Role-Based Collaboration and E-CARGO

Revisiting the Developments of the Last Decade

by Haibin Zhu

Role-based collaboration (RBC) is an emerging computational methodology that uses roles as the primary underlying mechanism to facilitate collaboration activities. It consists of a set of concepts, principles, models, and algorithms. RBC offers benefits and challenges that may not be revealed with the traditional methodologies and systems. Related research continues the process of improvement to the development, evaluation, management, and performance of computer-based systems. This article provides a concise introduction to RBC and its model, the Environments–Classes, Agents, Roles, Groups, and Objects (E-CARGO) model; reviews the related research achievements in RBC over the past decade; discusses the challenges requiring future research; presents fundamental methods for conducting related research; and analyzes the connections between RBC and other fields.

RBC and the E-CARGO Model

Collaboration is called for when task completion requires more than one individual. Success in this process poses challenges to both researchers and practitioners. The research in the fields of collaboration theory, technologies,

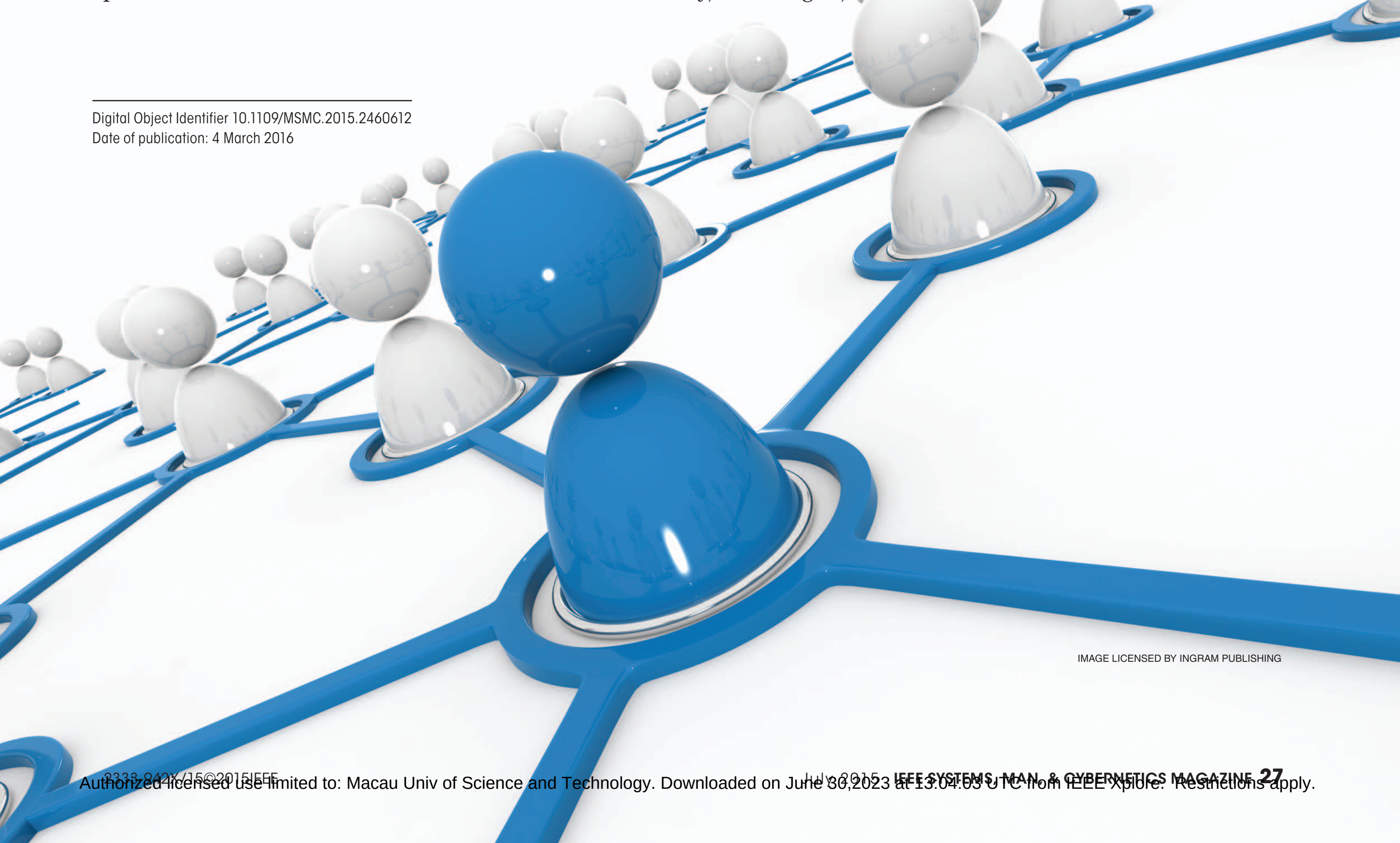

IMAGE LICENSED BY INGRAM PUBLISHING

Digital Object Identifier 10.1109/MSMC.2015.2460612
Date of publication: 4 March 2016

and systems helps people undertake collaboration in a more efficient and satisfactory manner. In practice, such ongoing research offers a continuous cycle of improvement. That is, a good theory of collaboration leads to more effective collaboration systems. On the other hand, advancements in technologies and systems allow collaboration theories to advance.

From the viewpoint of sociotech systems and our preferred taxonomy, collaboration can be divided into the following categories:

- natural collaboration among people in the real world
- computer-supported cooperative work (CSCW), which is collaboration involving people through computers and related technologies
- human–computer interaction (HCI) or human–machine interaction, which is collaboration that occurs between people and computers (machines)
- distributed systems [including multiagent systems (MASs)] are collaborations that take place among systems (or agents)
- a computer system is a collaboration among system components.

At the abstract level, collaboration is composed of two major intersupplementary aspects: task distribution and coordination, i.e., more attention paid to task distribution would decrease the effort on coordination or vice versa. RBC focuses on providing better task distribution to save the effort of coordination, which is believed to be more complex than task distribution. Coordination has more complex problems than does task distribution, where complex problems cannot be formalized by mathematical symbols and expressions or can be formalized but solved in nonpolynomial time.

A computational methodology can be used to discover, consider, model, understand, and solve the real-world problems with the help of computer-based systems. RBC is such a methodology, using roles as the primary underlying mechanism to facilitate collaboration activities [58]–[88]. RBC was proposed in 2003 [58], [67], [68] and has been the subject of research and investigation for more than a decade. During this period, many significant challenges have arisen [58]–[88] (see the "Problems Discovered But Not Yet Fully Solved" section), including the role transfer problem (RTP), the group role assignment (GRA) problem, and the GRA with conflicting agents (GRACA) problem. Amazingly, these challenges have interesting parallels to engineering problems in the real world. Solving such problems satisfies the requirements of good engineering practice. Previous research has solved typical problems in role assignment and role transfer [58]–[88]. GRA [80] has arisen as an important challenge and has been revealed as a complex task in the life cycle of RBC (Figure 1), i.e., agent evaluation, role assignment, and role transfer. GRA aims at finding an optimal assignment from roles to agents with the agent evaluation result [71], [84], and it significantly affects the efficiency of collaboration and the degree of satisfaction among the members involved in RBC.

