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A formal model for intellectual relationships among knowledge workers and knowledge organizations ☆

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ABSTRACT

An academic learning network consists of multiple knowledge organizations and knowledge workers. The intellectual relationships can be derived from the interactions among them. In this paper, we propose a formal model to describe the interactions in an academic learning network and further provide an evaluation process to quantify intellectual relationships. Our approach is also integrated with a realistic social network platform SMNET.

1. Introduction

The analysis of social network relationships becomes a critical issue in recent years. People build their own network and connect to others by sharing their interests (e.g. photos, videos, articles, etc.) on specific platforms (e.g. Google+, Facebook, etc.). These platforms support approaches to analyse the information provided by users and further discover potential relationships among users. Numerous approaches including graph theory, information retrieval and machine learning techniques are used to evaluate the relationships among users and groups in conventional social networks. Such relationships will also be significant in defining metrics for commercial purpose (e.g. in advertisement and in recommendation systems).

An academic learning network can be considered as another type of social network. An academic learning network consists of knowledge workers and knowledge organizations. Knowledge workers/organizations publish/upload their papers and view/download other publications. Knowledge workers can cooperate with others in an knowledge organization for the same research goal or compete with knowledge workers in other knowledge organizations. However, there are few discussions about how to model and analyze these intellectual relationships among different academic organizations.

In this paper, we propose a formal model to describe the intellectual relationships of an academic network. Combined with existing social network platform, the relationships among different people/groups in academic learning network can be visualized and further provide more information about an academic learning network.

Our main contributions are as follows:

1. We propose a formal ownership model to describe academic learning networks.
2. This model can be combined with social graph to visualize intellectual relationships.
3. This model also provides significant and flexible characteristic metrics to evaluate relationships without using sophisticated algorithms.

The intellectual relationships would allow us to recognize who are the collaborators and who are the competitors in an academic learning network. Slow Intelligence

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principles [5] can then be applied so that the academic learning network can achieve its learning goals.

The paper is organized as follows: In Section 2 we present the background and previous works regarding academic learning network. The formal model will be presented in Section 3. In Section 4, we introduce extended social graph, and then we propose an evaluation approach in Section 5. Finally, we describe a case study on academic learning network implemented in SMNET platform.

2. Related work and background

Social network analysis uses different metrics (measures) for evaluating the relationships among various individuals in social network, e.g. centrality, degree and closeness and so on [2]. Most of these metrics are based on the relationships of nodes and links in social network and then using graph theory to analyze the relationships. In the proposed model, in addition to the above static metrics, we further consi der various dynamic situations in the academic learning network.

Some analysis utilizes software such as UCInet [4] to help explore various type of social networks with visualization and further investigation. Our ownership model is applicable in a realistic academic learning network SMNET [1], which is integrated with Intellectual Property Rights (IPR) model to formalize an institutional aggregator for metadata and content. In addition to traditional social graph, SMNET can represent hierarchical levels in an academic learning network, from individual worker to academic organization. Users can describe their network with our formal descriptions, and upload their contents to the academic learning network. The content could be academic publications, technical reports and the social graph can be generated automatically.

For the evaluation of relationships in academic learning network, many researchers [6,7] use bibliometric approaches such as citation and co-citation analysis to estimate the relationships in the network. The results can be used for finding strategic alliance or identifying the structure of invisible colleges. Our formal model also can include citation and co-citation metrics, because the source of these two metrics can be obtained from the references in a publication. Furthermore, out model can be extended to evaluate the degree of cooperation and competition in an academic learning network.

3. Ownership model

In this section, we first introduce the concept of an academic learning network. Then we present the definition of our proposed ownership model and illustrate an academic network with the proposed ownership model.

3.1. Academic learning network

The concept of an academic social network is that people are connected with each other by sharing their knowledge. Hence, in an academic learning network, in additional to the knowledge itself, there are other two significant elements: knowledge worker and knowledge organization, since knowledge provider can be an individual or a group of people. Furthermore, the interactions of these knowledge providers reflect various degree of relationships among them.

