Learning Construction Decision Making with Arbitrator - Competing and Evolving in Dynamic Role Interplay

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ABSTRACT: Among construction process, decision making is often depended on different construction methods invoked within different events occurred. The re-action sequence is hard to predicate and hard to reproduce in different situations, also. For resolving this problem, we adopt a model called Dynamic Role Interplay Process (DRI). Based on the mechanism of DIM (Dynamic Idea Map) (Lai and Chang 2005), competing learning and evolving learning between different roles, and then the knowledge within roles will involve evolving learning. We adopt learning metaphors in design sequence generations. Competing among design events and concepts are treated as the agents who are competing for surviving in the sense of genetic programming. And Roles start to evolve to different knowledge or preserving the core ontology of design for the evolving learning concept. Each process follows the metaphor of natural selection and design problem solving paradigms in design domain. A simulation agent-based system is implemented in CELA.

1 INTRODUCTION

1.1 Construction decision making

A successful construction process depends on satisfaction on many different and often conflict problems. Many researches have addressed this problem with management approach. However, since situations change dynamically and unexpected sometime within minutes, a total solution or simulation for construction decision making is not even possible. Therefore, for addressing this issue, we re-frame the decision-making process differently by viewing every decision-made is a different situation. Then, the transaction between different situations might show some insights for a closer simulation in construction process. Therefore, we will focus on the interaction between different solutions and their reactions. In addition, the decision mentioned here is regarded as an idea (or a construction concept) for solving a particular construction problem brought up by certain situations before.

Regardless of the practical factors of construction process, it is a process that contains many inter-connected distributed situations. Each situation has its own participants and triggers for another different situation. For our simplified purpose, we use a concept called *role-play* (Chang 2004, Chang and Lai 2004) for modeling such distributed inter-connected situations in the construction process. Such process is called *interplays*.

With this approach, construction decision-making is treated as different roles such as client or construction manager played by different actors to achieve a common agreement (construction decision) with different interplays.

1.2 Learning construction decision making

With the views above, we go further address one of key issue in making the simulation more closer to the chaotic reality of construction process—learning. With learning capability, the simulation for challenging the situated interaction among decision factors can be varied from time to time. As declared before, the situations of construction process cannot be analyzed full due to its characteristics. In addition, most of analysis is fixed, then, the resolution has to be discovered before the simulation. However, with some learning capabilities, the interplay can be more dynamic and vivid. This resolves the problem for supporting more distributed interplay situations.

1.3 Competing and Evolving Learning Decision

Among the learning, we discover two main metaphors: competing and evolving such that the domain knowledge of each role can be evolved or competed within the interplay process. Therefore, these learning processes or behaviors frame the possible solutions: *competing learning* and *evolving learning*. Through competing learning between different roles, and then the knowledge within roles will invoke evolution in its own knowledge bases. These two types of learning provide interesting insights for understanding the knowledge among the construction process in this paper.

For computational purposes, agent technology will work in coordination with a role-play like agent framework called *dynamic idea maps* (DIM) (Lai and Chang 2004). Each role has its functionalities and skillful knowledge to accomplish construction decision-making in different situations. In addition, DIM is used for representing the inter-connected structure of construction concepts described above.

1.4 The battle concept in competing-like behavior with construction decision making

For searching for suitable metaphor in framing our agent learning behaviors, we discover that "compete" is often used for describing the conflict and learning process during decision-making process. For example, while facing a particular design issue, design concepts are either competing with others for wining a particular design issue or the design concepts will be elaborated by others *better* concepts. Such design phenomenon that unleash in ideas association can be treated as the inter-connecting mechanism used for competing and invoking. Furthermore, the "battle" concept is the central concept for constructing our competing-like behaviors.

The observation we have is that competing among design concepts is treated as survival in the sense of genetic programming and the metaphor of design field. In addition, the battle concept uncovers the designers' mental reactions and physical behaviors during the interplay process. Practically, when dealing with certain construction problems, many design concepts battle with each other for wining the chance to solve current construction problem. The better or winner of battle will be adopt and further trigger another different battles. The capabilities of each role will be improved while learning from the winner or the "better" colleagues. This concept forms the basic behavior of our simulation.