Through continuous effort, RBC-related research has been developed into a methodology of discovery in the collaboration-systems research field. The RBC-related research has been done by taking advantage of formalizations and abstracting system components, at differing levels, by mathematical expressions. The instances of such abstractions are easily found in real-world scenarios. The problems discovered through RBC research have direct parallels in the real world (see the sections "Problems Discovered and Solved by RBC" and "Problems Discovered But Not Yet Fully Solved").

The fundamental model of RBC is E-CARGO. E-CARGO is highly abstracted from natural and man-made systems, in particular, collaboration systems. Many researchers may find that their systems involve components similar to those in the E-CARGO model.

RBC and the E-CARGO model bring in new visions to a collaboration system by dividing the system into six different classes of components, i.e., classes, objects, agents, roles, environments, and groups. Among them, many relationships can be formalized through mathematical symbolization. In this way, many problems previously considered to be too complex to solve with computer-based systems can now be well defined and, finally, solved. This article intends to provide a brief introduction to the E-CARGO model and RBC while advocating the need for further investigation of these topics.

The Components of the E-CARGO Model

With the E-CARGO model [84], a system Σ can be defined as a nine-tuple $\Sigma ::= <\mathcal{C}, \mathcal{O}, \mathcal{A}, \mathcal{M}, \mathcal{R}, \mathcal{E}, \mathcal{G}, s_0, \mathcal{H}>$, where $\mathcal{C}$ is a set of classes, $\mathcal{O}$ is a set of objects, $\mathcal{A}$ is a set of agents, $\mathcal{M}$ is a set of messages, $\mathcal{R}$ is a set of roles, $\mathcal{E}$ is a set of environments, $\mathcal{G}$ is a set of groups, s_0 is the initial state of the system, and $\mathcal{H}$ is a set of users. In such a system, $\mathcal{A}$ and $\mathcal{H}$, and $\mathcal{E}$ and $\mathcal{G}$ are tightly coupled sets. A human user and his or her agents may perform a role together. Every group should work in an environment. An environment regulates a group. Note that E-CARGO is an abstract model, and it is developed continuously. Investigations may emphasize different aspects in different ways.

In the following descriptions, c, o, a, ♪, r, e, g, and h are used to denote an element of $\mathcal{C}, \mathcal{O}, \mathcal{A}, \mathcal{M}, \mathcal{R}, \mathcal{E}, \mathcal{G}$, and $\mathcal{H}$ respectively. If S is a set, $|S|$ is its cardinality. If a and b are objects, $a.b$ denotes b of a or a's b; and $\{a, b, \ldots\}$ denotes a set of enumerated elements of a, b, and others. If a and b are real numbers, $[a, b]$ and $[a, b)$ denote the set of all the real numbers between a and b, where the former includes both a and b, but the latter includes a but not b. If Υ is a vector, $\Upsilon[i]$ denotes the element at its ith position. If Υ is a matrix, $\Upsilon[i, j]$ denotes the element at the intersection of row i and column j in Υ. N denotes the set of natural numbers or, more exactly, nonnegative integers, i.e., $\{0, 1, 2, 3, \ldots\}$. In the following discussions, components instead of concepts are used to emphasize that the elements in the

E-CARGO model are much easier to reuse than the concepts because of formalizations. In addition, to make this article more readable, detailed formalizations are omitted. Readers interested in the formal definitions of the E-CARGO components may refer to [84].

First-Class Components of the E-CARGO Model

From the viewpoint that everything in the world is an object, each of which has a class, we have the definitions for classes and objects. A class is an abstraction and template of entities that have similar properties and features. An object is an expression of an entity that is not a role-player in RBC and E-CARGO.

A role is an entity that represents a combination of responsibilities, rights, and objects that can be concentrated on or ignored based on concrete applications. Note that the current agent set A_c and the potential agent set A_p in the definition of a role are empty before a group is formed, i.e., a role can be specified before agents are specified. On the other hand, the E-CARGO model does not restrict the details of their components, including roles. A role can be defined in different ways in modeling specific problems.

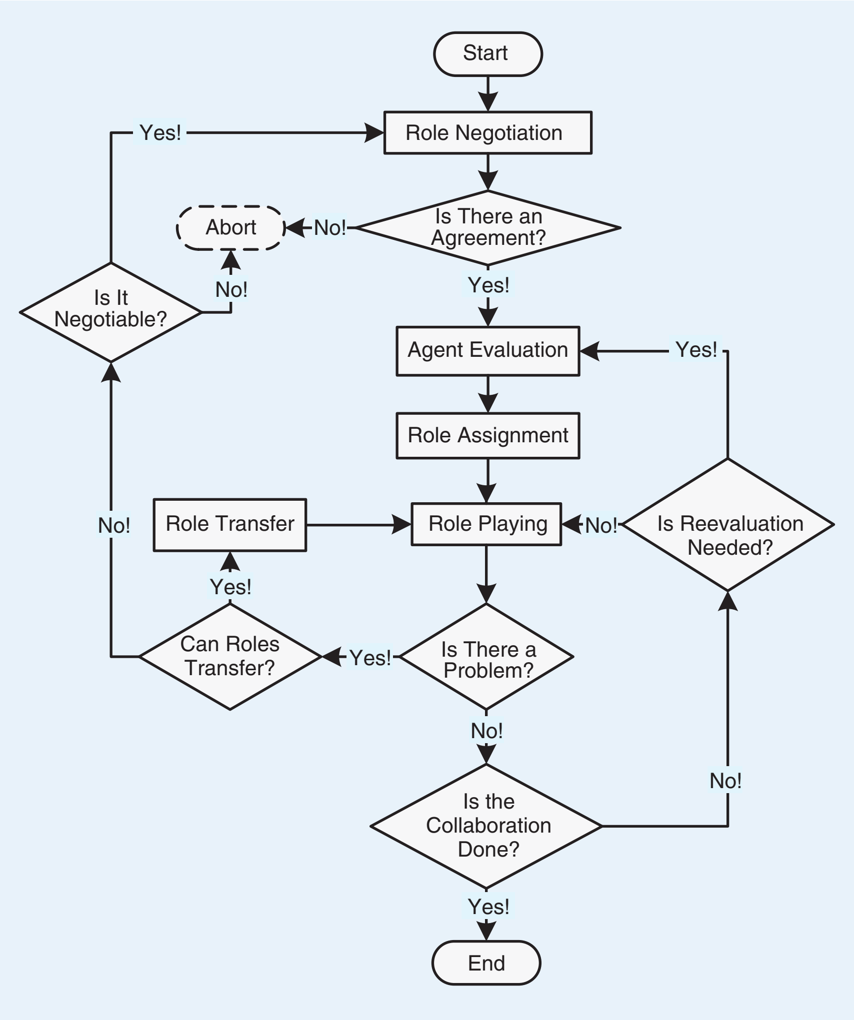

Figure 1. The life cycle of RBC.