3.1.1. Knowledge worker

Individual researchers in an institution or graduate students in a university have their own research interests. These individuals are instances of knowledge workers. If several knowledge workers share common research interests or other common features, they form a knowledge worker class. A knowledge worker class is a type of abstracted knowledge worker.

3.1.2. Knowledge organization

Knowledge organization can be regarded as an aggregate of knowledge workers, e.g. universities or research institutes are made out of different types of knowledge workers. We can further distinguish different types (classes) of knowledge organizations, such as a university medical school or a research institute on human-computer interaction.

3.1.3. Examples of academic learning networks

Fig. 1a shows an example of an academic learning network. Ben and John are individual researchers and they have the same research interests, so they will be classified as the same type of knowledge worker (KW_1). Mike belongs to another type of knowledge worker (KW_2). All of them are the members of an institution which means they are in the same knowledge organization (KO_1). Researchers publish their

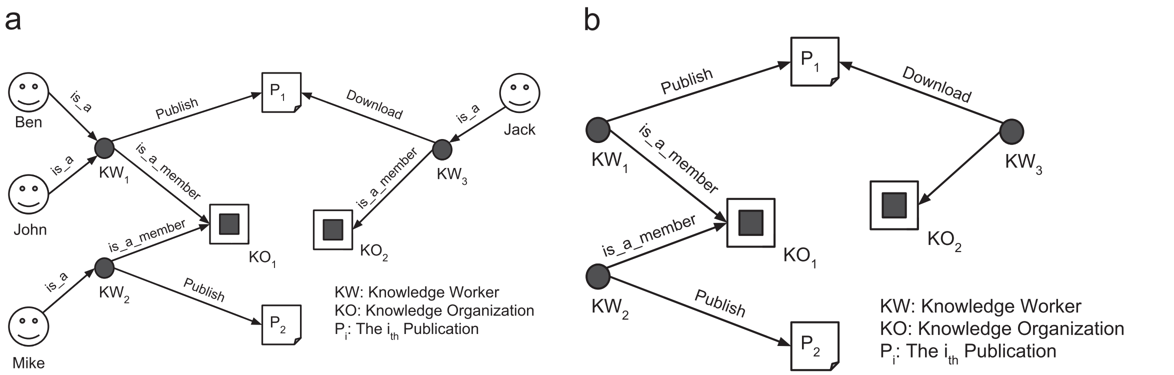


Fig. 1. Examples of academic learning network. (a) an example of academic learning network and (b) an example of abstracted academic learning network.

research papers. Ben in KW_1 publishes P_1, Mike in KW_2 publishes P_2 and also view/download academic paper from other knowledge workers (e.g. Jack is a type of KW_3 belonging to KO_2 and he can download P_1). Workers/Organization have the ownership of their publications and can assign specific permission for their publications. The academic learning network can be modeled through multiple workers/organizations and their interactions. To reduce the complexity of modeling process, we can also abstract the academic social network by concentrating on the interactions among classes of knowledge workers as illustrated in Fig. 1b.

3.2. Definition of formal ownership model

In this section, we introduce our proposed ownership model. DISIT [3] describes a set of formal definition for Intellectual Property Right (IPR) model for Sentient Multimedia Network (SMNET) Platform. We construct our formal ownership model based upon their definitions and further refine them for academic learning network so our ownership model can be seamlessly integrated into the SMNET platform. In the following, we first explain the meaning of each formal ownership model concept and then we present the mapping between formal ownership model and IPR Model in SMNET.

3.2.1. Formal definition

An academic learning network is a graph *G* where the nodes are knowledge workers, knowledge worker classes and knowledge organizations, and links are relationships among these entities.

An abstracted academic learning network is a graph *AG* where the nodes are knowledge worker classes and knowledge organizations, and links are relationships among these entities. Usually AG is obtained from G by removing the nodes representing knowledge workers and dangling links without anchoring nodes.

