Modeling, Discovering, and Visualizing Workflow Performer-Role Affiliation Networking Knowledge

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Received January 1 , 2014; accepted January 21, 2014; published February 28, 2014

Abstract

This paper formalizes a special type of social networking knowledge, which is called "workflow performer-role affiliation networking knowledge." A workflow model specifies execution sequences of the associated activities and their affiliated relationships with roles, performers, invoked-applications, and relevant data. In Particular, these affiliated relationships exhibit a stream of organizational work-sharing knowledge and utilize business process intelligence to explore resources allotting and planning knowledge concealed in the corresponding workflow model. In this paper, we particularly focus on the performer-role affiliation relationships and their implications as organizational and business process intelligence in workflow-driven organizations. We elaborate a series of theoretical formalisms and practical implementation for modeling, discovering, and visualizing workflow performer-role affiliation networking knowledge, and practical details as workflow performer-role affiliation knowledge representation, discovery, and visualization techniques. These theoretical concepts and practical algorithms are based upon information control net methodology for formally describing workflow models, and the affiliated knowledge eventually represents the various degrees of involvements and participations between a group of performers and a group of roles in a corresponding workflow model. Finally, we summarily describe the implications of the proposed affiliation networking knowledge as business process intelligence, and how worthwhile it is in discovering and visualizing the knowledge in workflow-driven organizations and enterprises that produce massively parallel interactions and large-scaled operational data collections through deploying and enacting massively parallel and large-scale workflow models.

A preliminary version of this paper appeared in APIC-IST 2013, August 12-14, Jeju-Do, Korea. This version tries to discover the defined perforer-role affiliation networking knowledge and visualize the implementation results using the suggested model and algorithms in the conference paper. This study was supported by the NRF (No. 2012006971) and the 2013 reseach fund of Dongnam Health College, Korea.

http://dx.doi.org/10.3837/tiis.2014.02.0022

Keywords: workflow-supported affiliation network, performer-role affiliation networking knowledge, workflow model, ICN (information control net), business process intelligence

1. Introduction

In general, a workflow management system consists of two components - a modeling component and an enacting component. The modeling component allows a modeler to define, analyze and maintain workflow models, by using all of the workflow entities that are necessary to describe work procedures; and the enacting component supports users, in playing essential roles of invoking, executing and monitoring instances of the workflow model defined by the modeling component. In particular, the logical foundation of the workflow management system is based upon the modeling component, which is the so-called workflow model. Until now, many workflow models have been proposed in the workflow literature, and almost all commonly employ five essential entity-types, of activity, role, actor/performer, repository and application entity-types, to represent organizational works and their procedural collaborations. These entity-types eventually reflect typical people-oriented organizational perspectives like behavioral, social, informational, collaborative, and historical perspectives, onto workflow models. Therefore, we can conclude that these workflow management systems are "human conceptual systems" that must be designed, deployed, and understood within their social and organizational contexts; and that must also be conveyed, facilitated, and navigated in large-scaled operational knowledge collections.

More recently, individuals as employees and their companies' workers have started to adopt the concept of social networks both intra-organizationally and inter-organizationally. The technology to support such social networking is diverse, ranging from the standard desktop, to immersive virtual environments, and other applications and services. Likewise, the workflow literature has started to become interested in "social networking." This begins from the strong belief that the social relationships and collaborative behaviors among employees who are involved in enacting the specific workflow models affect the overall performance, and that those social relationships and collaborative behaviors are also crowned with great success in real businesses and working productivity. As a consequence, the application of the concept of the social network and its analytic methods to workflows has been emerging in the literature, and is termed the workflow-supported social network [20, 21]. The workflow -supported affiliation networks, and it reveals the human-centered affiliated relationships with the various types of organizational resource, such as employees (workflow performers), roles, repositories, programs, jobs, tasks, activities, business processes, and procedural packages.

By analyzing these human-centered affiliated relationships, we can explore various types of organizational resources that allot and plan knowledge, in modeling and enacting workflow procedures. A typical type of human-centered affiliated relationship ought to be the affiliated relationships between workflow performers and workflow roles, which are the essential information required to build workflow performer-role affiliation networking knowledge. This paper proposes a series of formalisms and their related algorithms that models, discovers, and visualize the workflow performer-role affiliation networking knowledge from an ICN-based workflow model. The affiliation network is also called a workflow membership network, and represents the involvement of a set of performers with a set of roles, in a workflow model, or a group of workflow models. In a workflow model, performers (or actors) are linked through their joint participation in performing roles. Conversely, workflow roles are assigned to the performers who are involved in the roles. Through the performer-role affiliation networking knowledge, it is possible to visualize in a workflow model how performers and roles are simultaneously.

Of course, two main research issues might exist in workflow performer-role affiliation networking knowledge. One is the planned knowledge discovery issue. The other has something to do with the enacted knowledge discovery issue. The latter is concerned with mining workflow performer-role affiliation networking knowledge from workflow enactment event logs; the former explores workflow performer-role affiliation networking knowledge from performer-role associations of workflow models. More specifically, this paper focuses on discovering planned knowledge from the performer-role entity-types of associations in workflow models. In other words, the paper tries to discover the planned performer-role affiliation networking knowledge (workflow build-time aspect) embedded in a workflow model; and so it gives a series of concepts and algorithms for discovering performer-role affiliation networking knowledge from an ICN-based workflow model.

In terms of making up the paper, the next section gives the technological background, mainly focusing on the ICN-based workflow model and its perspectives. The next sections expound the detailed formalisms and algorithms of modeling, discovering, and visualizing the planned performer-role affiliation networking knowledge. Finally, we give a summary, with a brief description of its related works, and draw conclusions including future works.

2. Preliminary

This section briefly introduces the basic concept of an ICN-based workflow model [1–3, 17] as a technological background for the planned workflow performer-role affiliation networking knowledge. In describing the ICN-based workflow model, we start from defining a workflow meta-model that is the theoretical basis of the ICN-based workflow model, and next we introduce the graphical notations and their formal representations of the model.