1.5 Approach: arbitrator

To fulfill the battle among decision concepts, we use a special role called *arbitrator*. The construction concept for using arbitrator is to make the decision-making process clearer in the sense of battle or competing. No matter how complicate a competing process is, when it comes to decision: who is the winner, there must have a role that can judge the winning criteria or the comparison between two knowledge bases. The mechanisms and technology supports of Arbitrator concepts will be introduced in section 2.4 and the following sections.

With role-play, construction decision-making can be described as two set of roles: 1) the main controlling roles (DA in the sense of DIM): server, construction architect and 2) participating roles (the UA in DIM): construction manager, contractor and construction worker. With participating roles involved in the competing process, the construction concepts can be done via agent learning which needs a distributed computing environment and computational mechanism.

Following these concepts, a Competing and Evolving Learning Arena (CELA) within a distributed role-interplay environment is developed and tested in this paper.

2 BACKGROUND AND SUPPORT

2.1 Dynamic Idea Maps (DIM)

DIM originally is case-based reasoning framework for supporting idea association in the early conceptual design stage (Lai 2004). Furthermore, Lai and Chang (2005) integrate DIM with Dynamic Agent Role Interplay System (DARIS) for implementing distributed interactions of *linking* ideas in the process of idea association. Inspired from the mechanism of Acting Role Model (ARM) proposed by Chang (2004), DARIS is an agent-based system for implementing distributed interactions in a multi-designers collaboration environment. In DARIS, there are dynamic interactions through five different agent entities including the user agent (UA), the role agent (RA), the director agent (DA), the stage agent (StA) and the scene agent (ScA) within the three system layers.

Besides, DIM provides four components to integrate the mechanisms of various agents within DARIS. For linking ideas in the conceptual design stage, *knowledge representation* represents design ideas and memory organization within agents'. *Linking principles* provide the capability to allow agents to associate diverse ideas differently. Through *dynamic linking process* (or simply *linking process*) in the internal and external interplay, agents can dynamically interact various design situations. Finally, agents can engage in *linking interactions* for learning through competing and evolving. The details are described as follows:

1) Knowledge representation: In DIM, ICF schemata proposed by (Oxman, 1994) mainly represent design knowledge within RAs' long-term memory. Through integrating the three principles of idea association, each RA's design knowledge includes a set of maps: an ICF map for installing various idea entities and three knowledge maps functioned as dictionary. They are issue map, concept map and form map.

2) Linking principles: three linking principles provide RAs' reasoning behaviors to link idea entities. The three linking principles are similarity, contrast and contiguity (Lai, 2004). Based on the ICF knowledge representation, each principle has an individual mechanism for textual matching to link dynamic idea entities within various RAs' ICF maps.
3) Linking process: according to different design situation within the distributed interactions, the linking process provides various agents' communication methods in two interplays: internal interplay and external interplay. Besides, these agents can dynamically interplay each other through different communication network topologies (including ring, peer to peer, star and cluster) based on the mechanisms of agent communication language (ACL) (Lai et al. 2005).
4) Linking interactions: linking interaction is a learning process among agents in DIM. Basically, there are two types of learning: competing and evolving. Competing among design ideas are treated as the agents (such as RAs) who are competing for surviving in the linking process. Furthermore, agents and ideas start to evolve to different knowledge or preserving the core ontology of design in the evolving process.

2.2 *Agent learning using competing and evolving metaphors*

Idea association can be considered as an ideas generation behaviors according to their individual long-term memory, as well as the knowledge from different participants (Osborn 1963). The purpose is to produce diverse design ideas that can serve as leads to development of possible design alternatives (Petrovic 1997). For making decision about selecting ideas (or concepts) in the process of idea association, participants always compete each other, and then the knowledge within the participants will involve evolving learning.

Basically, there are different computational mechanisms can handle decisions making problems, like if-then hierarchy (Jackson 1999), statistical optimization (Radford 1988) etc. However, these computational mechanisms can't effectively provide such learning support in the distributed collaboration environment. It is towards a real-time and automatic communication for supporting construction-decision-making.

Considerate with multi-agents system, the agent reinforcement-learning domain acknowledge can provide a suitable living environment and construct the agent framework of sequence or procedure during deign domain representation. As borrowed from GA (Genetic Algorithm) (Coley 1999), we adapt the metaphors of competing and evolving as well as mutation requirements in design generations. In addition, within the agent learning environment, Q-learning (Clausen and Wechsler 2000), learning rate concepts and WoLF-based learning algorithm (Bowling and Veloso 2002), have explored the possibility to allow learning occurred outside of self-knowledge (non-self-play). These form the base of our learning theory.