An agent is a role-player. In the definition of an agent, all of the current and potential roles of agent a (i.e., $a.R_p \cup \{a.r_c\}$) form its repository role set. If $a.r_c$ is empty, then a is currently free. The term *agent* can be any entity described by the definition, such as a human being, software agent, machine, or commodity. It does not have to carry the meaning of the term *agent* in MASs [10], [11], [28] if researchers only concentrate on the relationships between roles and agents. In addition, this definition leaves space to express the traditional agent concept. In E-CARGO, we could conduct "divide-and-conquer" and "optimizations" to deal with collaboration problems among agents. Note that the definitions are developed continuously from their original forms [58]–[87] to accommodate changing requirements.

An environment is a plan, proposal, or blueprint to establish a team. A group is a team of agents to be established to fit an environment. From the definition of a group, we emphasize the role assignment to agents. From this point of view, many challenges can be discovered to improve the performance of a group, including agent evaluation and role assignment.

In general, E-CARGO clearly differentiates among its components. Objects are not agents and do not play roles. Agents, as role-players, deal with the messages dispatched by their roles and access objects with the rights regulated by their roles. Roles are message exchangers and dispatchers. Environments are specified by roles and objects. A group is composed of dynamic agents in an environment by playing roles.

Supplemental Components of the E-CARGO Model

A message is a way to facilitate the interactions among the components of the E-CARGO model. In RBC, we emphasize that messages are sent to roles. Messages are exchanged among roles. A role is also a message dispatcher to the agents that are playing this role. Therefore, in E-CARGO, objects are passive entities that are accessed by agents through roles. Objects cannot process messages. Role-players, i.e., agents, are the only components to process messages. This idea clarifies the differences among agents, roles, and objects.

A role assignment or an agent assignment is defined as a tuple of an agent and a role. This tuple makes a role attach to an agent. In formalizing role-assignment problems [40], [57], [61]–[63], [69], [72], [80], only agents and roles are emphasized. Current agents or roles are the focus of role assignment. Environments and groups are simplified into vectors and matrices, respectively. Furthermore, the nonnegative integers $m(=|\mathcal{A}|)$ express the size of the agent set A; $n(=|\mathcal{R}|)$ expresses the size of the role set $\mathcal{R}$; $i, i_1, i_2, \ldots$ expresses the indices of agents; and $j, j_1, j_2, \ldots$ expresses the indices of roles.

Role range vectors are two vectors, i.e., L and U, of the lower and upper bounds of roles in environment e of group g. $L[j](0 \le j < n)$ expresses how many agents must be assigned to role j, and $U[j]$ expresses the most number of agents that can be assigned to role j. L and U are the valuable components in supplementing the E-CARGO model. They reveal many challenges in role assignment and the process of RBC. Without L, we would not discover many related problems discussed in this article. L and U are, in fact, the simplified and derived components from the environment component in the E-CARGO model. They show the smallest/largest numbers of agents for each role in a group to be in the working state.

A qualification matrix Q is an $m \times n$ matrix, where $Q[i,j] \epsilon [0,1]$ expresses the qualification value of agent $i \epsilon \mathcal{N}(0 \le i < m)$ for role $j \epsilon \mathcal{N}(0 \le j < n)$. $Q[i,j]=0$ means the lowest, and one is the highest. Note that a Q matrix can be obtained by comparing all the qualifications, i.e., Ⓠs, of agents with all the requirements, i.e., Ⓡs, of roles. Q is, in fact, a component to depict one specific relationship between roles and agents. It significantly affects the problem of role assignment in RBC. Because this component is an assumed one, it brings in the significance of another problem, agent evaluation, in RBC. A role-assignment matrix T is defined as an $m \times n$ matrix, where $T[i,j] \epsilon \{0,1\} (0 \le i < m, 0 \le j < n)$ expresses if agent i is assigned to role j. $T[i,j]=1$ means yes and zero means no.

The group performance σ of group g is defined as the sum of the assigned agents' qualifications, i.e., $\sigma = \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} Q[i,j] \times T[i,j]$. Role j is workable in group g if it is assigned with enough agents, i.e., $\sum_{i=0}^{m-1} T[i,j] \ge L[j]$. T is workable if each role j is workable, i.e., $\forall (0 \le j < n) \sum_{i=0}^{m-1} T[i,j] \ge L[j])$. Group g is workable if T is workable. For example, Figure 2(a) is a qualification matrix. Figure 2(b) is an assignment matrix that makes the group work with vector $L=[2,1,1,2]$. The group performance is 4.21.

$$\begin{bmatrix} 0.71 & 0.6 & 0.0 & 0.22 \\ 0.29 & 0.67 & 0.44 & 0.76 \\ 0.69 & 0.92 & 0.92 & 0.6 \\ 0.0 & 0.0 & 0.53 & 0.0 \\ 0.97 & 0.51 & 0.77 & 0.65 \\ 0.58 & 0.64 & 0.24 & 0.0 \end{bmatrix} \qquad \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

(a) (b)

Figure 2. (a) A qualification matrix *Q*. (b) An assignment matrix *T*.

From the previously given definitions, group g can be simplified by Q, an L, and T. By scrutinizing these three elements, we discover the related optimization and search problems.

Problems Discovered and Solved by RBC

Research efforts have discovered and solved some significant problems related to RBC [61], [72], [80]–[82].

Definition 1 [80]

Given Q and L, GRA is to find a matrix T to

$$\max \sigma = \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} Q[i,j] \times T[i,j]$$

subject to

$$T[i,j] \in \{0,1\} \quad (0 \le i < m, 0 \le j < n) \tag{1}$$

$$\sum_{i=0}^{m-1} T[i,j] = L[j] \quad (0 \le j < n) \tag{2}$$

$$\sum_{j=0}^{n-1} T[i,j] \le 1 \quad (0 \le i < m), \tag{3}$$

where (1) shows that an agent can only be assigned or not, (2) makes the group workable, and (3) means that each agent can only be assigned to one role.

GRA was formalized and solved efficiently in [80]. It is also applied to solving practical problems, such as the scheduling of health-care services [77].

Definition 2 [82], [86]

A potential role matrix M^p is defined as $M^p : \mathcal{A} \times \mathcal{R} \in \{0,1\}$, where $M^p[i,j]=1$ expresses $i \in j.\mathcal{A}_p$, and $M^p[i,j]=0$ means $i \notin j.\mathcal{A}_p$, where $\mathcal{A}_p$ is the potential agent set of role j [82].