The node types, node attributes, link types and link attributes are from the following:

- PID:={$PID_1 \ldots PID_n$} is the set of publication IDs, where each publication has its unique ID as its identification.
- WID:={$WID_1 \ldots WID_n$} is the set of worker IDs, where each knowledge worker has its unique ID as its identification.
- OID:={$OID_1 \ldots OID_n$} is the set of organization IDs, where each organization has its unique ID as its identification.
- Description:={Dublin core, taxonomy, technical, etc.} is the set of possible model text descriptions.
- ContentKind:= Journal, Conference, Workshop, etc.} is the set of publication categories.
- Right :={ViewAll, viewPartial, download, etc.}
- UserKind :={user role, user preference, etc.}
- Permission:={ContentKind, Right, UserKind} is the set of permission depending on ContentKind and UserKind to map corresponding action rights.
- Access History:={Who, When, What, Frequency} is the set of access history attributes of each publication.
- Relationships:={author, member, leader…} is the set of relat ionships among workers, organizations and publications.

3.2.2. Ownership model

In SMNET, license models (LM) describe the ownership relationship among users, groups and objects. To represent the ownership in academic learning network, we describe a filter concept with license model to achieve the purpose of granting or denying permissions.

(A) License model (*LM*): A license model is composed of a set of permissions for each user kind plus a license model. Therefore the permissions are rights plus conditions. The expression for license model is

$$LM_i = P_i + L,$$

where P_i are a subset of permissions and *L* is one of the Creative Commons Licenses or a Private License. License model is applied to a set of objects (publications) and issued by content providers (authors). Table 1 presents the semantic relations of license model. The more detailed description of license model can be found in [1].

(B) Filter: A filter can be considered an abstract aggregate of license model to provide more intuitive ownership concept. License Models provide detailed static permission configuration to maintain the ownership when users upload their objects, while filter visualizes dynamic actions to help us analyze the relationships in academic learning network. In the following sections we will first introduce the extended social graph and then explain the details of the filter.

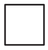
4. Extended social graph

The formal definitions introduced above help us to describe our knowledge workers, organizations and publications. To further analyze the relationships among these participants in

Table 1
Table semantic relations of license models.

	Semantic relation	Meaning
1	⟨User⟩⟨**hasLimitedAccessRights**⟩⟨License Model⟩	An user can view all the license models of the platform
2	⟨License Model⟩⟨isAppliedTo⟩⟨Object⟩	A license model can be associated to many objects
3	⟨Object⟩⟨**hasLicenseModelApplied**⟩⟨License Model⟩ (Inverse of (2))	An object has only one license model associated
4	⟨License Model⟩⟨**Limits**⟩⟨User⟩ (Inverse of (1))	A license model limits all the platform users
5	⟨User⟩⟨**hasIssued**⟩⟨License Model⟩	An user can Issue a set of license models
6	⟨Group⟩⟨**hasLicenseModel**⟩⟨License Model⟩	An user can Issue a set of license models and he/she can associate each license model to one group
7	⟨Group⟩⟨**hasMember**⟩⟨User⟩	A group has a link for each member

Table 2
Icons for extended social graph.

Name	Graph	Attributes
Author		{WID, OID, PID, Permission, Filters}
Knowledge organization		{WID, OID, Leader}
Publication		{UID, WID, PID, ContentKind, Description, Permission}
Knowledge worker		{WID}
Action		{Right}
License model		$\{P_i + L\}$ P_i: a set of permission L:License
Filter		{WID, PID Permission, ContenKind, UserKind}
Relationship		{Relationship}

academic learning network, we consider an academic learning network as a graph and workers/organizations/publications/filter in network as objects (node) and the relationships among these participants can be represented by the links connecting the nodes. With this visual representation, we can quantify the features in graph, e.g. the number of nodes, the number of links to evaluate the relationship among participants in an academic learning network.

4.1. Object representation

Each object (node) is comprised of various attributes. Here we exploit the social graph feature in SMNET [1] and then extend it for academic learning network. Table 2 lists all the icons we use in our model.