2.1 The Workflow Meta-Model

In describing an ICN-based workflow model, we would use the basic workflow terminology-workflow procedure, activity, job, work-case, role, actor/group, and invoked application, including web services. These terms become the primitive entity types to be composed into an ICN-based workflow model, and they also have appropriate relationships with each other, as shown in **Fig. 1**. The followings are the basic definitions of the primitive entity types:

- A workflow procedure is defined by a predefined or intended set of tasks or steps, called activities, and their temporal ordering of executions. A workflow management system helps to organize, control, and execute such defined workflow procedures. A workflow procedure can conclusively be described by a temporal order of the associated activities through combinations of sequential logic, conjunctive logic (after activity A, do activities B and C), disjunctive logic (after activity A, do activity B or C), and loop logic.
- An **activity** is a conceptual entity of the basic unit of work (task or step), and the activities in a workflow procedure have precedence relationships with each other, in terms of their execution sequences. Also, the activity can be precisely specified by one of the three entity types-compound activity, elementary activity, and gateway activity. The compound activity represents an activity containing another workflow procedure,

which is called a sub-workflow. The elementary activity is an activity that can be realized by a computer program, such as an application program, transaction, script, or web service. The gateway activities imply those activities that are used to control the execution sequences of elementary/compound activities. The types of gateway activities consist of conjunctive gateway (after activity A, do activities B and C), disjunctive gateway (after activity A, do activity B or C), and loop gateway. In particular, both the disjunctive gateway and the loop gateway need some specific **transition conditions** to be set in order to select one of the possible transition paths during the execution time. The transition condition itself can be defined by using the input/output relevant data in the **repository**. Additionally, each activity has to be associated with a real performer, such as organizational staff (role, participant) and system, who possesses all ownerships over that activity.

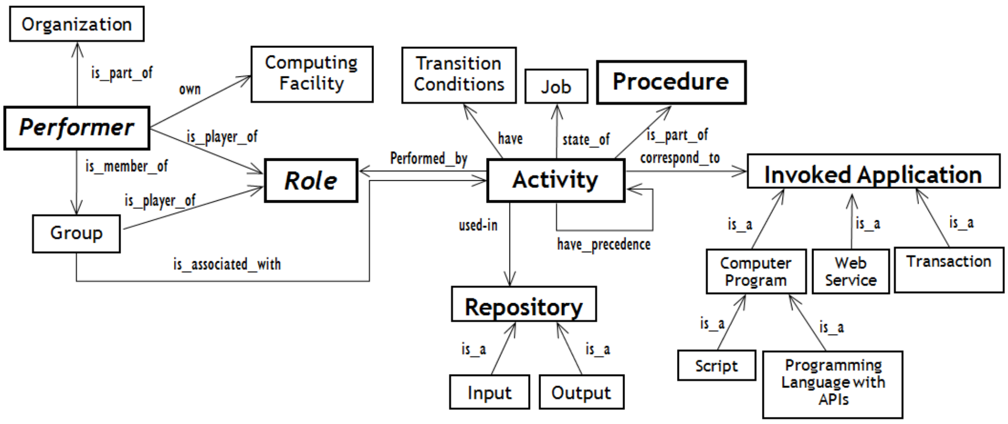


Fig. 1. The workflow meta-model

- A **role**, as a logical unit of the organizational structure, is a named designator for one or more participants, which conveniently acts as the basis for participating work, skill, access control, execution controls, authority, and responsibility over the associated activity.
- A **performer(actor)** is a person, program, or entity that can fulfill the roles of executing, of being responsible for, or of being associated in some way with activities and workflow procedures.
- Multiple instances of a workflow procedure may be in various stages of execution. Thus, the workflow procedure can be considered as a class (in object oriented terminology), and each execution, called a **workcase**, can be considered as an instance. A workcase is thus defined as the locus of control for a particular execution of a workflow procedure.
- An **invoked application program** that automatically performs the associated activity, or provides automated assistance within hybrid activities, is called s **script**. If an activity is executed in automatic or hybrid mode, this means that whole/part of the invoked application program associated with the activity is automatically launched by a workflow enactment service.
- Finally, a **repository** is a set of input and output relevant data of an activity. Eventually, the repository provides a communication channel between the workflow enactment domain and the invoked application programs domain. That is, the input and the output repositories are used to realizing the input parameters and the output parameters of the

associated invoked application program, respectively.

2.2 Information Control Net

The ICN-based workflow model can be defined by capturing the notations of workflow procedures, activities and their control precedence, invoked applications, roles, actors, and input/output repositories, as explained in the previous section of the workflow meta-model. In this section, we define the basic concept of the workflow model with respect to the formal and graphical descriptions of the ICN-based workflow model. The following [**Definition 1**] is a formal definition of the ICN-based workflow model, and its functional components to be used for retrieving workflow-related information, such as activity precedence (control flow), activity-role association, activity-relevant data association (data flow), activity-invoked application association, activity-transition condition association, and role-actor association information. Based upon these types of information, it is possible to retrieve several types of derived workflow-related information like activity-actor association, relevant data-invoked application association, role complexity, actor complexity information, and so forth.

[Definition 1] Information Control Net (ICN) for formally defining a workflow model. A basic **ICN** is a 9-tuple $\Gamma = (\delta, \rho, \gamma, \lambda, \varepsilon, \pi, \kappa, \mathbf{I}, \mathbf{O})$ over a set of **A** activities (including a set of group activities), a set of $\mathbf{E} \subseteq (\mathbf{A} \times \mathbf{A})$ edges (pairs of activities), a set **T** of transition conditions, a set **R** of repositories, a set **G** of invoked application programs, a set **P** of roles, and a set **C** of actors (including a set of actor groups), where **P**(**A**) represents a power set of the activity set, **A**:

- **I** is a finite set of initial input repositories, assumed to be loaded with information by some external process, before execution of the ICN;
- **O** is a finite set of final output repositories, perhaps containing information used by some external process after execution of the ICN;
- $\delta = \delta_i \cup \delta_o$
  where, δ_o: $\mathbf{A} \rightarrow \mathbf{P}(\mathbf{R})$ is a multi-valued mapping function from an activity, to its sets of (immediate) successors; and δ_i: $\mathbf{A} \rightarrow \mathbf{P}(\mathbf{R})$ is a multi-valued mapping function from an activity, to its sets of (immediate) predecessors;
- $\rho = \rho_i \cup \rho_o$
  where, ρ_o: $\mathbf{A} \rightarrow \mathbf{P}(\mathbf{A})$ is a single-valued mapping function from an activity, to its set of output repositories; and ρ_i: $\mathbf{A} \rightarrow \mathbf{P}(\mathbf{A})$ is a single-valued mapping function, from an activity, to its set of input repositories;
- $\gamma = \gamma_i \cup \gamma_o$
  where, γ_o: $\mathbf{R} \rightarrow \mathbf{P}(\mathbf{A})$ is a single-valued mapping function from an repository, to its set of out-degree activities; and γ_i: $\mathbf{R} \rightarrow \mathbf{P}(\mathbf{A})$ is a single-valued mapping function, from a repository, to its set of in-degree activities;
- $\lambda = \lambda_a \cup \lambda_g$
  where, λ_g: $\mathbf{A} \rightarrow \mathbf{G}$ is a single-valued mapping function, from an activity, to its invoked application program; and λ_a: $\mathbf{G} \rightarrow \mathbf{P}(\mathbf{A})$ is a single-valued mapping function, from an invoked application program, to its set of associated activities;
- $\varepsilon = \varepsilon_a \cup \varepsilon_p$