Based on the mechanisms of DIM, competing is learning about what RAs can survive and evolving is learning about the mutation of RAs' knowledge including RAs' skill learning and idea entity linking learning within the ICF maps.

2.3 *How we approach*

Finally, this paper follows four steps to investigate the competing and evolving in dynamic role interplay. The purpose is to develop a computational learning mechanism for decision making in the early conceptual design stage. These steps are 1) building learning mechanisms through competing and evolving among various agents, 2) constructing computational learning strategies and methods, 3) implementing the learning strategies and methods and 4) simulating an example to investigate the computational feasibility of the competing and evolving learning mechanisms for decision making. These steps are described in the following sections.

3 THE ARBITRATOR

Following the arbitrator concept, we construct an *arbitrator* to operate and manipulate construction concepts in construction decision-making of design domain knowledge representation. The arbitrator is comprised of five components: preferences training for search, competing method, evolution operators, learning strategies and selections procedures. One implementation of arbitrator (CELA) is shown in session 5.

3.1 *Preferences training and search*

The main purpose of training is to increase the alternative solutions in the same construction problems (ScA). The UAs (users) continuously construct the links of construction concepts when they are in dynamic interplays hosted by the DA to solve a particular construction problem in the same ScA. From the DIM, idea preferences adopt three principles of idea association: (1) Similarity; (2) Contrast; (3) Contiguity to build the ideas relationship links. The user (UA) will use these preferences to play. As ideas (construction concepts) link with preferences increase more and more in the same ScA, the construction problems will find more suitable solutions and RA's skills is improved in the meantime.

According to the results of learning practical process from dynamic decision-making association, arbitrator will collect interplay *degree* (details will be described in section 3.3) and construction concepts *links*. These variable obtainments have the effects upon construction resolutions because arbitrator trains the knowledge representation for outcomes which base on these. In the view of increased construction concepts, suitable construction references are getting more and clearer.

3.2 Search for preferences training

When one UA process learning procedure, arbitrator will search the RA's skill in the same ScA with the interactive UAs by the preference and continue following procedures. We adopt the lexical keywords comparison kind approach for the foundation of search to find the skills (construction solutions) which have the relationship of select preference or the focus on the specific ScA.

RA's skills described by ICF maps characterizations are represented by keywords in the system. One idea entity (thus the construction concept) is formed by three main keywords following the ICF maps and their each material, like text or photos, will improve the understanding ability to each UA. The information data model will be elaborated in section 4.1.

3.3 Arbitrator with battle concept

Since there are five agents in DIM to process interplay, the arbitrator is also a specialized agent on competing leaning and evolving learning purpose. Arbitrator, the agent, starts by these two types of learning procedures. And, arbitrator agent will be suspended and wait while the learning procedures are not invoked.

Competing environment which bases on battle concept is via agent acts to advance evolving learning and other procedures. Distributed agents system has the possibilities in a whole unbounded field for competing environment where RAs-RAs (many-to-many) using their skills to compete. It looks chaotic indeed, like the battle in Rome arena, slaughters and kills keep going and going. At final, some survivals will stand in the arena. That presents the survivals with the superiority to survive.

In CELA, the arbitrator simply plays a judgment agent. That is to say, arbitrator in CELA will not participate in the competing but take determinations and manipulate the learning process instead. In addition, we will only focus on one-to-one battle with its simplest representation. However, the complex battle matches such as RAs-RAs (many-to-many) can be represented is by the combination of one-to-one RA-RA (1-1) competing process.

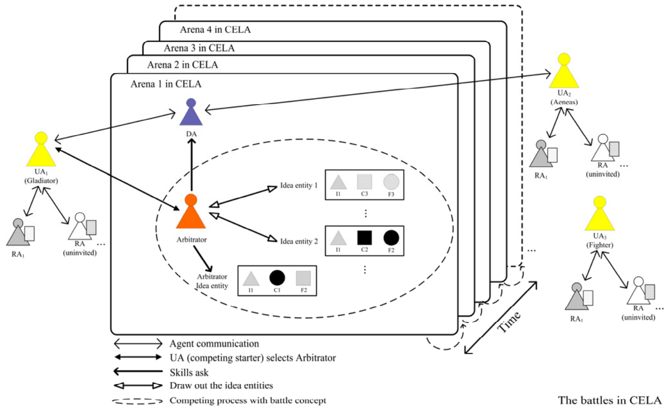

Figure 1. Arbitrator with battle concept

In the agents battle view:

1) One UA starts the competing process.
2) The arbitrator is selected.
3) Arbitrator takes one RA's ideas entity (construction concept) from UA and one *RA's concepts* from the other *UA*.
4) The two idea entities enter the competing arena.
5) Arbitrator continues other processes.

