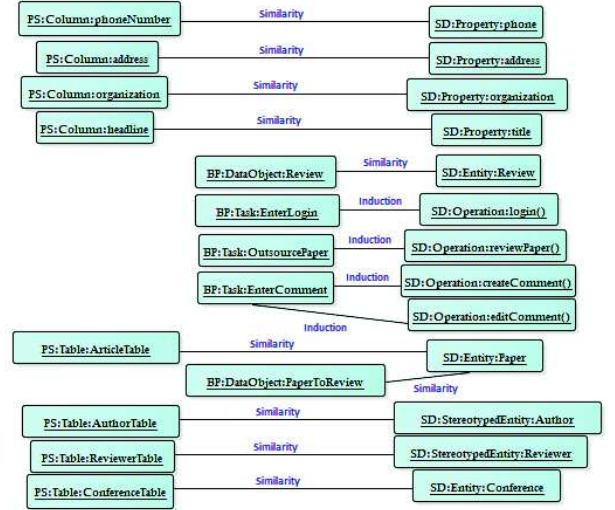


Fig. 7. MIC of the CMS.

TABLE I
METRIC EVALUATION OF THE CMS CASE STUDY

| Relationship | Precision | Recall | F-measure |
|--------------|-----------|--------|-----------|
| Similarity | 0.86 | 0.75 | 0.8 |
| Induction | 0.77 | 0.91 | 0.83 |
| Deduction | 0.33 | 1 | 0.5 |

VI. OVERVIEW OF HMCS TOOL

HMCS tool lies on 5 complementary modules to support collaborative alignment of models:

- Matching Tool (MT): performs model matching via two sub-modules: (1) Assisted Matching Tool (AMT) that allows designers to perform M2C creation and (2) Refining Tool (RT) which reproduces meta-correspondences to models level (Cartesian product of instances of meta-elements involved in a meta-correspondence), then filters them thanks to the semantics of their relationships;
- Consistency Management Tool (CMT): ensures the consistency of model of correspondences in case of partial models evolution;
- Collaboration Tool (CollabT): ensures collaboration mechanisms (e.g. communication, group management and group-awareness);
- Decision Management Tool (DMT): contains a set of decision-making policies and the implementation of their selection process. This module and CollabT are invoked by both MT and CMT;
- Transformation Tool (TT): supports two kinds of transformation: Model to Text (M2T) and Text to Model (T2M).

The HMCS architecture is an Eclipse Platform add-on that uses several frameworks as illustrated in Fig. 8. Based on the Eclipse Modeling Framework (EMF) components, models are stored and maintained in a central model repository. EMFCollab let multiple users edit a single EMF model concurrently. Eclipse Communication Framework (ECF) provides an abstract communication layer and some of the most common collaborative features, either in terms of API or visual components, such as shared object, presence and chat. KOMMA is a framework based on the technologies of semantic web that helps managing and editing RDF and OWL data. TwoUse bridges the gap between semantic web and Model Driven Software Development by developing ontology-based software models and model-based OWL ontologies. Some bricks of the tool are already in place (matching tool) and our work is going ahead on both the collaborative part and the definition of the semantics of a larger number of relationships.

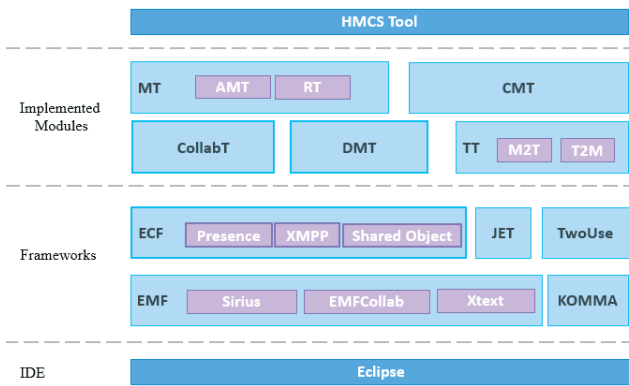


Fig. 8. HMCS tool architecture (collaboration concepts' are embolden).

VII. CONCLUSION

This paper presents a generic metamodel that provides a holistic support for collaboration by combining both static and dynamic aspects of collaborative work. It proposes various policies to manage group decision-making and may be extended regarding the context requirements (application domains, collaboration policies, etc.). We applied this metamodel to the issue of collaborative matching of heterogeneous design models. The main advantages of our collaborative matching process are (1) producing a customized model of correspondences (MIC) that satisfies involved stakeholders, and (2) concentrating human efforts at metamodel level instead of model level since there are fewer concepts to handle. Notice that this process requires a basic background knowledge in meta-modeling.

As a logical follow-up, to have a complete collaborative alignment process for heterogeneous models, we will manage the consistency of correspondences model in case of partial models evolution. We also intend to finalize the implementation of the HMCS tool in terms of collaborative aspects, graphical visualization of models and definition of additional

semantic links. Endly, we plan to apply this approach to large mechatronic systems to ensure the HMCS tool scalability and validate the effective contribution of the collaborative matching by using cognitive and non-cognitive metrics (e.g. team efficiency, team behavior, required time, human effort, team satisfaction, etc.).

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