where, ε_p: $\mathbf{A} \rightarrow \mathbf{P}$ is a single-valued mapping function, from an activity, to a role; and ε_a: $\mathbf{P} \rightarrow \mathbf{P}(\mathbf{A})$ is a single-valued mapping function, from a role to its set of associated activities;

- $\pi = \pi_p \cup \pi_c$
  where, π_c: $\mathbf{P} \rightarrow \mathbf{P}(\mathbf{C})$ is a single-valued mapping function from a role, to its set of associated performers; and π_p: $\mathbf{C} \rightarrow \mathbf{P}(\mathbf{P})$ is a single-valued mapping function, from a performer, to its set of associated roles; and,
- $\kappa = \kappa_i \cup \kappa_o$
  where, κ_i: $\mathbf{E} \rightarrow \mathbf{P}(\mathbf{T})$ is a single-valued mapping function from an edge, to a set of control-transition conditions; and κ_o: $\mathbf{T} \rightarrow \mathbf{P}(\mathbf{E})$ is a single-valued mapping function, from a control-transition condition, to a set of edges.

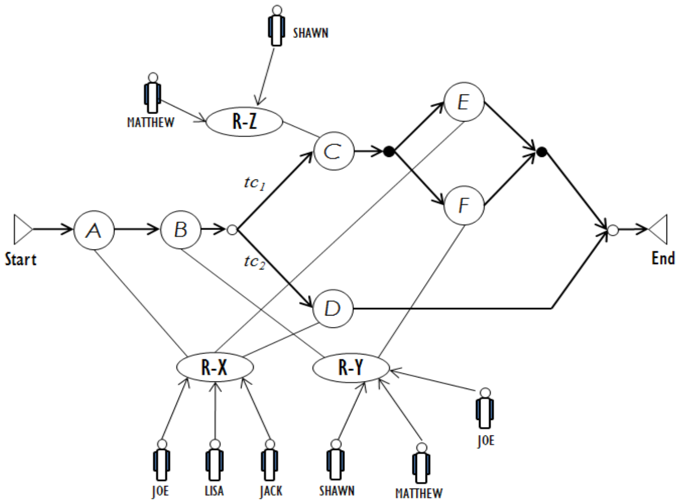


Fig. 2. Graphical Representation of an ICN-based Product-Order Workflow Model

As an example, we apply the information control net to a typical example of product-order workflow procedure [6], to formally and graphically describe the workflow procedure and to verify its applicability. **Fig. 2** shows a graphical representation of an ICN-based product-order workflow model that consists of two event-type activities (α_{Start}, α_{End}), two pairs of gateway-type activities ($\alpha_{\text{or\_split}}$, $\alpha_{\text{or\_join}}$, $\alpha_{\text{and\_split}}$, $\alpha_{\text{and\_join}}$), six normal activities (α_{A}, α_{B}, α_{C}, α_{D}, α_{E}, α_{F}), three roles ($\eta_{\text{R-X}}$, $\eta_{\text{R-Y}}$, $\eta_{\text{R-Z}}$), and five performers (ϕ_{jack} , ϕ_{joe} , ϕ_{lisa} , ϕ_{matthew} , ϕ_{shawn}). In terms of the graphical notations, the small triangles are start/end event activities, circles are normal activities, ovals are roles, human-shaped nodes are performers, small_hollow dots are OR split/join gateway activities, and small_filled dots are AND split/join gateway activities. The association relationships between nodes and between temporal orderings of activities are represented by straight lines and arrows, respectively. Note that we do not depict the relevant data repositories in this example, because the data flow aspects ($\rho = \rho_i \cup \rho_o$ and $\gamma = \gamma_i \cup \gamma_o$) are unrelated to the workflow performer-role affiliation networking knowledge.

Table 1 gives a formal representation of the ICN-based product-order workflow model. In particular, in the formal notation of the temporal orders of activity enactments ($\delta = \delta_i \cup \delta_o$), the OR gateway activities and the AND gateway activities are represented by set-forms of $\{\{\alpha_{\text{C}}\}, \{\alpha_{\text{D}}\}\}$ and $\{\{\alpha_{\text{E}}, \alpha_{\text{F}}\}\}$, respectively. Likewise, in the formal notations of other association relationships, OR memberships and AND memberships are denoted in the same set-forms of $\{\{\phi_{\text{shawn}}\}, \{\phi_{\text{matthew}}\}, \{\phi_{\text{joe}}\}\}$ and $\{\{\eta_{\text{R-X}}, \eta_{\text{R-Y}}\}\}$, respectively.

Table 1. Formal Representation of the ICN-based Product-Order Workflow Model

Γ=(δ, ε, π, κ) over **A**, **R**, **P**, **T** /* An ICN-based Product-Order Workflow Model
A = $\{\alpha_A,\alpha_B,\alpha_C,\alpha_D,\alpha_E,\alpha_F,\alpha_{or\_split},\alpha_{or\_join},\alpha_{and\_split},\alpha_{and\_join},\alpha_{start},\alpha_{end}\}$ /* Activities
R = $\{\eta_{R\text{-}X}, \eta_{R\text{-}Y}, \eta_{R\text{-}Z}\}$ /* Roles
P = $\{\phi_{jack}, \phi_{joe}, \phi_{lisa}, \phi_{matthew}, \phi_{shawn}\}$ /* Performers
T = {d(default), tc_1, tc_2} /* Transition Conditions
I = Ø /* Initial Input Repositories
O = Ø /* Final Output Repositories

