An Analysis of Interoperability between Licenses*

Kunihiko Fujita
NTT Communication Science Laboratories
NTT Corporation
3-1, Morinosato Wakamiya, Atsugi-shi,
Kanagawa, 243-0198 Japan
fujita@theory.brl.ntt.co.jp

Yasuyuki Tsukada
NTT Communication Science Laboratories
NTT Corporation
3-1, Morinosato Wakamiya, Atsugi-shi,
Kanagawa, 243-0198 Japan
tsukada@theory.brl.ntt.co.jp

ABSTRACT

The emergence of different licenses has led to problems with the smooth flow of digital content across them. To activate digital content distribution, license interoperability must be revealed. In this paper, we present a framework for formally examining license interoperability by using many-sorted first-order logic. We show how the framework can be used to formalize three actual licenses and examine the interoperability between them. The results show that the framework reveals the relationship between licenses.

Categories and Subject Descriptors

D.2.4 [**Software Engineering**]: Software/Program Verification—*Formal methods*; F.4.m [**Mathematical Logic and Formal Languages**]: Miscellaneous

General Terms

Legal Aspects, Security, Theory

Keywords

Content Circulation, Creative Commons, Niconi Commons, GNU Free Documentation License

1. INTRODUCTION

With recent advances in information and telecommunications technologies, the states of digital content distribution have changed. In the past, it was necessary to construct and maintain physical media distribution channels because the content and media, such as CDs and DVDs, were inseparable. However, nowadays more and more digital content is being distributed through the Internet.

With this changing state of digital content distribution, various licenses that provide rights and conditions for contents have been offered. For example, Creative Commons (CC) [3] supports licenses that can be attached to contents by creators easily. CC also offers user interfaces that make it easy for content users to understand what can and cannot be done to the contents. For another example, Nico Nico Douga [14], a video sharing website with more than 16 million registered users at present, is one of the most active UGC sites for content circulation in Japan. One of its features is that users can insert comments on the video screen. This allows comments that respond directly to events occurring in a video, in sync with the viewer, creating a sense of a shared watching experience. Nico Nico Douga started providing a group of licenses called Niconi Commons (NiC) [15] in August 2008 to promote digital content distribution. Nico Nico Douga offers content creators a place to exhibit contents that can be used freely to promote content distribution by supplying a comprehensive licenses. The GNU Free Documentation License (GFDL) [6] is also a widely used license. GFDL is a copyleft license for free documentation, designed by the Free Software Foundation (FSF) for the GNU Project. The GFDL was designed for manuals, textbooks, other reference and instructional materials, and documentation, which often accompany GNU software. However, it can be used for any text-based work, regardless of subject matter.

The need for rights management technologies over the past decade and a half has led to the emergence of multiple DRM (Digital Rights Management) systems. Interoperability is one of the biggest challenges faced by the DRM industry [12]. Consequently, a lot of researches about interoperability of DRM have been conducted [11] [17] [5] [4]. However, to our knowledge, detailed analyses of interoperability between licenses have not been reported previously. Since CC, NiC, and GFDL are widely used, it would be useful to examine the interoperability between them. Examining license interoperability is important for promoting content distribution on the Internet. Licenses are generally written in natural language, which is open to various interpretations, making it difficult to compare them in a rigorous way. Therefore, we have constructed a framework that can formally examine license interoperability. In this study, we define a *framework for license analysis* as a common framework for formalizing licenses in many-sorted first-order logic. We formalize CC licenses version 2.1, the NiC licenses issued in August 2008, and GFDL version 1.2 as examples and verify the interoperability and its validity strictly. As a result, we clarified the relationship between them.

*This is a revised and extended version of a preliminary report [7], which was presented in the short-papers session of IWSEC2009.

DRM'10, October 4, 2010, Chicago, Illinois, USA.

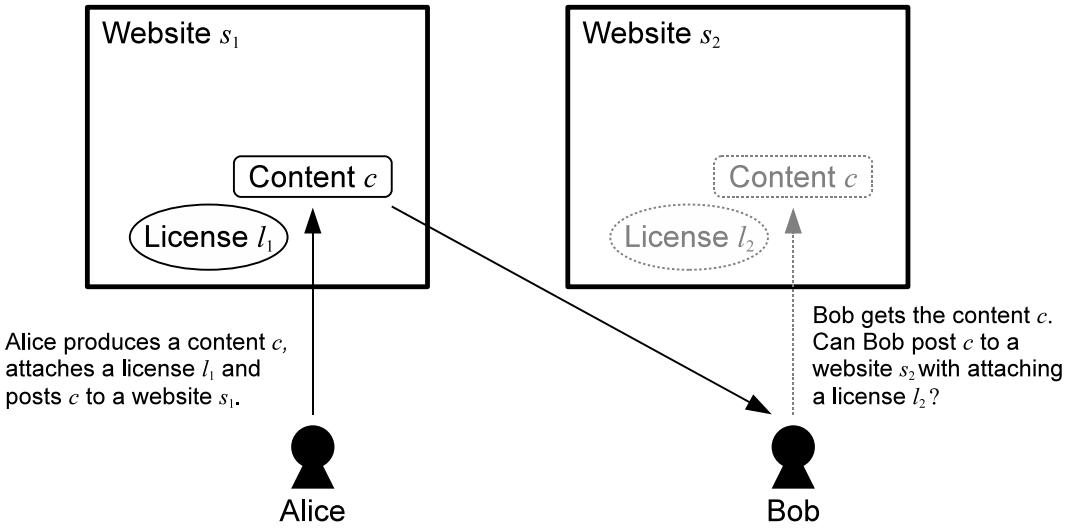

Figure 1: Necessity for examining the license interoperability.