Definition 3 [82], [86]

Role transfer is a process to exchange ones of T with M^p, i.e., if there are agent i, and roles j_1 and j_2, $T[i,j_1]=1, M^p[i,j_1]=0, T[i,j_2]=0$, and $M^p[i,j_2]=1$, a role transfer occurs when $T[i,j_1]:=0$, $M^p[i,j_1]:=1, T[i,j_2]:=1$, and $M^p[i,j_2]:=0 (0 \le i < m$, $0 \le j_1, j_2, < n)$; on the other hand, if there are role j, and agents i_1 and i_2, $T[i_1,j]=1, M^p[i_1,j]=0, T[i_2,j]=0$, and $M^p[i_2,j]=1$, a role transfer also occurs when $T[i_1,j]:=0, M^p[i_1,j]:=1, T[i_2,j]:=1, M^p[i_2,j]:=0 (0 \le i_1$, $i_2 < m, 0 \le j < n)$ (where ":=" means "is assigned with").

Definition 4 [82], [86]

Given m, n, L, M^p, and T that are not workable, the RTP is to find a workable T' by doing role transfers.

The RTP was formalized and solved efficiently in [82], [86], and [88]. The investigation of this problem also produced a copyrighted software product: the Visualized Role-Transfer Tool [75].

RBC offers benefits and challenges that may not be revealed with the traditional methodologies and systems.

Definition 5 [61], [65], [72]

Two different agents i_1 and i_2 are in conflict on roles/groups (R/G) if i_1 and i_2 cannot be assigned to the same R/G. i_1 is called a conflicting agent of i_2 and vice versa.

For example, unresolved emotional conflicts may prevent John and Matt from working together. An obvious danger exists if a bottle of poisonous chemicals is placed into the same box with similarly packaged bottles of water.

Definition 6 [61], [65], [72]

A conflicting agent matrix is defined as an $m \times m$ matrix $A^c : A^c[i_1, i_2] \in \{0,1\}$, where $A^c[i_1, i_2] = 1$ expresses that agent i_1 is in conflict with agent i_2, while $A^c[i_1, i_2] = 0$ means not.

Note that from the definitions, the conflicting agent matrix is a symmetric one along the diagonal from $[0, 0]$ to $[m-1, m-1]$, $A^c[i_1, i_2] = A^c[i_2, i_1] \wedge A^c[i, i] = 0$ $(i_1 \neq i_2, i, i_1, i_2 = 0, 1, \ldots, m-1)$.

Definition 7 [61], [65], [72]

GRACA on R/G finds a workable role assignment matrix T from Q and L to $\max \sigma$ subject to (1)–(3) and on roles

$$A^c[i_1, i_2] \times (T[i_1, j] + T[i_2, j]) \leq 1 \quad (0 \leq i_1, i_2 < m, i_1 \neq i_2, 0 \leq j < n) \tag{4}$$

or on groups

$$A^c[i_1, i_2] \times (T[i_1, j_1] + T[i_2, j_2]) \leq 1 \quad (0 \leq i_1, i_2 < m, i_1 \neq i_2, 0 \leq j_1 j_2 < n). \tag{5}$$

The GRACA (R/G) problems were formalized and solved in [61], [65], and [72]. The solutions are satisfactory because they are able to deal with such problems for a group up to 200 agents [72]. It is still valuable to investigate new solutions that can solve a larger problem efficiently.

Problems Discovered But Not Yet Fully Solved

The collective role assignment problem is a complex one that has been formalized in [63]. However, the initial solution is of limited use due to such complexity.

Agent evaluation is an important step in RBC, as shown in Figure 1. It creates the qualification matrix Q as the foundation to conduct role assignment. Even though some work [71], [74] related to agent evaluation has been done, there are still many challenges unsolved. The current situation is that problems are solved case by case, and we still need to obtain a generalized and easy-to-follow method that is well accepted.

One important problem in RBC is to specify and define the required relationships among roles [60], [66]. These relationships are a theoretic foundation for a role-based system working on a role engine. This problem is still open and needs more investigation in formalizations and implementations. The implementation of a role engine or the proof of a minimum and sufficient logic will verify the specified role relationships. By *minimum*, we mean that removing any logic component from such a system leads to failure of the establishment of an application. By *sufficient*, we mean that such a system can support all the activities of agents on roles and specify all the relationships among roles.

Role-based interaction has been presented as an innovative way to facilitate HCI [44], [76]. Further efforts are required in implementation and simulation. More empirical studies are also required to verify the claimed benefits.

Role-based software engineering [87] and programming [27], [33], [41]–[44], [83] are innovative and promising methodologies that have much potential to improve the productivity of software development teams and the quality of a software product. More work in these areas is required. Although aspect-oriented programming (AOP) [26] and subject-oriented programming (SOP) [15] claim to provide similar approaches to software engineering and programming, we believe that the reason AOP and SOP are not widely accepted after two decades is the lack of formal specifications for roles/role-players and the design of a role engine to support high-level role-based design and agent development.

Role-based chatting is supported by a web-based tool [70]. It provides a tradeoff between anonymity and trust. It helps shy people present their ideas and significantly improves the satisfaction of those participating in collaboration. Named collaboration allows aggressive contributors to dominate the process, thus potentially excluding useful ideas presented by shy people. More applications and empirical studies are required to present and verify the promises.

Adaptive collaboration systems (ACSs) [1], [30], [39], [78], [79] are another important branch that needs to be investigated. From our previous work, RBC and E-CARGO are verified as a solid foundation for adaptive systems to be established. The RBC process and the dynamic parameters in the E-CARGO model promise to contribute more in the development of ACSs.

How to Discover Challenges by RBC and E-CARGO

Because RBC is a well-specified methodology and the E-CARGO model is well defined, it is not difficult to use these tools to discover new challenges in the research of collaboration systems. We suggest the following streams.

- By introducing new parameters and conditions into role assignment, one may discover different constraints to role requirement. This stream may discover many challenges that belong to the categories of linear programming (LP) or nonlinear programming (NLP). For example, GRACA (R/G) problems are challenges discovered in this way [61], [65].
- By introducing relationships among the components in the E-CARGO model, one may discover challenges related to coordination, interaction, and management [60], [66]. These challenges may overlap with those in logical systems or algebraic systems [20].
- By detailing or adding the parameters of the components of E-CARGO, one may find challenges to facilitate collaboration. The solutions to these challenges will facilitate the implementations of collaboration systems, such as MASs. For example, if individual role-playing logic is added to an agent and group role-playing logic is added to an environment, one may discover many challenges in intelligent agent systems or MASs [3]–[6], [11]–[14], [19], [28], [30].
- By applying RBC and E-CARGO in related areas such as CSCW [84], software engineering [26], MASs [3]–[6], [11]–[14], [19], [28], scheduling [8], cloud computing [2], [45], and web services [16], [21]–[24], [38], [47], [48], [56], one may formalize the problems in related areas and propose innovative solutions. For example, applying GRA algorithms to role-based access control (RBAC) solves the problem of different levels of assignments in RBAC.