$\delta = \delta_i \cup \delta_o$	$\delta_i(\alpha_{start}) = \varnothing$; $\delta_i(\alpha_A) = \{\{\alpha_{start}\}\}$; $\delta_i(\alpha_B) = \{\{\alpha_A\}\}$; $\delta_i(\alpha_C) = \{\{\alpha_B\}\}$; $\delta_i(\alpha_D) = \{\{\alpha_B\}\}$; $\delta_i(\alpha_E) = \{\{\alpha_C\}\}$; $\delta_i(\alpha_F) = \{\{\alpha_C\}\}$; $\delta_i(\alpha_{end}) = \{\{\alpha_D\}, \{\alpha_E, \alpha_F\}\}$;	$\delta_o(\alpha_{start}) = \{\{\alpha_A\}\}$; $\delta_o(\alpha_A) = \{\{\alpha_B\}\}$; $\delta_o(\alpha_B) = \{\{\alpha_C\}, \{\alpha_D\}\}$; $\delta_o(\alpha_C) = \{\{\alpha_E, \alpha_F\}\}$; $\delta_o(\alpha_D) = \{\{\alpha_{end}\}\}$; $\delta_o(\alpha_E) = \{\{\alpha_{end}\}\}$; $\delta_o(\alpha_F) = \{\{\alpha_{end}\}\}$; $\delta_o(\alpha_{end}) = \varnothing$;
$\varepsilon = \varepsilon_a \cup \varepsilon_r$	$\varepsilon_r(\alpha_{start}) = \varnothing$; $\varepsilon_r(\alpha_A) = \{\eta_{R\text{-}X}\}$; $\varepsilon_r(\alpha_B) = \{\eta_{R\text{-}Y}\}$; $\varepsilon_r(\alpha_C) = \{\eta_{R\text{-}Z}\}$; $\varepsilon_r(\alpha_D) = \{\eta_{R\text{-}X}\}$; $\varepsilon_r(\alpha_E) = \{\eta_{R\text{-}X}\}$; $\varepsilon_r(\alpha_F) = \{\eta_{R\text{-}Y}\}$; $\varepsilon_r(\alpha_{end}) = \varnothing$;	$\varepsilon_a(\eta_{R\text{-}X}) = \{\alpha_A, \alpha_D, \alpha_E\}$; $\varepsilon_a(\eta_{R\text{-}Y}) = \{\alpha_B, \alpha_F\}$; $\varepsilon_a(\eta_{R\text{-}Z}) = \{\alpha_C\}$;
$\pi = \pi_r \cup \pi_p$	$\pi_p(\eta_{R\text{-}X}) = \{\{\phi_{jack}\}, \{\phi_{jo}\}_e, \{\phi_{lisa}\}\}$; $\pi_p(\eta_{R\text{-}Y}) = \{\{\phi_{shawn}\}, \{\phi_{matthew}\}, \{\phi_{joe}\}\}$; $\pi_p(\eta_{R\text{-}Z}) = \{\{\phi_{matthew}\}, \{\phi_{shawn}\}\}$;	$\pi_r(\phi_{jack}) = \{\eta_{R\text{-}X}\}$; $\pi_r(\phi_{joe}) = \{\eta_{R\text{-}X}, \eta_{R\text{-}Y}\}$; $\pi_r(\phi_{lisa}) = \{\eta_{R\text{-}X}\}$; $\pi_r(\phi_{shawn}) = \{\eta_{R\text{-}Y}, \eta_{R\text{-}Z}\}$; $\pi_r(\phi_{matthew}) = \{\eta_{R\text{-}Y}, \eta_{R\text{-}Z}\}$;
$\kappa = \kappa_i \cup \kappa_o$	$\kappa_i(\alpha_{start}) = \varnothing$; $\kappa_i(\alpha_A) = \{d\}$; $\kappa_i(\alpha_B) = \{d\}$; $\kappa_o(\alpha_C) = \{d\}$; $\kappa_i(\alpha_D) = \{tc_2\}$; $\kappa_i(\alpha_E) = \{d\}$; $\kappa_i(\alpha_F) = \{d\}$; $\kappa_i(\alpha_{end}) = \{d\}$;	$\kappa_o(\alpha_{start}) = \{d\}$; $\kappa_o(\alpha_A) = \{d\}$; $\kappa_o(\alpha_B) = \{\{tc_1\}, \{tc_2\}\}$; $\kappa_o(\alpha_C) = \{d\}$; $\kappa_o(\alpha_D) = \{d\}$; $\kappa_o(\alpha_E) = \{d\}$; $\kappa_o(\alpha_F) = \{d\}$; $\kappa_o(\alpha_{end}) = \varnothing$;

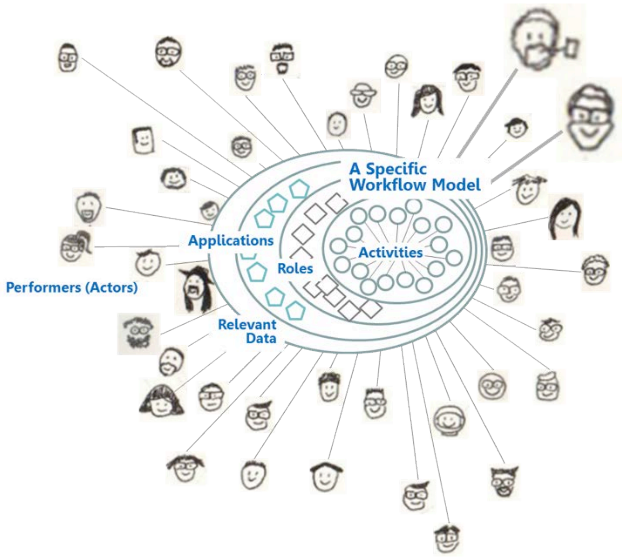
3. Modeling the Knowledge

This section starts by introducing the basic concept of workflow performer-role affiliation networking knowledge. Next, we define the formal and mathematical representations of the knowledge, and describe an algorithmic approach to generate a bipartite matrix from the formal representation of the proposed knowledge.