This will show in Figure 1. (Selections mechanisms will describe in the following sections.) The performance of arbitrator agent performance will be realized in the system. According to the preferences selections and degrees form ideas linking. Arbitrator will determine wining construction concepts. But the arbitrator gives only suggestions not the decision itself. The final decisions are still decided by the human.

3.4 Evolution operators

The main evolution operator is based on the *degree* concept. Degree represents the variable values associated with ideas linking preference, solving in the same design issues and design requests of construction problems. Arbitrator itself will only include one single idea entity to be the decision reference.

The arbitrator takes the preference, two idea entities, and then advances to search the degree of two idea entities to judge which one is better and suitable on the moment (1-1, RA-RA). This will further decide the winner for survival in the match of arena within a particular design issue. Image that, each RA-RA competition needs some way of judgment, even the RAs-RAs.

Therefore, the win or lose should be decided by an authorized third agent, here is the arbitrator standing for with the help of degree. With degrees modifies and promotes the evolving learning gets more construction concepts inspirations and increases the RA's skills in the same construction design problems. The range of degree variable will describe in section 4.1 and the modification of degree is using computational programming to attend the purpose.

3.5 *Evolution procedures*

How the degree be modified? Since the RAs' battle in the distributed agent system is chaotic, but the evolution procedures can be discussed in the well arrangement and concentrate on arbitrator who modifies the degree in evolution procedures and base on the competing starter's (one UA's) preference. The winning ideas entity increase value will under the arbitrator degree.

The degree modifications are illustrated with the condition of RA-RA (1-1) match and have three different statuses:

1) RA_1 lose, RA_2 win. The wining idea entity from RA_2 immigrates to RA_1, and the degree of wining ideas entity is increase.
2) RA_1 win, RA_2 lose. Arbitrator continues the next ideas entities competition and sends the RA_1's winning ideas entity to RA_2. The yes or no acceptance is decided by RA_2.
3) The ideas entities of RA_1 and RA_2 are equal, no win and lose with the same degree. It seems a little weird here, but in design domain, their will have the close-fought ideas which means not the best and top resolutions exists but the suitable or better ideas can survival. Arbitrator pushes out two ideas entities in this round and continues the next competition.

These will show in the figure 2.

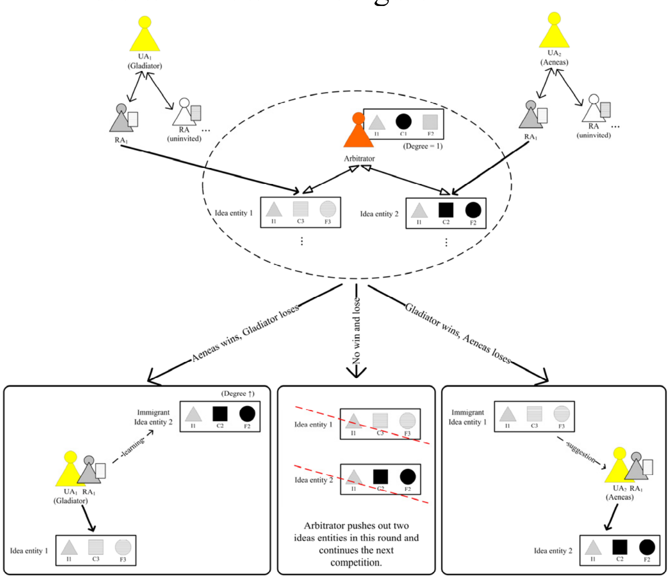

Figure 2. Arbitrator modifies the degree in evolution procedures during interactive interplay.