Note that the aforementioned innovative discoveries are not intuitively deduced in related research methodologies other than RBC, such as NLP, logic systems, algebraic systems, and MASs. It is RBC and E-CARGO that provide such opportunities for researchers to discover because RBC and E-CARGO illustrate new requirements in the sense of collaboration.

With E-CARGO, many real-world problems can be discovered and formalized, and then computer-based solutions can be specified or provided.

Connections with Other Research Fields

Optimizations

It is interesting to note that many RBC problems involve optimization. In fact, the RBC research establishes a useful bridge between collaboration and optimization. Optimization methods can be applied to problem solving only when the problem can be well defined in terms of optimizations [35], [49] such as integer programming, LP, or NLP. RBC provides an approach to specify many complex problems in terms of optimization. In fact, RBC expands the application areas of the optimization theory and models to include collaboration. The difference between RBC and optimization research is that RBC presents a new viewpoint for researchers in their investigations of collaboration systems.

On the other hand, not all RBC problems are optimizations. In RBC, some problems are so complex that we only need to provide a feasible solution. For example, the RTP is only to find a feasible solution. Also from the RTP, even though it is hard to set up an optimized group that has no critical agents, we could use a computer-based solution, such as the role-transfer tool to check whether an existing group has critical agents [75], [81], [82], [86], [88]. The GRACA (R/G) problems can be transferred into LP, but a solution may not have to use LP.

Agent-Oriented Software Engineering

Many researchers in this field advocate that roles, agents, and groups are considered as fundamental concepts in the development of software products [11], [32], [50]. Compared with agent-oriented software engineering (AOSE), RBC offers the advantages of well-defined components and formalizations. AOSE lacks formalizations in spite of some effort to establish them [32]. This hampers the research in AOSE because it is difficult to expand and clarify problems and, furthermore, to verify and validate the proposed approaches. Software development is of such complexity that it is difficult to undertake in the absence of well-defined specification tools. Unified Modeling Language (UML) is grammatical but not fully formalized. RBC and the E-CARGO model present a promising way to overcome this obstacle.

MASs

MASs have been a hot, leading-edge research topic for many years [11], [12], [30], [50]. Compared with MASs' approach that encourages the individualism of agents, RBC offers advantages based on a view of collectivism, more specifically, on collaboration. In MASs, it is considered essential to design highly intelligent agents that collaborate with others while mainly considering self-benefit. RBC counters by emphasizing the group benefit. Although there are some trials in the formalizations of role allocations in MASs [7], RBC is a promising supplementary research to MASs.

The Benefits of RBC

Compared with other role-based approaches [6], [10], [11], [18], [25]–[33], [41]–[44], [50], RBC possesses the following properties that are considered advantages.

- RBC has a specific and formalized model, E-CARGO.
- RBC presents a clearly stated process of collaboration.

- In E-CARGO, objects and agents are clearly clarified as different entities in collaboration, i.e., agents are role-players, but objects are not.
- The E-CARGO model provides more reusable components by its formalized definitions other than concepts in other approaches.
- With the E-CARGO model, many real-world problems can be discovered and formalized, and then computer-based solutions can be specified or provided.
- RBC provides a computational discovering methodology for a variety of industry problems.
- RBC provides new visions into collaboration and assists collaboration technologies to be applied into other areas.
- RBC introduces a new viewpoint of collaboration, i.e., collectivism that emphasizes team effort/performance rather than traditional individualism.

Conclusions and Future Work

RBC is a well-specified methodology that mainly uses roles as underlying components to facilitate collaboration activities. Its fundamental E-CARGO model is abstract and can be extended and instantiated in different ways to discover challenges and, furthermore, to investigate effective solutions. It is valuable to extend research and investigations on RBC and E-CARGO to promote the analysis, design, and development of collaboration systems.

Future work can be conducted along different directions by overlapping with other research fields and by scrutinizing each step in the life cycle of RBC and each component of E-CARGO, and the examples are as follows.

- Role negotiation is the initial step in the life cycle of RBC. It has not yet been investigated deeply and thoroughly.
- When should we conduct role transfer during collaboration? This is another challenge for researchers to put effort into theories and practice.
- Goal setting is a problem discussed significantly in MASs and intelligent systems. However, from the viewpoint of RBC, how to set up a goal for a group needs to be clarified. Solving this problem will innovate the way to conduct collaboration, the design of MASs, and distributed systems. More implementations or simulations are needed to verify that roles can be considered the dynamics of a system [64].
- Introducing role mechanisms into popular programming languages [27] is also an interesting field for researchers and programmers to investigate.
- RBC and E-CARGO can be used to solve the real-world problems related to teams [9], [55], interactions [10], [37], [44], and production [46]. RBC has wide and promising applications in industry [50]–[55].

Acknowledgments

Thanks to Mike Brewes of Nipissing University for his assistance in proofreading this article.

About the Author

Haibin Zhu (haibinz@nipissingu.ca) earned his B.S. degree in computer engineering from the Institute of Engineering and Technology, Zhengzhou, China, in 1983 and his M.S. and Ph.D. degrees in computer science from the National University of Defense Technology (NUDT), Changsha, China, in 1988 and 1997, respectively. He is a full professor in the Department of Computer Science and Mathematics and the founder and director of the Collaborative Systems Laboratory, Nipissing University, Canada, and a visiting professor in the Department of Control Science and Engineering, Nanjing University, China. He was previously a visiting professor and a special lecturer in the College of Computing Sciences, New Jersey Institute of Technology, Newark, and a lecturer, an associate professor, and a full professor at NUDT. He has published more than 140 research papers, five books, and four book chapters on object-oriented programming, distributed systems, collaborative systems, and computer architecture. He is serving or has served as a cochair of the IEEE Systems, Man, and Cybernetics Society Technical Committee on Distributed Intelligent Systems; an associate editor for *IEEE Systems, Man, and Cybernetics Magazine;* an associate editor for *International Journal of Agent Technologies and Systems;* an associate editor-in-chief for *International Journal of Advances in Information and Service Sciences;* a managing editor of *International Journal of Electrical, Electronics, & Computing Technology* and *Computer Sciences;* a member of the editorial board of *International Journal of Software Science and Computational Intelligence;* a guest editor for *IEEE Transactions on Systems, Man, and Cybernetics* (A); an organizer of the workshops and special sessions on role-based collaboration (RBC) for more than ten international conferences; and a program committee member for more than 50 international conferences. He is a member of the Association for Computing Machinery; a life member of the Chinese Association for Science and Technology, United States; and a Senior Member of the IEEE.

References

[1] E. Alonso, D. Kudenko, and D. Kazakov, Eds., *Adaptive Agents and Multi-Agent Systems* (Lecture Notes in Artificial Intelligence, vol. 2636). Berlin, Germany: Springer-Verlag, 2003.