3.1 Performer-Role Affiliation Relationships

Workflow management systems are "human-centered systems," because workflows must be designed, deployed, and understood within their social and organizational contexts, and because, at the same time they must be conveyed, facilitated, and navigated in large-scaled operational knowledge collections. Individuals as employees in workflow-supported organizations work intra-organizationally and inter-organizationally, under the controls of workflow enactment systems. We assume that the workflow model is described as the information control net (ICN) of [Definition 1]. It is important to know the human-centered affiliation relationships that reveal how each of the individuals is associated with the essential entity-types of the ICN-based workflow model, such as activity, role, application, and relevant data, as defined in [Definition 1]. **Fig. 3** illustrates the human-centered affiliation relationships in a specific ICN-based workflow model. There are four types of human-centered affiliation networking knowledge of an ICN-based workflow model as follows:

- Performer-Activity Affiliation Networking Knowledge
- Performer-Role Affiliation Networking Knowledge
- Performer-Application Affiliation Networking Knowledge
- Performer-Relevant Data Affiliation Networking Knowledge



- **Fig. 3.** Human-Centered Affiliation Relationships in a Specific Workflow Model

The essential performer-role human-centered knowledge that is considered as the primary knowledge of discovery in this paper implies a workflow membership network that represents the involvement (or participation) of a set of performers, with a set of roles, in a corresponding workflow model. That is, workflow performers (or actors) are linked through their joint participation in performing roles; conversely, workflow roles are connected to some performers, who have the same role in common. Through the workflow performer-role affiliation networking knowledge, it is possible to visualize how performers and roles are simultaneously interrelated in a workflow model or package. The main purpose of this paper is to theoretically develop a means, which is called the “workflow performer-role affiliation network model”, for discovering and visualizing performer-role affiliation knowledge, in workflow-supported organizations.

3.2 Formal and Mathematical Modeling of the Knowledge

In order to represent the workflow performer-role affiliation networking knowledge, the paper newly defines a graphical (bipartite graph) and formal representation model, which is dubbed the workflow performer-role affiliation network model. A workflow performer-role affiliation network model, which is abbreviated as PRANM, consists of two types of nodes, a set of performers and a set of roles, and a set of relationships between the nodal types. Thus, a workflow performer-role affiliation network is a two-mode network, which is mathematically represented in both a bipartite graph and a bipartite matrix, through which it is used to accomplish the following dual objectives:

- To uncover the relational structures of workflow-performers through their joint involvement in roles; and
- to reveal the relational structures of workflow-roles through their joint participation of common performers.

Additionally, those relational structures can be weighed to measure the extent of their strengths by assigning a value to each of the relationships between nodal types. There are two types of performer-role affiliation networks the binary performer-role affiliation network and the valued performer-role affiliation network. In the binary performer-role affiliation network, its value (0 or 1) implies a binary relationship of involvement (or participation); whereas, values in the valued performer-role affiliation network may represent various implications, according to their application domains. Typical examples of values might be stochastic (or probabilistic) values, strengths, and frequencies. The formal knowledge representation of the workflow performer-role affiliation network model is defined in [Definition 2].

[**Definition 2**] **Workflow Performer-Role Affiliation Network Model (PRANM)**. The workflow performer-role affiliation network model is formally defined as the 3-tuple formula, $\Lambda = (\sigma, \psi, \mathbf{S})$, over a set $\mathbf{C}$ of performers(actors), a set $\mathbf{P}$ of roles, a set $\mathbf{V}$ of weight-values, a set $\mathbf{E_p} \subseteq (\mathbf{C} \times \mathbf{P})$ of edges (pairs of performers and roles) and a set $\mathbf{E_a} \subseteq (\mathbf{P} \times \mathbf{C})$ of edges (pairs of roles and performers), where, $\mathbf{P}(\mathbf{P})$ represents a power set of the role set, $\mathbf{P}$:

- $\mathbf{S}$ is a finite set of work-sharing performers or groups, of some external workflow performer-role affiliation network models;
- $\sigma = \sigma_p \cup \sigma_v$
  where, σ_p: $\mathbf{C} \rightarrow \mathbf{P}(\mathbf{P})$ is a single-valued mapping function, from a performer, to its set of involved roles; σ_v: $\mathbf{E_p} \rightarrow \mathbf{V}$ is a single-valued mapping function, from an edge ($\in \mathbf{E_p}$) to its weight-value; and,
- $\psi = \psi_a \cup \psi_v$
  where, ψ_a : $\mathbf{P} \rightarrow \mathbf{P}(\mathbf{C})$ is a single-valued mapping function, from a role, to a set of participated performers; and ψ_v : $\mathbf{E_a} \rightarrow \mathbf{V}$ is a single-valued function, from an edge ($\in \mathbf{E_a}$) to its weight-value.

The graphical representation of the knowledge is depicted by an affiliated performer-role bipartite graph. So, a workflow performer-role affiliation network's graphical model consists of two types of graphical nodes -a set of performers (of circular shape), and a set of roles (of oval shape) - and a set of non-directed edges between the nodal types, which means that a workflow performer-role affiliation network is a non-directed and bipartite graph. In an affiliated performer-role affiliation graph, non-directed lines connect performers aligned on one side of the diagram to the roles aligned on the other side. Importantly, an affiliated performer-role affiliation graph does not permit lines among the performers, nor among the roles themselves. Mathematically, an affiliated performer-role affiliation graph with g performers and h roles can be transformed into a bipartite matrix with 2-dimension of $g \times h$.

4. Discovering the Knowledge

It is important to emphasize that workflow performer-role affiliation networking knowledge is not modeled or designed, but is automatically discovered from a workflow procedure, or a group of workflow procedures. So, this paper devises an algorithmic discovery methodology to discover workflow performer-role affiliation knowledge, which is represented by the workflow performer-role affiliation network model, by exploring the internal social perspectives ($\pi = \pi_p \cup \pi_c$: role-performer mapping relationships) of an ICN-based workflow model. The following is the algorithm to automatically discover a workflow performer-role affiliation network model from an ICN-based workflow model:

Performer-Role Affiliation Knowledge Discovering Algorithm:
Input An ICN, $\Gamma = (\delta, \rho, \tau, \lambda, \varepsilon, \pi, \kappa, \mathbf{I}, \mathbf{O})$;
Output A Binary Workflow Performer-Role Affiliation Network Model, $\Lambda = (\sigma, \psi, \mathbf{S})$;

Begin Procedure
  For ($\forall \phi \in \mathbf{C}$) **Do** /* For all members of the performer set, **C** */
    Begin
      Add *all members of* $\pi_p(\phi)$ **To** $\sigma_p(\phi)$;
      Set "*weight-value* ← 1" **To** σ_v(*all edges of* $(\phi, \sigma_p(\phi))$);
    End

  For ($\forall \eta \in \mathbf{P}$) **Do** /* For all members of the role set, **P** */
    Begin
      Add *all members of* $\pi c(\eta)$ **To** $\psi_a(\eta)$;
      Set "*weight-value* ← 1" **To** ψ_v(*all edges of* $(\eta, \psi_a(\eta))$);
    End
End Procedure

As stated in the previous section, there are two types of workflow performer-role affiliation network models: one is binary, the other is valued. The current knowledge discovering algorithm shows only the discovery of a binary workflow performer-role affiliation network model from an ICN-based workflow model, because no weighted relationships nor any meaningful semantics except existence relationships, are applied to the involvement and participation relationships between performers and roles. If each of the relationships has something to do with differentiated values or weights, except existence relationships, the algorithm has to assign corresponding values greater than 1.0 to the variable, "*weight-value*." Then, it implies that the algorithm is able to discover a valued performer-role affiliation network model from an ICN-based workflow model.