3.6 *Learning strategies*

The arbitrator handles the learning strategies following the arena environment with design domain. There are two parts of learning strategies and will show in the figure 3:

1) UA ideas linking preference learning: The Arbitrator searches the construction concepts by three preferences. The unsuitable findings will have large amounts in the beginning of learning, but after the competing and evolving repeat in the same design issues, arbitrator can make the linking more direct into the suitable solutions and gives the suggestions to UAs.
2) RA ICF skills learning: If the immigrants ideas entities survive on the lose RA, the concept map and form map can let the lose RA to learn new skills in the same issues maps. In the view of evolving programming approach, the learning metaphors show the need of representation hierarchies. RA learning the new skills is through the outcomes of preferences and learning or not is decided by the UA.

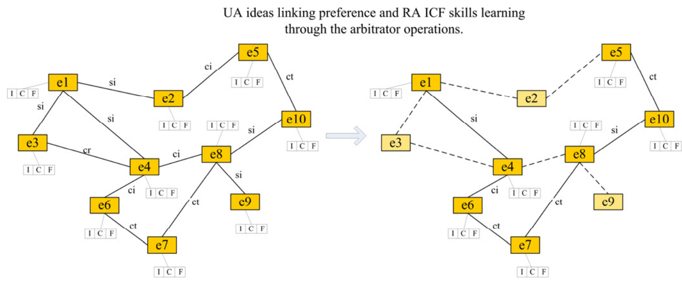

Figure 3. The RA's skills learning procedure are companied with the goal satisfaction learning strategy in arbitrator theory.

3.7 *Selection procedures*

With the learning strategies described above, selection procedures are the procedure to decide who the winner within the battles is. There are three selections: (1) human selection: Basically UA is selecting the winner with personal preferences, the results will be recorded to influence further learning; (2) natural selection: UA expresses the preferences via controlling strategies and allows system to decide who is the winner respectively; (3) Agent-auto selection: through the automatic mechanism, system will decide who is the winner and start the learning process automatically. These three selection procedures will show in the Figure 4.

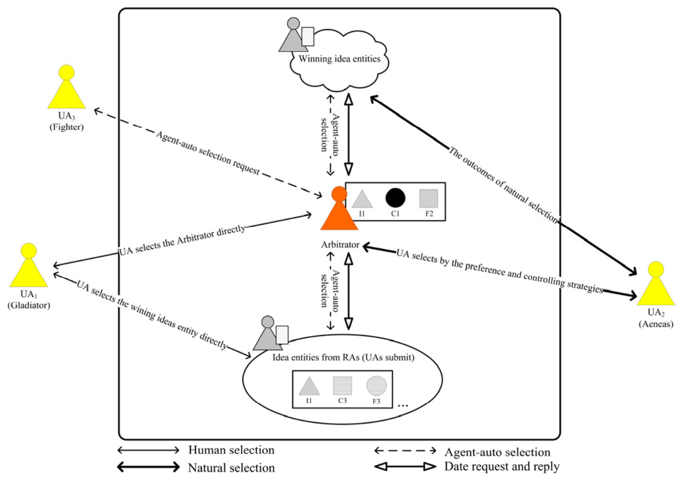

Figure 4. Three selection procedures with the arbitrator.

4 LEARNING WITH ARBITRATORS

Base on the reinforcement learning in multi-agents environment and programming foundations, we construct an arbitrator theory to operate and manipulate construction concepts in construct decisions making of design domain knowledge representation. The arbitrator theory is composed by five components: preferences training for search, competing method, evolution operators, learning strategies and selections procedure. Arbitrator surrounds in the battle environment in CELA with judgment property.

4.1 The information data model

The ideas entities structure from ICF concept and ARM recognition theory for learning construction decision making and competing will show in figure 5. There will be focus on the I-Maps, C-Maps, F-Maps and it depends on the needs, even the entire ICF Map can be chosen to manipulate by agent environment. The ICF maps perform the RA's skills for the construction resolutions of constructors. The slots prepare to remain link references for further idea links inform and reply purpose. Idea links have the graph structures attributes alike in data structure. The main achievement of idea links perform is the links to I, C, and F Maps with the degree of ideas linking preferences. Degree is one of the measurements with the arbitrator. In the beginning of degree construction, the range is set between 0 and 1. The select arbitrator will be 1 and on the top. The ideas linking will be the RA skills relationships and connections.