4.2. Example

In this section, we describe a simple example of academic learning network as an extended social graph. We will also further explain the concept of license model and filter.

4.2.1. SMNET social graph

Fig. 2a presents an example of a social graph for an academic learning network described in accordance with the SMNET platform. There are three knowledge workers (Mike, Jack and Ben) in this academic learning network. Solid lines represent the action of relationship (e.g. creator, admin, etc.) and dotted lines represent the action of ownership (e.g. hasIssued, isAppliedto, etc.). Mike publishes two academic papers (P_1 and P_2), he will also issue a specific license model (LM_1) to his publications. In this example, we assume the permission in LM_1 will be like this: only author/co-author can view this publication. Note that since Mike is the author/creator of his publications, he has all rights of his publications. Mike is the administrator/leader of a knowledge organization (KO_1), and Jack is also a member of KO_1. Mike and Jack publish a paper (P_2) cooperatively in the same knowledge organization, the corresponding license model (LM_2) for P_2 can be issued by their respective knowledge organization. We assume the permission in LM_2 is: only members in the same knowledge organization can view this publication.. Now if another author Ben wants to access P_1, since Ben is not the author or co-author of P_1, he has limited right to access P_1 due to the permission in LM_1. In this example, Ben cannot view P_1. Note that the actions of ownership and license models are invisible in SMNET platform.

Fig. 2a demonstrates how academic learning network and its ownership model can be represented by SMNET social graph. To reduce complexity, instead of an academic learning network we can also consider an abstracted academic learning network for knowledge worker classes. In the above example, Mike, Jack and Ben would then be replaced by KW_1, KW_2 and KW_3.

License models determine the static permission of publication, e.g. a publication can be viewed by the author who is in the same knowledge organization. Single license model can apply to multiple publications. However, dynamic actions like the number of download/view are updated individually and significantly affect the relationship evaluation. To further explain the relationships among authors or organization, the type of interconnections within academic learning network play a significant role. In an extended social graph, we visualize the various links among worker/organization/publication to help us understand the effect of dynamic actions.

4.2.2. Extended social graph

An extended social graph is a social graph with two additional type of nodes called filters and relationships. Filters are nodes whose two links must be a filter-action link with a publication as the anchor node and a request access link with a knowledge worker (or knowledge worker class) as the other anchor node. Relationships are nodes whose links must be relationship links. For clarity of visualization, we can depict the filter as a trapezoid and the relationship as a hexagon. With the above extensions, we can visualize dynamic actions among workers/organizations for further analysis.

The links in academic social network can be categorized into three types:

1. *Relationship link*: How workers/organizations cooperate with each other.
2. *Filter-action link*: How one accesses the publication of others.