As an example, we apply the knowledge discovering algorithm to the ICN-based product-order workflow model [6], in order to verify that the algorithm works correctly. The input of the algorithm is the internal property sets of the ICN-based product-order workflow model formally described in **Table 1**. The formal representation is not a full description of the original ICN-based workflow model, but just covers a partial description, showing only the temporal precedence of activities (δ), assignment of roles (ε), association of performers (π), and the transition conditions (κ) that are directly related to the point of view of the social perspective. **Fig. 4** and **Table 2** depict the graphical and formal representations, respectively of the performer-role affiliation network model discovered by the knowledge discovery algorithm. As can be seen, the discovered performer-role affiliation network model represents the involvement knowledge (σ), as well as the participation knowledge (ψ), between the performers and the roles associated with the ICN-based product-order workflow model of **Fig. 1**.

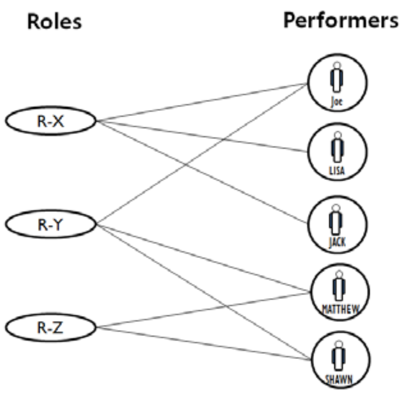


Fig. 4. Graphical Representation of the Discovered Performer-Role Affiliation Network Model

Table 2. Formal Representation of the Discovered Performer-Role Affiliation Network Model.

$\Lambda = (\sigma, \psi, \mathbf{S})$ over **C**, **P**, S /* A Workflow Performer-Role Affiliation Network Model $\mathbf{C} = \{ \phi_{jack}, \phi_{joe}, \phi_{lisa}, \phi_{matthew}, \phi_{shawn} \}$ /* Performers $\mathbf{P} = \{ \eta_{R\text{-}X}, \eta_{R\text{-}Y}, \eta_{R\text{-}Z} \}$ /* Roles $\mathbf{S} = \varnothing$ /* Performers of External Workflow PRANMs		
$\sigma = \sigma_p \cup \sigma_v$ (Involvement knowledge)	$\sigma_p(\phi_{jack}) = \{\{\eta_{R\text{-}X}\}\}$; $\sigma_p(\phi_{joe}) = \{\{\eta_{R\text{-}X}, \eta_{R\text{-}Y}\}\}$; $\sigma_p(\phi_{lisa}) = \{\{\eta_{R\text{-}X}\}\}$; $\sigma_p(\phi_{matthew}) = \{\{\eta_{R\text{-}Y}, \eta_{R\text{-}Z}\}\}$; $\sigma_p(\phi_{shawn}) = \{\{\eta_{R\text{-}Y}, \eta_{R\text{-}Z}\}\}$;	$\sigma_v(\phi_{jack}, \eta_{R\text{-}X}) = \{\{1\}\}$; $\sigma_v(\phi_{joe}, \eta_{R\text{-}X}) = \{\{1\}\}$; $\sigma_v(\phi_{joe}, \eta_{R\text{-}Y}) = \{\{1\}\}$; $\sigma_v(\phi_{lisa}, \eta_{R\text{-}X}) = \{\{1\}\}$; $\sigma_v(\phi_{matthew}, \eta_{R\text{-}Y}) = \{\{1\}\}$; $\sigma_v(\phi_{matthew}, \eta_{R\text{-}Z}) = \{\{1\}\}$; $\sigma_v(\phi_{shawn}, \eta_{R\text{-}Y}) = \{\{1\}\}$; $\sigma_v(\phi_{shawn}, \eta_{R\text{-}Z}) = \{\{1\}\}$;
$\psi = \psi_a \cup \psi_v$ (Participation knowledge)	$\psi_a(\eta_{R\text{-}X}) = \{\{\phi_{jack}, \phi_{joe}, \phi_{lisa}\}\}$; $\psi_a(\eta_{R\text{-}Y}) = \{\{\phi_{joe}, \phi_{matthew}, \phi_{shawn}\}\}$; $\psi_a(\eta_{R\text{-}Z}) = \{\{\phi_{matthew}, \phi_{shawn}\}\}$;	$\psi_v(\eta_{R\text{-}X}, \phi_{jack}) = \{\{1\}\}$; $\psi_v(\eta_{R\text{-}X}, \phi_{joe}) = \{\{1\}\}$; $\psi_v(\eta_{R\text{-}X}, \phi_{lisa}) = \{\{1\}\}$; $\psi_v(\eta_{R\text{-}Y}, \phi_{joe}) = \{\{1\}\}$; $\psi_v(\eta_{R\text{-}Y}, \phi_{matthew}) = \{\{1\}\}$; $\psi_v(\eta_{R\text{-}Y}, \phi_{shawn}) = \{\{1\}\}$; $\psi_v(\eta_{R\text{-}Z}, \phi_{matthew}) = \{\{1\}\}$; $\psi_v(\eta_{R\text{-}Z}, \phi_{shawn}) = \{\{1\}\}$;

5. Visualizing the Knowledge

In this section, we start by defining a theoretical and systematical framework for modeling, discovering, and visualizing the workflow performer-role affiliation networking knowledge, which is used for implementing the knowledge visualization system. As depicted in **Fig. 5**, we devise not only a series of theoretical algorithms but also a series of implementing algorithms related to the framework. Next, we describe the details of an implemented system, such as the system architecture, and the system's visualization results. The implemented system eventually provides meaningful knowledge of how performers and roles are simultaneously interrelated (involvement and participation) in enacting the corresponding workflow models.