[2] M. Armbrust, A. Fox, R. Griffith, A. D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica, and M. Zaharia, "A view of cloud computing," *Commun. ACM*, vol. 53, no. 4, pp. 50–58, Apr. 2010.

[3] A. O. Al-Zaghameem and M. Alfraheed, "An expressive role-based approach for improving distributed collaboration transparency," Int. *Comput. Sci. Issues*, vol. 10, nos. 4–2, pp. 61–67, July 2013.

[4] G. Cabri, "Environment-supported roles to develop complex systems," in *Engineering Environment-Mediated Multi-Agent Systems* (Lecture Notes in Computer Science, vol. 5049), D. Weyns, S. A. Brueckner, and Y. Demazeau, Eds. Berlin, Germany: Springer-Verlag, 2008, pp. 284–295.

[5] G. Cabri, "Agent roles for context-aware P2P systems," in *Agents and Peer-to-Peer Computing* (Lecture Notes in Computer Science, vol. 6573), S. Joseph, Z.

Despotovic, G. Moro, and S. Bergamaschi, Eds. Berlin, Germany: Springer-Verlag, 2012, pp. 104–114.

[6] A. Caetano, A. R. Silva, and J. Tribolet, "A role-based enterprise architecture framework," in *Proc. 24th Annu. ACM Symp. Applied Computing*, Honolulu, HI, Mar. 8–12, 2009, pp. 253–258.

[7] A. Campbell and A. S. Wu, "Multi-agent role allocation: Issues, approaches, and multiple perspectives," *Auton. Agent Multi-Agent Syst.*, vol. 22, no. 2, pp. 317–355, 2011.

[8] R. W. Conway, W. L. Maxwell, and L. W. Miller, *Theory of Scheduling*. New York: Courier Dover Publications, Aug. 2012.

[9] Z.-P. Fan, W.-L. Suo, B. Feng, and Y. Liu, "Trust estimation in a virtual team: A decision support method," *Expert Syst. Applicat.*, vol. 38, no. 8, pp. 10240–10251, Aug. 2011.

[10] X. Fan and J. Yen, "Modeling cognitive loads for evolving shared mental models in human–agent collaboration," *IEEE Trans. Syst. Man*, Cybern. B, vol. 41, no. 2, pp. 354–367, Apr. 2011.

[11] J. Ferber, O. Gutknecht, and F. Michel, "From agents to organizations: An organizational view of multi-agent systems," in *Agent-Oriented Software Engineering IV* (Lecture Notes in Computer Science, vol. 2935), P. Giorgini, J. Müller, and J. Odell, Eds. Berlin, Germany: Springer-Verlag, 2004, pp. 214–230.

[12] L. Ferrari and H. Zhu, "Autonomous role discovery for collaborating agents," *J. Softw.—Pract. Exp.*, vol. 42, no. 6, pp. 707–731, June 2012.

[13] L. Ferrari and H. Zhu, "Enabling dynamic roles for agents," in *Proc. ACM/IEEE Int. Conf. Collaborative Technologies Systems*, Philadelphia, PA, May 23–27, 2011, pp. 500–507.

[14] L. Ferrari and H. Zhu, "Making Agent roles perceivable through proxy bytecode manipulation," in *Proc. ACM/IEEE Int. Symp. Collaborative Technologies Systems*, Baltimore, MD, 2009, pp. 408–416.

[15] W. Harrison and H. Ossher, "Subject-oriented programming—A critique of pure objects," in *Proc. 8th Annu. Conf. Object-Oriented Programming Systems, Languages, Applications*, 1993, pp. 411–428.

[16] E. A. Gomez and K. Passerini, "Service-based crisis management: Local and global community roles and communication options," *Int. J. Intell. Control Syst.*, vol. 12, no. 2, pp. 198–207, June 2007.

[17] M. Hou, H. Zhu, M. Zhou, and G. R. Arrabito, "Optimizing operator-agent interaction in intelligent adaptive interface design," *IEEE Trans. Syst. Man, Cybern. C*, vol. 41, no. 2, pp. 161–178, 2011.

[18] A. Lang and Y. Pigneur, "Digital trade of human competencies," in *Proc. IEEE 32nd Annu. Hawaii Int. Conf. System Sciences*, Maui, HI, 1999, pp. 1–9.

[19] X. Li, Y. Chen, and Z. Dong, "Qualitative description and quantitative optimization of tactical reconnaissance agents system organization," *Int. J. Comput. Intell. Syst.*, vol. 5, no. 4, pp. 723–734, 2012.

[20] D. Liu, S. Teng, H. Zhu, and Y. Tang, "Minimal role playing logic in role-based collaboration," in *Proc. IEEE Int. Conf. Systems, Man Cybernetics*, San Diego, CA, Oct. 5–8, 2014, pp. 1439–1444.

[21] H. Liu, H. Yu, Y. Li, and Y. Sun, "A role modelling approach for crowd animation in a multi-agent cooperative system," in *Proc. 15th Int. Conf. Computer Supported Cooperative Work Design*, Lausanne, Switzerland, June 2011, pp. 304–310.

[22] L. Liu, H. Zhu, and Z. Huang, "Analysis of minimal privacy disclosure in web services collaboration with role mechanisms," *Expert Syst. Applicat.*, vol. 38, no. 4, pp. 4540–4549, Apr. 2011.

[23] L. Liu, Z. Huang, and H. Zhu, "A privacy access control framework for web services collaboration with role mechanisms," in *Advanced Research on Electronic Commerce, Web Application, and Communication* (Series Communications in Computer and Information Science, vol. 144). Berlin, Germany: Springer-Verlag, 2011, pp. 258–263.

[24] Y. Lu and T. Käkölä, "A dynamic life-cycle model for the provisioning of software testing services," *Syst. Sci. Control Eng.: An Open Access J.*, vol. 2, no. 1, pp. 549–561, 2014.

[25] W. Luo and Y. A. Tung, "A framework for selecting business process modeling methods," *Ind. Manage. Data Syst.*, vol. 99, no. 7, pp. 312–319, 1999.

[26] E. A. Kendal, "Role model design and implementation with aspect-oriented programming," in *Proc. 14th ACM SIGPLAN Conf. Object-Oriented Programming, Systems, Languages, Applications*, Oct. 1999, vol. 34, no. 10, pp. 353–369.

[27] T. Kühn, M. Leuthäuser, S. Götz, C. Seidl, and U. Aßmann, "A metamodel family for role-based modeling and programming languages," in *Software Language Engineering* (Lecture Notes in Computer Science, vol. 8706), B. Combemale, D. J. Pearce, O. Barais, and J. J. Vinju, Eds. Berlin, Germany: Springer-Verlag, 2014, pp. 141–160.

[28] X. Mao, M. Dong, and H. Zhu, "A two-layer approach to developing self-adaptive multi-agent systems in open environment," *Int. J. Agent Technol. Syst.*, vol. 6, no. 1, pp. 65–85, Jan.–Mar. 2014.