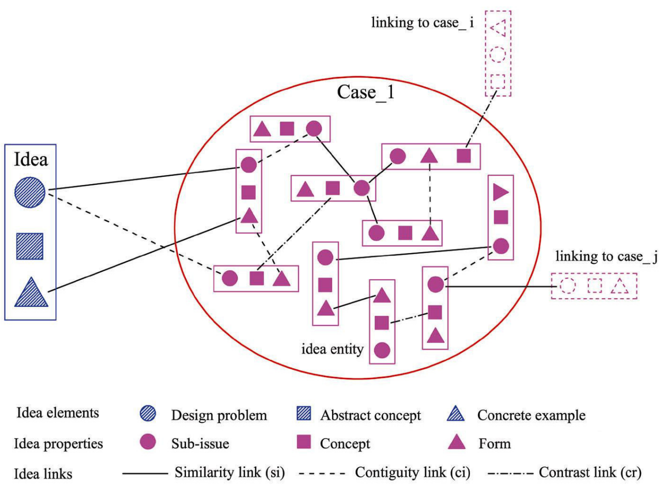

Figure 5. The ICF ideas entities and idea links.

For storage, search and using, the links take by the ID in RA's skills and these are like the knowledge representation of category design skills which built by the user, not the fixed linking association in the beginning of one ScA and it also means the training part of the construction problem through information data model is broadened within to enlarge the knowledge representations. The person owns design Maps acknowledge and construction decisions by himself. It will different from others construction concepts. Therefore, we adopt XML for individual person knowledge presentation, because XML has the clear hierarchy for ICF and idea links storage purpose. The potential reuse ability can accomplish ICF Maps and idea links which described above.

4.2 Competing learning with arbitrators

With the mechanism described in section 3 and the information data model above, competing-learning proposed by this research invokes a different dimension for solving the problems we have. The decision made by DA will be influenced by two stages of competing learning—internal and external competing learning.

Internal competing learning is a ring-type of communication. With arbitrator, there are two learning situations:

First, within the same construction company, everyone involved in a particular construction process is regarded as one UA. This is to say that there is one common goal for all UAs: to solve the problem with the interest of the company, therefore, the optimized solution or the construction concepts will be achieved by competing each other within the same problem. Arbitrator can act as a supporting agent for every group of UAs within the same construction problem. The outcome of the solution will be through the competing stage following the mechanism above.

Secondly, each participant can learn better solution via his/her own arbitrator who will help to compete or judge the suitability or practicality of the construction concept he/she has.

External competing learning is a peer-to-peer type of communication with each peer represents different company with association. With arbitrator, the learning objective can be achieved via cross-evaluation and critics over better construction methods in certain construction problems. Through competing, the better or more creative solution might be discovered or searched and learned. Furthermore, another possible learning situation is that each UA can learn how other UA reacts to the same construction problem with external competing process.

4.3 Evolving learning with arbitrators

In the evolving learning process, there are also two different situations: internal evolving learning and external evolving learning.

The differences occur when the events are different. In internal evolving learning, with the arbitrator and the degree mechanism, each construction concept generated within the competing process will be recorded and emphasized that will refine the knowledge in the agent as well as the company. Another situation is that the knowledge of participants for certain particular construction problems will be evolved and can resolve the better solution in the future. The degree for each stored winning cases will have a better chance to be selected later.

External evolving learning situation is another similar situation in our context since the concept of competing will evolve the knowledge locally and externally.

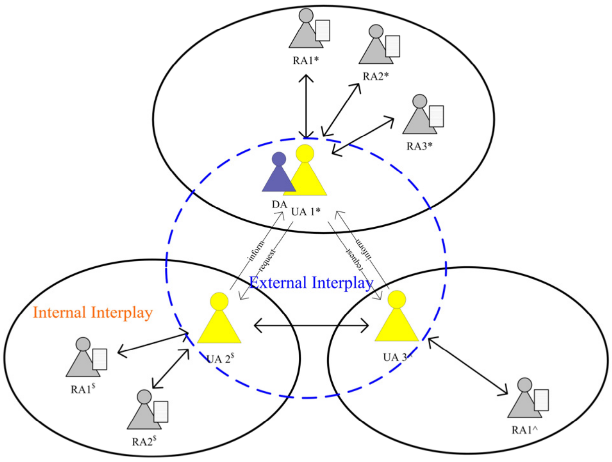

Figure 6. The internal and external circumstances in the interplay of competing learning and evolving learning

4.4 *Three selections with UA (User)*

The arbitrator should be chosen for competing process. UA uses the three selections procedures to build arbitrator, also. But the selection meanings here are different from the three selections in the arbitrator selection procedures. There are UA selections: (1) human selection: UA selects the arbitrator by personal favorites; (2) natural selection: UA chooses the preferences and allows system to decide who the arbitrator is; (3) Agent-auto selection: through the automatic mechanism, system will decide who the arbitrator is and start the competing process automatically.