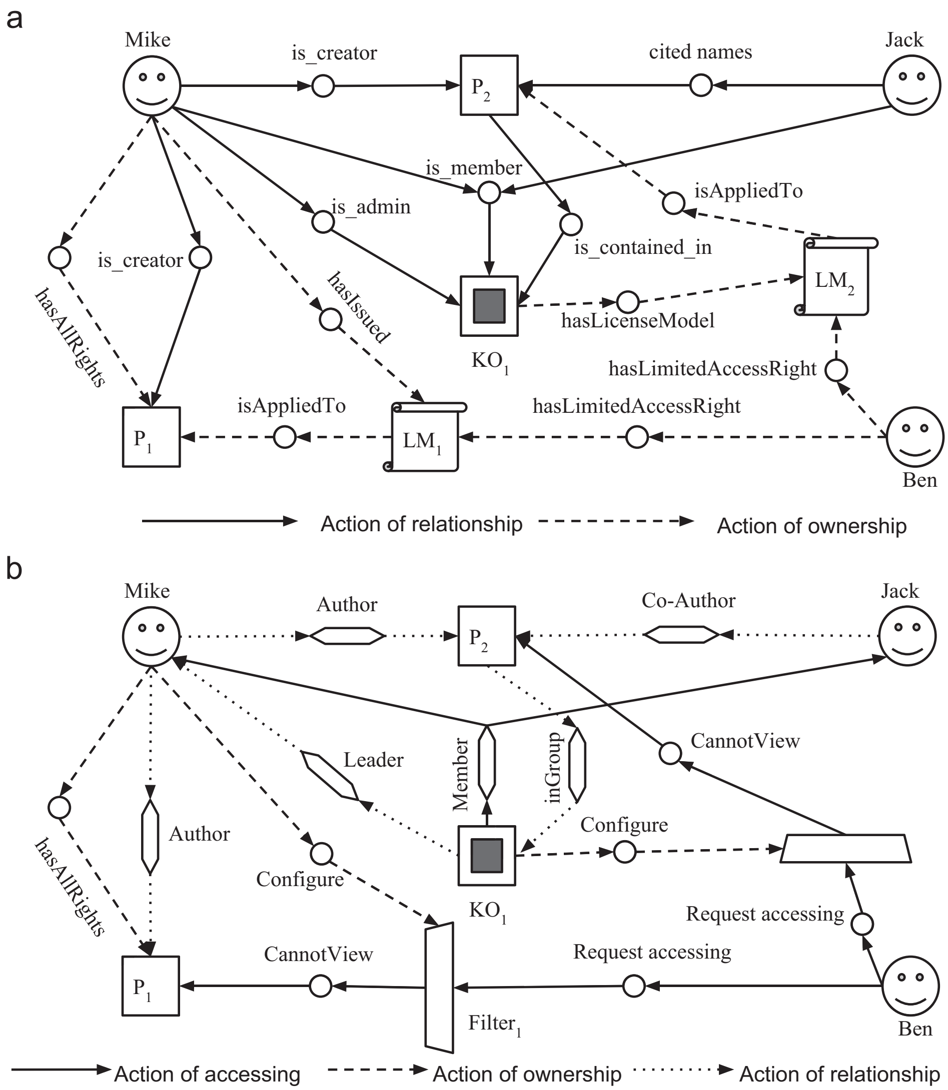


Fig. 2. Examples of SMNET and extend social graph.

3. *Group link*: How workers in the same knowledge organization are grouped together.

Fig. 2b depicts the same example described in Fig. 2a as an extended social graph. Mike and Jack are author/co-author of P_2, so there is a ⟨Author, co − Author⟩ relationship link between them, and then they are in the same knowledge organization KO_1. Since Mike is the administrator/leader of KO_1, there is another ⟨Leader, Member⟩ group link between Mike and Jack. Now if Ben wants to access P_1, since Ben is not author of P_1, the request will pass through the filter Filter_1 configured by Mike. The permission of Filter_1 makes use of the license model (LM_1) in SMNET platform, and we use filter to focus on this access. According to the permission in LM_1, Ben cannot view P_1 since he is not the author. This connection is called Filter-action link and denoted by ⟨Filter_1, CannotView⟩. The access history of a publication can be obtained in the metadata in SMNET platform.

This extended social graph is flexible and can be expanded further with arbitrary connections. In the next section, we will discuss how to utilize the features in social graph to evaluate the relationships in an academic learning network.

5. Relationship evaluation

After establishing academic learning network with proposed social graph, now we explain how to utilize our social graph to heuristically evaluate the relationships in academic learning networks. In this section, we focus on the degree of cooperation and competition in a relationship. Fig. 3 shows a spectrum to represent our heuristic evaluation. Here we consider positive weight to represent the degree of cooperative relationship and negative weight the degree of competitive relationship.

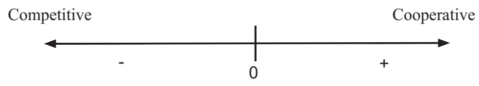


Fig. 3. The spectrum of relationship.

5.1. Evaluation metrics

The metrics we introduce have two parts – baseline weight and link weight. The evaluation process will add up the weights from these two parts.