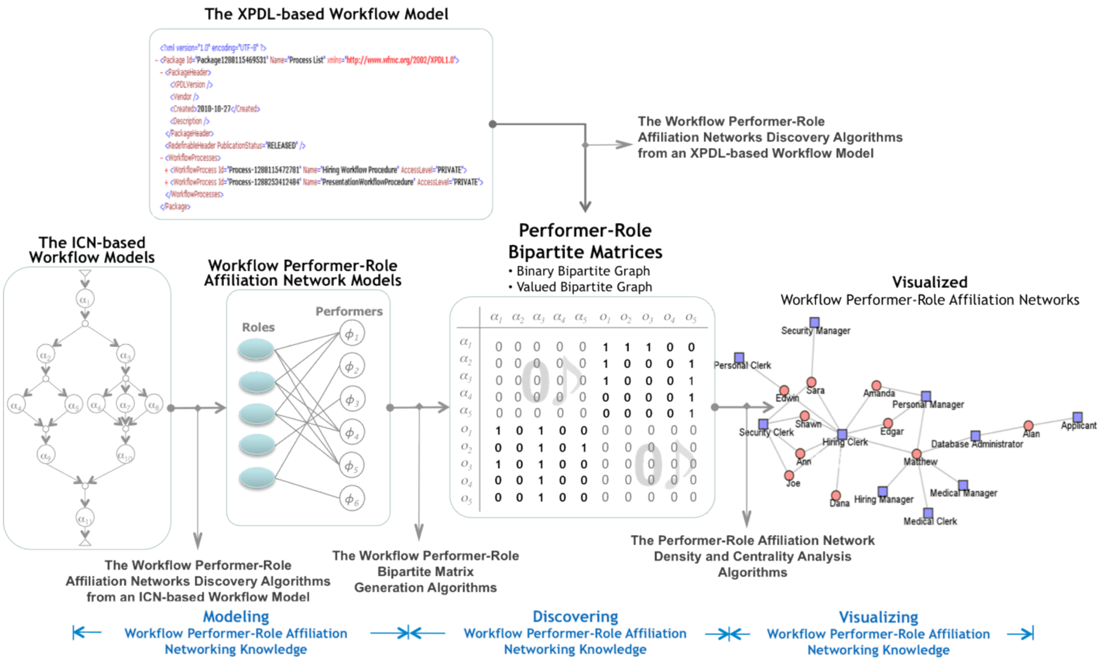


Fig. 5. The Theoretical and Systematical Framework for the Workflow Performer-Role Affiliation Networking Knowledge

Fig. 5 illustrates a knowledge visualization framework for two paths of visualization: a theoretical path, and a systematic path. The theoretical path has already been elaborated through the previous sections of modeling and discovering the knowledge, while the systematic path is described as the main part of this section. The systematic path copes with dissolving an XPDL-based workflow model, through to analyzing and visualizing and the discovered workflow performer-role affiliation networking knowledge conducted by the system. The systematic knowledge visualization framework is realized through three essential functionalities: those knowledge discovery functionality, performer-role bipartite matrix analysis functionality, and knowledge visualization functionality. Eventually, the system colorfully visualizes the workflow performer-role affiliation networking knowledge, also called the human-resources allotting knowledge, by analytically illustrating the involvement of a set of performers with a set of roles, in enacting the underlying workflow model. Performers are linked through their joint participation in workflow roles, or by their common work-sharing networks in organizations. Conversely, workflow roles are connected to those performers who have the same role in common. The workflow performer-role bipartite matrix is an eventual target of both the theoretical path and the systematic path to be used, to visualize the workflow performer-role affiliation networking knowledge.

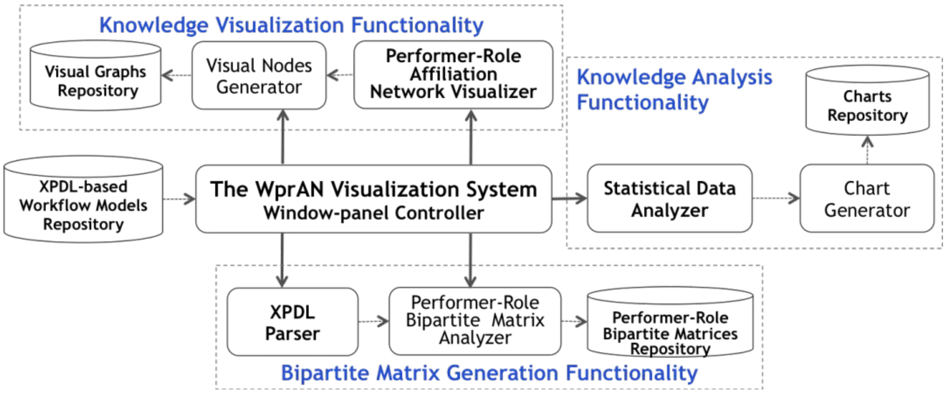


Fig. 6. The Systematical Architecture for the Workflow Performer-Role Affiliation Networking Knowledge Discovery and Visualization System

Based upon the knowledge visualization framework, we implement a workflow performer-role affiliation networking knowledge visualization system that is able to model, discover, and visualize the affiliated performer-role relationships as workflow performer-role affiliation networking knowledge. In **Fig. 6**, we depict a systematic architecture made up of three groups of essential components in the implemented knowledge visualization system. The essential functional component-groups are bipartite matrix generation functionality, knowledge visualization functionality, and knowledge analysis functionality. These component-groups are systematically implemented by using the Java programming language. In particular, the XPDL parser of the analysis component-group takes charge of generating a performer-role bipartite matrix from an XPDL-based workflow model, and the performer-role affiliation network visualizer of the knowledge visualization component-group depicts the knowledge as a colorful bipartite graph transformed from the bipartite matrix. In terms of the knowledge analysis aspect, the system is theoretically backed up by the extended versions of the workload-centrality analysis equations [16], such as actor-degree centrality analysis equations and group-degree centrality analysis equations, so as to mathematically analyze a workflow performer-role affiliation network model, discovered from an XPDL-based workflow model.