[29] R. Nair, M. Tambe, and S. Marsella. (2003). Role allocation and reallocation in multiagent teams: Towards a practical analysis. presented at 2nd Int. Joint Conf. Autonomous Agents Multiagent Systems ACM. pp. 552–559. [Online]. Available: http://teamcore.usc.edu/papers/2003/nair-aamas03.pdf

[30] J. J. Odell, H. van Dyke Parunak, S. Brueckner, and J. Sauter, "Changing roles," *J. Object Technol.*, vol. 2, no. 5, pp. 77–86, Sept.–Oct. 2003.

[31] M. Ould, *Business Processes—Modelling and Analysis for Re-Engineering and Improvement*. Chichester, West Sussex: Wiley, 1995.

[32] L. Padgham, M. Winikoff, S. DeLoach, and M. Cossentino, "A unified graphical notation for AOSE," in *Agent-Oriented Software Engineering IX* (Lecture Notes in Computer Science, vol. 5386), M. Luck, and J. J. Gomez-Sanz, Eds. Berlin, Germany: Springer-Verlag, 2009, pp. 116–130.

[33] M. Pradel, J. Henriksson, and U. Aßmann, "A good role model for ontologies," in *Enterprise Information Systems and Advancing Business Solutions*, M. Tavana, Eds. Hershey, PA: IGI Global, 2012, pp. 225–235.

[34] R. Pressman, *Software Engineering: A Practitioner's Approach*. New York: McGraw-Hill, July 30, 2007.

[35] R. L. Rardin, *Optimization in Operations Research*. Englewood Cliffs, NJ: Prentice Hall, 1997.

[36] D. Riehle and T. Gross, "Role model based framework design and integration," in *Proc. ACM Conf. Object-Oriented Programming Languages, Systems, Applications*, 1998, pp. 117–133.

[37] W. Seo, J. Yoon, J. Lee, and K. Kim, "A state-driven modeling approach to human interactions for knowledge intensive services," *Expert Syst. Applicat.*, vol. 38, no. 3, pp. 1917–1930, Mar. 2011.

[38] H. Shen and C. Sun, "Achieving data consistency by contextualization in web-based collaborative applications," *ACM Trans. Internet Technol.*, vol. 10, no. 4, pp. 13–37, Mar. 2011.

[39] Y. Sheng, H. Zhu, X. Zhou, and L. Feng, "Effective approaches to adaptive collaboration," in *Proc. IEEE Int. Conf. Networking, Sensing Control*, Miami, FL, Apr. 13–16, 2014, pp. 297–302.

[40] Y. Sheng, H. Zhu, X. Zhou, and Y. Wang, "Effective approaches to group role assignment with a flexible formation," in *Proc. IEEE Int. Conf. Systems, Man Cybernetics*, San Diego, CA, Oct. 5–8, 2014, pp. 1445–1450.

[41] P. Sousa, A. Caetano, and J. Tribolet, "Enterprise architecture modelling with the unified modelling language," in *Enterprise Modelling and Computing with UML*, P. Rittgen, Eds. Hershey, PA: Idea Group Inc., 2006, pp. 67–94.

[42] F. Steimann, "On the representation of roles in object-oriented and conceptual modelling," *Data Knowl. Eng.*, vol. 35, no. 1, pp. 83–106, 2000.

[43] F. Steimann. (2008). Role + counter-role = relationship + collaboration. presented at Workshop of Relationships and Associations in Object-Oriented Languages. OOPSLA. [Online]. Available: http://deposit.fernuni-hagen.de/2201/1/Role_Counter_Role _Relationship_Collaboration.pdf

[44] L. Tao and M. Zhang, "Understanding an online classroom system," *IEEE Trans. Hum.-Mach. Syst.*, vol. 43, no. 5, pp. 465–477, Sept. 2013.

[45] S. Teng, C. Zheng, H. Zhu, D. Liu, and W. Zhang, "A cooperative intrusion detection model for cloud computing networks," *Int. J. Secur. Applicat.*, vol. 8, no. 3, pp. 107–118, 2014.

[46] J. Wang and Y. Deng, "Incremental modeling and verification of flexible manufacturing systems," *J. Intell. Manuf.*, vol. 10, no. 6, pp. 485–502, Dec. 1999.

[47] S. Wang, J. Li, and S. Ma, "Dynamic and secure business data exchange model for SaaS-based collaboration supporting platform of industrial Chain," *Int. J. Adv. Pervasive Ubiquitous Comput.*, vol. 3, no. 3, pp. 46–59, 2011.

[48] S. Weerawarana, F. Curbera, F. Leymann, T. Storey, and D. E. Ferguson, *Web Services Platform Architecture*. Englewood Cliffs, NJ: Prentice Hall, 2008.

[49] L. A. Wolsey and G. L. Nemhauser, *Integer and Combinatorial Optimization*. New York: Wiley-Interscience, 1999.

[50] M. Wooldridge, N. R. Jennings, and D. Kinny, "The Gaia methodology for agent-oriented analysis and design," *Auton. Agents Multi-Agent Syst.*, vol. 3, no. 3, pp. 285–312, 2000.

[51] B. Xu, "Enabling the traceability of web information access in laboratory management via E-CARGO model," in *Computer, Informatics, Cybernetics and Applications* (Lecture Notes in Electrical Engineering, vol. 107). Berlin, Germany: Springer-Verlag, 2012, pp. 421–429.

[52] B. Xu, "Exploring the academic collaboration chance in open research community," *Inform. Technol. J.*, vol. 11, no. 5, pp. 577–586, 2012.

[53] B. Xu, X. Yang, and A. Ma, "Role based cross-project collaboration in multiple distributed software design projects," in *Proc. 12th Int. Conf. Computer Supported Cooperative Work Design*, Xi'an, China, Apr. 16–18, 2008, pp. 177–182.

[54] B. Xu, X. Yang, Y. Shen, S. Li, and A. Ma, "A role-based SOA architecture for community support systems," in *Proc. ACM/IEEE Int. Symp. Collaborative Technologies Systems*, Irvine, CA, 2008, pp. 408–415.

[55] B. Xu, H. Zhou, W. Chen, and Y. Ge, "Finding the academic collaboration chance in open research community," in *Computer, Informatics, Cybernetics and Applications* (Lecture Notes in Electrical Engineering, vol. 107), X. He, E. Hua, Y. Lin, and X. Liu, Eds. Berlin, Germany: Springer-Verlag, 2012, pp. 1549–1557.

[56] T. Zhang, S. Ying, S. Cao, and J. Zhang, "A modelling approach to service-oriented architecture," *Enterprise Inform. Syst.*, vol. 2, no. 3, pp. 239–257, 2008.

[57] Y. Zhang, "A role-based approach in dynamic task delegation in agent team work," *J. Softw.*, vol. 3, no. 6, pp. 9–20, 2008.