5.1.1. Baseline weight

The baseline weight represents a base relationship among different knowledge workers in the academic learning network. Here we use the similarity in their publications description. Firstly we can obtain abstract and keyword information in their publications description. This information can give us an initial evaluation for knowledge workers in academic learning network. We choose the number of identical words in their descriptions as a reference:

$$BW_{\langle a,b\rangle} = number\_of\_indentical\_words\_in\_publications\_descriptions\ of\_KW_a\_and\_KW_b.$$

5.1.2. Link weights

As we mentioned in the previous sections, the connections within knowledge workers are established with relationship link, filter-action link and group link. Hence, we can assign a specific weight to each link. The value can be determined according to different situations. Here we just propose some examples in our evaluation. The formula to represent the Link Weight can be as follows:

$$LW_{\langle a,b\rangle} = Weight\_RL\_\langle a,b\rangle + Weight\_FL_{\langle a,b\rangle} + Weight\_GL_{\langle a,b\rangle}$$

• *Weights for relationship link*: The weight of relationship link depends on the type of relationship. In our ownership model, the relationship among knowledge workers can be established through objects (cooperative publication) or knowledge organization (members, colleagues). We can assign different weights according to various relatio nship links. For example, we can set the weight of ⟨Author, CoAuthor⟩ relationship link to be larger than the weight of ⟨Author, Advisor⟩ relationship link:

$$Weight\_RL_{\langle a,b\rangle} = \sum_{i}^{n} weight\_relationship_i\_between\_KW_a\_and\_KW_b,$$

where i: Relationship in $Type_i$

• *Weights for filter-action link*: The weight of filter-action link depends on the information in access history of publications. The access can be View, PartialView or Download. The weight of each access depends on the type and whether the access can be completed by requester. E.g. Requester R_1 can view a publication P_1 created by Author A but another Requester R_2 cannot view P_1. The weight of filter-action link between R_1 and P_1 will be more positive(larger) than the weight of filter-action link between R_2 and P_1. Since filter-action links will be established when non-author knowledge workers access other knowledge workers publications, we can obtain such information from publications access history, e.g. number of downloads and viewings. Hence, we can use such information as a basis for evaluation:

$$Weight\_FL_{\langle a,b\rangle} = \sum_{n}^{i} number\_of\_Action_i * weight\_Action_i$$

• *Weights for group link*: The weight of group link depends on the connections in a knowledge organization, because in a knowledge organization there are various type of connections, e.g. ⟨Leader, Member⟩ or ⟨Colleague, Colleague⟩. We can assign different weights to these connections:

$$Weight\_GL_{\langle a,b\rangle} = \sum_{i}^{n} connection\_i\_between\_KW_a\_and\_KW_b\_in\_organization$$

Table 3
Metrics for links.

Category of link	Kind	Weight
Relationship link	⟨Author, Co – Author⟩	+20
Filter-Action Link	⟨CannotView⟩	−5
	⟨Download⟩	+10
Group link	⟨Leader, Member⟩	+5

5.2. Heuristic evaluation

Having defined baseline weight and link weights, we can evaluate the relationship among knowledge workers as follows.

$$Weight\_relationship(KW_a, KW_b) = BW_{\langle a,b\rangle} + LW_{\langle a,b\rangle}$$

Note that all weights in our evaluation approach can be adjusted and the type of relationship link and the connection in an organization can also be extended for different academic learning network.

5.2.1. An example

Now we can demonstrate our evaluation approach with an example. Table 3 lists heuristically assigned weights for different links. We can use these weights to evaluate the relationship among knowledge workers as shown in Fig. 2b.