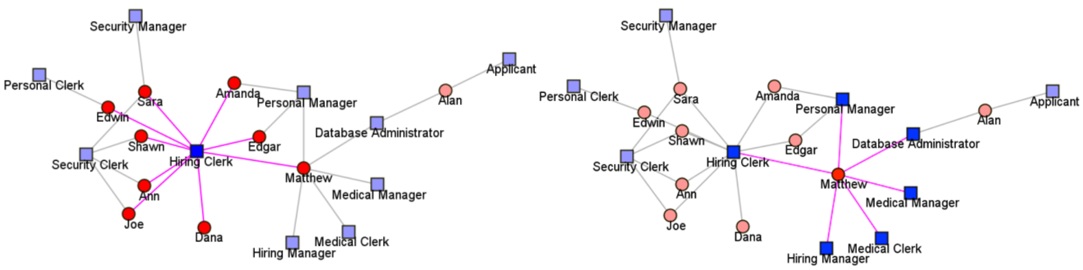


Fig. 7. The Visualization Examples of the Workflow Performer-Role Affiliation Networking Knowledge Systematically Generated by the Implemented System

Fig. 7 shows screen-captures depicting two operational examples of the workflow performer-role affiliation networking knowledge, systematically drawn by the implemented system. The blue-colored rectangles represent the roles, and the red-colored circles are the performers in the corresponding workflow models. The left-hand side of the figure shows that the specific role (Hiring clerk) of dark-blue rectangle is affiliated with nine performers of dark-red circles; whereas, the right-hand side of the figure gives the affiliated status of the specific performer (Matthew) who is affiliated with six roles of dark-blue rectangles in the corresponding workflow models.

The system's development environments are listed as follows. In particular, we suppose that the XPDL workflow model's release version is XPDL 1.0. So, it is necessary to be extended to support the recently released version of XPDL 2.0 (or higher), which reflects the BPMN that stands for business process modeling notations, and which was released by the OMG's BMI (Business Modeling & Integration) Domain Task Force.

- Operating System: Windows 7 Ultimate 64bit
- Programming Language: Java Development Toolkit v.6.0
- XPDL Version: XPDL 1.0
- Development Tool: Eclipse Indigo Release 2
- Libraries: Awt/Swing, Prefuse, Xpdl

6. Related Work

Recently, technology-supported social networks and organizational behavioral analytics issues [13, 14, 23, 24] have been raised in the IT literature. Naturally, the workflow literature has just started to transit to, and focus on, social and collaborative work analysis of process-oriented organizations. In particular, our work, in workflow-supported affiliation networking knowledge discovery, is directly related to a converged issue of the model-log comparison issue and the social networking knowledge discovery and analysis issue. With respect to this converged issue, there have been two main branches of research approaches: the workflow-supported social networking knowledge *discovery* issue and the workflow-supported social networking knowledge *rediscovery* issue.

The workflow-supported social networking knowledge rediscovery issue stems from the workflow mining issue, which tries to rediscover workflow processes from workflow execution event logs; while on the other hand, the workflow-supported social networking knowledge discovery issue, which explores social aspects or human behaviors from workflow models, hasn't been attracting attentions in the literature, as of yet. A typical research publication concerning the rediscovery issue might be [15], in which the authors suggested a methodology and system to rediscover social networks from the petri-net based workflow enactment event logs. Also, many research groups have so far pointed out the necessity of rediscovering actor or human behaviors from workflow enactment event logs through those publications, [4–7, 9, 11–13, 19]. In particular, [19] proposed an automatic rediscovery framework, covering almost all the perspectives of the workflow meta-model including the actors' behaviors; however, it did not directly cope with the social networking knowledge discovery and analysis issues.

A typical research result of several of the workflow-supported social networking knowledge discovery issue might be [18]. In this Ph.D. research, the thesis tried to build a fundamental theory of discovering organizational work-sharing networks, which would be a special type of social networks, from a specific workflow procedure. The organizational work-sharing networks discovered from the workflow procedure consist of two kinds of networks: one is the role-based organizational work-sharing network, and the other is the human-based organizational work-sharing network. Also, the thesis suggested a new statistical analysis approach for analyzing organizational work-sharing networks; however, the proposed statistical approach is not directly related to the social networking knowledge analysis methods. The most recently published research results on the discovery issue might be [20] and [21]. Through these two research publications, the authors proposed a conceptual framework and implemented the framework only for discovering workflow-supported social networks from ICN-based workflow models.

Fortunately, this special type of workflow-supported social networking knowledge, the workflow performer-role affiliation networking knowledge proposed in this paper, has been first addressed in [22] and [26]. The present paper is the conceptual and contextual extension of [22] and [26]. It should thus be possible to once again raise the discovery and rediscovery issues in the workflow literature. Through this paper, we have shown a possible approach for the workflow-supported affiliation networking knowledge discovery issues.

7. Conclusion

The recent trends in working environments require new types of enterprise information systems, which not only provide collaborative working facilities, but also the means by which a group of people work together simultaneously. A typical enterprise information system that satisfies this requirement is undoubtedly a large-scale workflow management system with increasingly large and complex workflow applications. The large-scale workflow management system ought to reflect the typical organizational perspectives, like behavioral, social, informational, collaborative, and historical perspectives, which implies that it is a "human conceptual system" that must be designed, deployed, and understood within their social and organizational contexts. It also starts from the strong belief that the relationships and collaborative behaviors among people who are involved in enacting specific workflow procedures affect the overall performance, and that this approach may lead to great success in real businesses and in working productivity.

In this paper, we suggested a possible way of projecting a special affiliation knowledge of the workflow-supported affiliation relations (involvement and participation behaviors) between workflow-based people and workflow-based roles by converging the social network techniques and the workflow discovering and rediscovering techniques. As a consequence of this suggestion, we newly defined a term, workflow performer-role affiliation networking knowledge, and proposed an algorithm to discover a performer-role affiliation network model from an ICN-based workflow model. Additionally, this paper visualizes a special type of workflow performer-role affiliation networking knowledge, which effectively exhibits the work-sharing relationships and collaborative behaviors among workflow performers. That is, we have conceived a knowledge visualization framework that is designated only for visualizing the knowledge defined in this paper, and realized the framework through implementing the workflow performer-role affiliation networking knowledge visualization system. Conclusively, we successfully verified the proposed algorithms, through application to the product-order workflow model already introduced in our research group's previous work.

However, the proposed algorithms only work for very limited functionality. In other words, they don't cover the performer-role affiliation knowledge analysis and rediscovery issues. So, we would leave those insufficient functionalities to the future works of this paper. In particular, the author's research group, in the near future, would try to extend the basic ideas of the performer-role affiliation knowledge discovery issue to the rediscovery issue.

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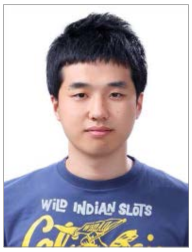

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