5 IMPLEMETATION AND FEEDBACKS

5.1 *Technical support and possibility*

For implementing CELA, we need (1) a platform for dealing with multi-agent communications; (2) a knowledge representation for representing the information model described before; (3) a computational mechanism that can implement the competing, evolving and the selection procedures.

With the implementation requirements above, a system called CELA is proposed and implemented in this paper. For agent communication, an interplay agent framework called DARIS is used as our interplay environment. On the top of DARIS, we implement a specific agent called "arbitrator" who contains the capabilities described in this paper. Different RAs with construction concepts are also implemented in DARIS environment.

5.2 *Framework and implementation*

The framework of CELA (Competing and Evolving Learning Arena) is shown in the Figure 7. Basically, CELA contains three layers: representation, communication and learning mechanism layers. CELA, as an agent-learning environment, depends on many components from other theory such as DIM for linking ideas and DARIS for dynamic role interplays. Each component represents different aspects of interplays and contributes the features required for implementing CELA.

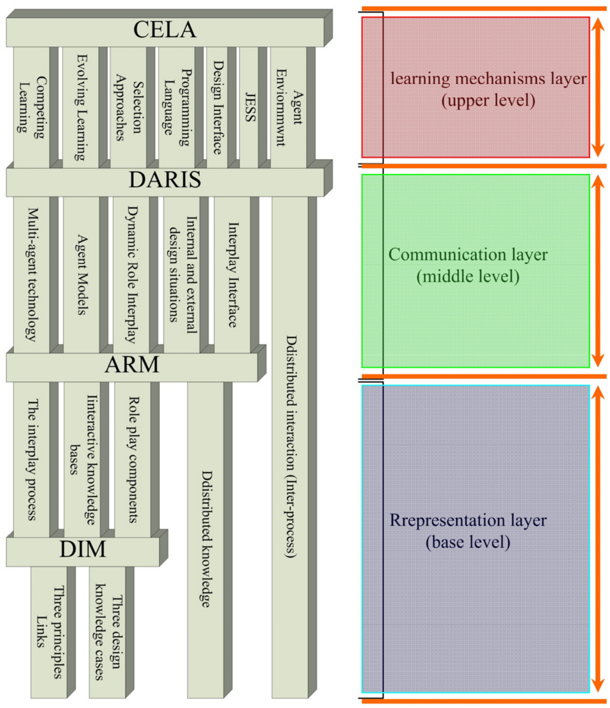

Figure 7. The three layer in CELA system

In addition, these three layers implementing the functionalities of arbitrator described in the section 3 and section 4. The relations between the arbitrator and the three layers are shown in Figure 8. This is to say that CELA has implemented the learning mechanisms and one specific agent (arbitrator) on the top of DARIS.

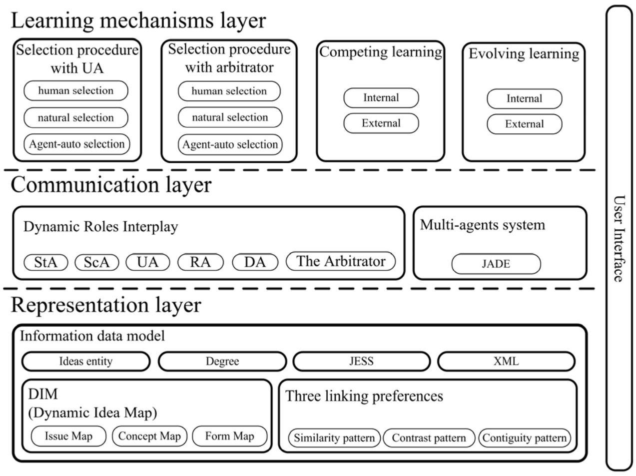

Figure 8. The framework and environment of CELA system

One implementation of CELA and its working status is shown in Figure 9. The programming language is Java with FIPA-like agent platform embedded in CELA implementation. The reasoning engine is JESS with XML extension.