First, we evaluate the relationship between knowledge workers Mike and Jack. We assume their baseline weight ($BW_{\langle Mike,Jack\rangle}$) is a constant C, and there are two links connecting them together: relationship link ⟨Author, Co – Author⟩ and group link ⟨Leader, Member⟩. According to the formula given in Section 5.1, the numeric relationship value between Mike and Jack is

$Weight\_Relationship_{\langle Mike,Jack\rangle}$

$$
\begin{aligned}
&= BW + (Weight\_RL + Weight\_GL) \\
&= C + (W\langle Author, Co-Author\rangle \\
&+ W_{\langle Leader, Member\rangle}) \\
&= C + (20 + 5) \\
&= C + 25
\end{aligned}
$$

And then we evaluate the relationship between Mike and Ben. We also assume that their baseline weight ($BW_{\langle Mike, Ben\rangle}$) is a constant C and there is a filter-action link $\langle Filter_1,\ CannotView\rangle$. According to the formula in Section 5.1, the numeric relationship value between Mike and Ben is

$$
\begin{aligned}
&Weight\_Relationship_{\langle Mike, Ben\rangle} \\
&= BW + (Weight\_FL) \\
&= C + (W_{\langle Filter1, CannotView\rangle}) \\
&= C + (-5)
\end{aligned}
$$

If the constant C is equal to zero, the $Weight\_-Relationship_{\langle Mike, Jack\rangle}$ is 25, signifying a cooperative relationship, and the $Weight\_Relationship_{\langle Mike, Ben\rangle}$ is -5, signifying a competitive relationship. This is reflected in the filters Mike, Jack and Ben set up for each other to enhance or restrict learning.

Table 4
The mapping between formal ownership model and SMNET IPR model.

Formal description	IPR model in SMNET
Publication ID (PID)	Content ID
Worker ID (WID)	User ID
Organization ID (OID)	Group ID
Descriptions	Descriptions
ContentKind	Existing features with metadata
Journal	Taxonomy terms
Conference, etc.	Content Type(audio,video,etc.)
Right	Right(set of permission)
	Download from PC/mobile, etc
UserKind	Existing features with metadata
	User role
	User preference in the user profile
Permission	Permission
Access History	Existing features with metadata
	Content viewed/downloaded
	Query made on the platform
	Connections made with other workers, content published
Relationships	Existing features with metadata
	Citation
	Groups
	User preference in the user profile
	Dynamic preferences obtained monitoring the user actions bonds of friendship

5.2.2. Discussion

From the above example, we can observe that the relationship evaluation depends on the type of links and their user-defined parameters. We can obtain static metrics e.g. the weights of relationship link and group link from metadata. During dynamic time, the access history records all dynamic accesses within academic learning network. Recorded information can help us capture more accurate relationships within workers/organizations since the dynamic actions are considered as a factor in evaluation. In general, we can consider that the group link (static) and filter-action link (dynamic) will occupy the major part in relationship evaluation. Since the knowledge workers are in the same knowledge organization, the probability of their cooperation will be higher. For example, the relationship link within a group will be more positive (e.g. ⟨Leader, Member⟩) than the relation link within different knowledge organization. Furthermore, if there are filter-action links between two knowledge workers, which means there are some restrictions on information sharing between them, their relationship will be affected by the dynamic actions within them.

6. A case study

In this section we describe a case study and the scenario of SMNET platform. Our formal description is an abstract aggregate of attributes in SMNET's IPR model, and these attributes may come from metadata or determined by users in SMNET platform. Table 4 presents the mapping between SMNET definition and our formal definition.

Fig. 4 shows the scenario of using our ownership model with SMNET platform. When knowledge workers want to upload their publications, the information should be provided according to the rules in SMNET. After filling publications' information, SMENT generates the corresponding social graph. Then the relationships within academic learning can be evaluate. On the right side of Fig. 4 we show a screen shot of the initial SMNET.