[58] H. Zhu, "A role agent model for collaborative systems," in *Proc. Int. Conf. Information Knowledge Engineering*, Las Vegas, NV, 2003, pp. 438–444.

[59] H. Zhu, "Conflict resolution with roles in a collaborative system," *Int. J. Intell. Control Syst.*, vol. 10, no. 1, pp. 11–20, 2005.

[60] H. Zhu, "Fundamental issues in the design of a role engine," in *Proc. ACM/IEEE Int'l Symp. Collaborative Technologies Systems*, Irvine, CA, 2008, pp. 399–407.

[61] H. Zhu, "Group role assignment with conflicting agent constraints," in *Proc. ACM/IEEE Int. Conf. Collaboration Technologies Systems*, Philadelphia, PA, May 23–27, 2011, pp. 516–523.

[62] H. Zhu, "Agent training plan for sustainable groups," in *Proc. ACM/IEEE Int. Conf. Collaboration Technologies Systems*, Denver, CO, May 21–25, 2012, pp. 322–329.

[63] H. Zhu, "Collective role assignment and its complexity," in *Proc. IEEE Int. Conf. Systems, Man, Cybernetics*, Anchorage, AK, Oct. 2011, pp. 351–356.

[64] H. Zhu, "Role as dynamics of agents in multi-agent systems," *Syst. Inform. Sci. Notes*, vol. 1, no. 2, pp. 165–171, 2007.

[65] H. Zhu, "Role Assignment for an agent group in consideration of conflicts among agents," in *Proc. Canadian Conf. Artificial Intelligence*, Toronto, ON, Canada, May 28–30, 2012, L. Kosseim and D. Inkpen, Eds., *Canadian Artificial Intelligence* (Lecture Notes in Artificial Intelligence, vol. 7310). Berlin, Germany: Springer-Verlag, 2012, pp. 267–279.

[66] H. Zhu, "Role-based autonomic systems," *Int .J. Softw. Sci. Comput. Intell.*, vol. 2, no. 3, pp. 32–51, July 2010.

[67] H. Zhu, "Some issues in role-based collaboration," in *Proc. IEEE Canada Conf. Electrical Computer Engineering*, Montreal, QC, Canada, vol. 2, May 4–7, 2003, pp. 687–690.

[68] H. Zhu, "The role analysis and transitions in a collaborative system," *Int. J. Intell. Control Syst.*, vol. 8, no. 1, pp. 1–7, 2003.

[69] H. Zhu and R. Alkins, "Improvement to rated role assignment algorithms," in *Proc. IEEE Int. Conf. Systems, Man Cybernetics*, San Antonio, TX, 2009, pp. 4861–4866.

[70] H. Zhu, R. Alkins, and M. Grenier, "Role-based chatting," *J. Softw.*, vol. 3, no. 6, pp. 69–78, 2008.

[71] H. Zhu and L. Feng, "Agent evaluation in distributed adaptive systems," in *Proc. IEEE Int. Conf. Systems, Man Cybernetics*, Manchester, U.K., Oct. 13–16, 2013, pp. 752–757.

[72] H. Zhu and L. Feng, "An efficient approach to group role assignment with conflicting agents," in *Proc. IEEE Int. Conf. Computer Supported Cooperative Work Design*, Whistler, BC, Canada, June 27–29, 2013, pp. 145–152.

[73] H. Zhu, L. Feng, and R. S. Grewal, "An efficient approach to solving the agent training problem for a sustainable group," in *Proc. Summer Computer Simulation Conf.*, Toronto, ON, Canada, July 7–10, 2013, pp. 209–216.

[74] H. Zhu and M. Grenier, "Agent evaluation for role assignment," in *Proc. IEEE 8th Int. Conf. Cognitive Informatics*, Kowloon, Hong Kong, 2009, pp. 405–411.

[75] H. Zhu, M. Grenier, R. Alkins, J. Lacarte, and J. Hoskins, "A visualized tool for role transfer," in *Proc. IEEE Int. Conf. Systems, Man Cybernetics*, Singapore, 2008, pp. 2225–2230.

[76] H. Zhu and M. Hou, "Role-based human-computer interaction," *Int. J. Cogn. Inform. Natural Intell.*, vol. 5, no. 2, pp. 37–57, 2011.

[77] H. Zhu, M. Hou, C. Wang, and M. C. Zhou, "An efficient outpatient scheduling approach," *IEEE Trans. Automat. Sci. Eng.*, vol. 9, no. 4, pp. 701–709, Oct. 2012.

[78] H. Zhu, M. Hou, and M. C. Zhou, "Adaptive collaboration based on the E-CARGO model," *Int. J. Agent Technol. Syst.*, vol. 4, no. 1, pp. 59–76, 2012.

[79] H. Zhu, M. Hou, and M. C. Zhou, "Establishing the foundations of adaptive collaboration," in *Proc. ACM/IEEE Int. Symp. Collaborative Technologies Systems*, Chicago, IL, May 2010, pp. 546–554.

[80] H. Zhu, M. C. Zhou, and R. Alkins, "Group role assignment via a Kuhn–Munkres algorithm-based solution," *IEEE Trans. Syst. Man, Cybern. A*, vol. 42, no. 3, pp. 739–750, 2012.

[81] H. Zhu and M. C. Zhou, "Efficient role transfer based on Kuhn–Munkres algorithm," *IEEE Trans. Syst. Man, Cybern. A*, vol. 42, no. 2, pp. 491–496, 2012.

[82] H. Zhu and M. Zhou, "M–M role-transfer problems and their solutions," *IEEE Trans. Syst. Man, Cybern. A*, vol. 39, no. 2, pp. 448–459, 2009.

[83] H. Zhu and M. Zhou, "New java mechanism for role-based information system development," *Int. J. Intell. Control Syst.*, vol. 13, no. 2, pp. 97–108, 2008.

[84] H. Zhu and M. Zhou, "Role-based collaboration and its kernel mechanisms," *IEEE Trans. Syst. Man, Cybern. C*, vol. 36, no. 4, pp. 578–589, 2006.

[85] H. Zhu and M. Zhou, "Roles in information systems: A survey," *IEEE Trans. Syst. Man, Cybern. C*, vol. 38, no. 3, pp. 377–396, 2008.

[86] H. Zhu and M. Zhou, "Role transfer problems and their algorithms," *IEEE Trans. Syst. Man, Cybern. A*, vol. 38, no. 6, pp. 1442–1450, 2008.

[87] H. Zhu and M. Zhou, "Supporting software development with roles," *IEEE Trans. Syst. Man, Cybern. A*, vol. 36, no. 6, pp. 1110–1123, 2006.

[88] H. Zhu and M. C. Zhou, "The role transferability in emergency management systems," in *Proc. 3rd Int. Conf. Information Systems Crisis Response Management*, Newark, NJ, 2006, pp. 487–496.

SMC