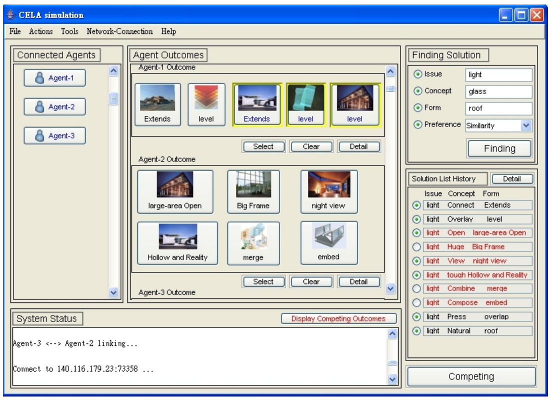

Figure 9. The programs implementation with user interfaces

6 CONCLUSION

A successful construction process depends on satisfaction on many different and often conflict problems. We address this issue by viewing each problem as individual construction situation. Then, a role-interplay simulation over construction concepts is proposed for understanding the computability of the finding suitable solutions from diverse resources.

Furthermore, based on an on-going agent based design system (DARIS), CELA proposed in this paper provides richer features: learning mechanisms and competing/evolving procedures on finding suitable or more alternatives on construction concepts with divergent participants. For elaborating these learning/competing mechanisms, a specialized agent called Arbitrator is described along with other interplay agents such as RA, DA and ScA. These agents simulate the competition and evolution among different knowledge that is often the most difficult part of construction decision process. Furthermore, in the agent lattice, each agent can only sense its local environment, and its behaviors of evolving and cooperation can only take place between the agent and its neighbors.

While giving the agent evolving mechanism, we also present several experimental results. These results demonstrate how the evolution of the distributed autonomous agents can enable the extraction of construction concepts features with the effects of behavioral parameters on the performance. In addition, the concepts feature extracted from CELA process are entirely determined by the locality and parallelism of the individual agents.

With the significances of agent simulation, the directions for the diffusion and self-reproduction of the agents are then able to be dynamically selected and evolved. With respect to real-life mechanisms, the proposed approach could have significant impact on difficult ideas analysis problems in various construction problems.

7 PREFERENCES

Bowling, M and Veloso, M: 2002, Multiagent learning using a variable learning rate, *Artificial Intelligence*, **136**(2): 215-250

Chang, T. W. (2004). Modelling Situated Generation Using Role-Interplay: From situated interplay to generative interplay. *Generation CAD Systems Symposium (G-CADS 2004)*, Carnegie Mellon University, School of Architecture

Chang, T. W. and Lai, I. C. (2004), Dynamic Agent-Based Role Interplay System, National Science Council, Taipei, technical report.

Clausen, C and Wechsler, H. (2000), Quad-Q-learning, *Transactions on Neural Networks*, **11**(2): 279 – 294

Coley, DA: 1999, *An Introduction to Genetic Algorithms for Scientists and Engineers*, World Scientific Publishing Co. Pte. Ltd

Lai, I. C. and Chang, T. W. (2005), A distributed linking system for supporting idea association in the conceptual design stage, National Science Council, Taipei, technical report.

Lai, I. C. (2004), Framework for Case-Based Reasoning to Support Idea Association in a Brainstorming Session, *the Proceedings of 9th Conference on Computer Aided Architectural Design Research (CAADRIA)*, pp. 209-222

Lai, Ih-Cheng, Kao, Kun-Tai and Chang, Teng-Wen (2005). Role Playing for Linking Ideas in the Idea Association Process, *the Proceedings of 10th Conference on Computer Aided Architectural Design Research (CAADRIA)*, New Delhi (India). pp. 119-129

Jackson, Peter (1999), *Expert Systems*. Third Edition, Addison-Wesley press

Osborn, A. F. (1963), *Applied Imagination: Principles and Procedures of Creativity Thinking*. New York: Charles Scribiner's Son press

Oxman, R. E., (1994), Precedents in design: a computational model for the organization of precedent knowledge, *Design Studies Vol. 15, No. 2,* pp. 141-157

Petrovic, I. K. (1997), Computer Design Agents in a Brainstorming Session, *the Proceedings of 1997eCAADe*, Vienna

Radford, A. D. and Gero, J. S. (1988), *Design by Optimisation in Architecture, Building, and Construction*. Van Nostrand Reinhold Company press