Since the filters and dynamic actions (view, download,…) are invisible in SMNET social graph, In Fig. 5 we use dotted lines to represent filters and dynamic actions, which should be recorded in access history. In Fig. 5, Mike, Ben and Jack (knowledge workers) are the members in Intellectual Network group (knowledge organization). Mike is the admin (leader) and the creator (author) of P_1 in Intellectual Network. Mike and Ben are author and co-author of P_2, respectively. Hence,

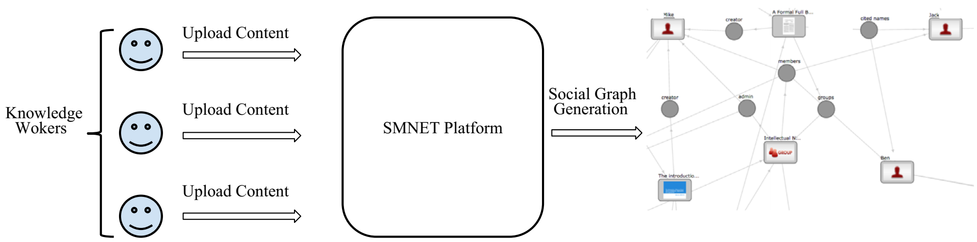


Fig. 4. The scenario of SMNET.

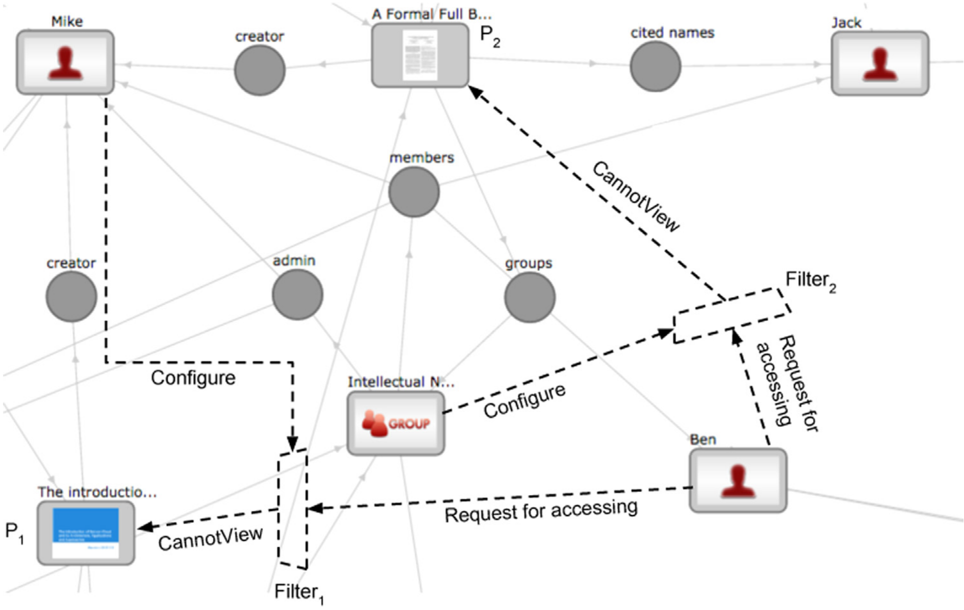


Fig. 5. Extended social graph in SMNET.

there is a cited name node linking Ben and P_2. As an author of publication P_1, Mike sets the permission of filter that only the author can view P_1. So Ben (non-author) cannot view P_1. All dynamic actions will be recorded in access history of each publication for future evaluations of relationships. Having obtained the extended social graph, the weights and heuristic relationship values can then be computed to visualize the cooperative and competitive relationships among research workers.

7. Conclusion and future work

Academic learning networks can be seen as a subset of social networks, but there are few specific approaches to clearly define them to analyze and evaluate the relationships in cost-effective ways.

In this paper, we propose a formal ownership model capable of modeling academic learning network and it can be integrated with a realistic social network platform.

The concept of filter can be further extended, so that filter can be used not only to passively grant or deny permissions, but also to actively provide suggestions and/or recommendations. The suggestions can be enumerated and selected according to Slow Intelligence principles [5]. Therefore cooperative workers can help each other to enhance learning.

With quantified metrics, the degree of relationship can be evaluated and further help us to analyze academic learning network. 2 In addition to static factors in social network, we will further consider various dynamic actions as our evaluation reference. More sophisticated relationship and evaluation metrics can be added to measure more complex social networks.

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