The rest of the paper is organized as follows. Section 2 explains the concept of license analysis and defines its formal syntax. It also defines what license interoperability is in the formal syntax. Section 3 explains CC, NiC, and GFDL in more detail. Section 4 provides formal definitions of domains and predicates and presents the results of the formalization of CC, NiC, and GFDL. Section 5 discusses the interoperability between CC, NiC, and GFDL. Section 6 reviews related work. Section 7 concludes the paper and summarizes future work.

2. LICENSE INTEROPERABILITY

We first describe the necessity of examining the license interoperability with reference to the situation shown in Figure 1. Alice produces a content c and attaches a license l_1 to it, and then posts it to a website s_1. Bob likes c and wants to advertise its wonderfulness widely by posting it to a website s_2. As for contents posted to s_2, it is necessary to attach a license l_2. The problem is whether Bob can post c to s_2. For instance, if we assume that l_1 only permits non-commercial use and l_2 permits commercial use, Bob cannot post c to s_2. This is because the commercial use contradicts the rule of l_1. In this study, we examine license interoperability to solve this issue.

Licenses are generally written in natural language, whose various interpretations make it difficult to achieve precise license interoperability. In this study, we formalize licenses on many-sorted first-order logic and analyze their relationships.

2.1 Formal Syntax for Licenses

In general, rules, including laws and contracts, are described in logical form as a condition and conclusion. Examples are "If a certain condition holds, a certain action can be taken", "If a certain condition holds, a certain action cannot be taken", and "If a certain condition holds, a penalty will be imposed". Thus, the linguistic expressions of a rule are forms that show a "conclusion" when a "condition" is met.

On the basis of the above description, a syntax for licenses is defined as follows. Each *license* is a conjunction

$$r_1 \wedge \cdots \wedge r_n$$

of *rules*, where each rule r_i is a logical formula of the form

$$f_1 \wedge \cdots \wedge f_m \rightarrow p,$$

where each f_j denotes a "condition" and p is a "conclusion". More specifically, f_j is an atomic formula and p is of the form $\mathbf{Perm}(x, w, act, c)$, where **Perm** is a specific predicate symbol for expressing rights permission and $\mathbf{Perm}(x, w, act, c)$ expresses that an agent x permits an agent w to do an action act to a content c.

2.2 Definition of the License Interoperability

Let α and β be licenses described in accordance with the syntax defined in subsection 2.1. We say that α has *interoperability* with β if $\alpha \rightarrow \beta$ holds. This intuitively means that when α is attached to a content c, β can also be attached to c.

3. LICENSES

In this section, we explain CC, NiC, and GFDL, which are the targets of the formalization in this study. We also describe the specifications of them that should be given attention.

3.1 CC

In CC, there are four *license attributes* as shown in Table 1. The conditions for content use are plainly shown by displaying marks and abbreviations.

When contents are opened to the public in the CC framework, license attributes are combined. There is a limitation in how the license attributes can be combined, and six combinations (`BY`, `BY_NC`, `BY_SA`, `BY_NC_SA`, `BY_ND`, and `BY_NC_ND`) can be selected. These combinations are called *license elements* in CC, which are hereafter called *licenses*. Authors can decide what license should be attached to their contents by answering the two questions shown in Table 2.

Table 1: License attributes in CC.

Abbreviation	Term	Definition
BY	Attribution	Users may use works only if they give the author or licensor the credits. (fixed condition)
NC	Non-Commercial	Users may use works only for non-commercial purposes.
SA	Share Alike	Users may distribute derivative works only under a license identical to the license that governs the original work.
ND	No Derivs	Users may use the work, not derivative works based on it.

Table 2: Two questions to decide what licenses in CC should be attached to.

		Do you permit commercial use of the work?	
		Yes	No
Do you permit modification of the work?	Yes	BY	BY_NC
	Permit only if license is succeeded.	BY_SA	BY_NC_SA
	No	BY_ND	BY_NC_ND

3.2 NiC

In NiC, there are five license attributes as shown in Table 3. However, unlike in CC, marks and abbreviations are not officially provided in NiC. In this paper, for expediency, we assign abbreviations following CC as shown in the Table 3. The meanings of the abbreviations are as follows.

- BY: In NiC, links from a certain page of work registered to the page of registrant information can be traced by displaying the NiC ID. The NiC ID can be considered to be a kind of display of copyright information because the page of registrant information can be referred to on the page of the work of interest by displaying the NiC ID. For this reason, we use the abbreviation BY for displaying a NiC ID, which is the abbreviation for displaying copyright information in CC.
- NC: NC stands for non-commercial, as it does in CC.
- AC: AC means that users may use works only for non-commercial purposes and that if another license is concluded, commercial use is possible.
- IL: IL means that use of contents is permitted on the entire Internet. In other words, use in the real world is not permitted.
- NL: NL means a condition of permitting limited use at NiC tie-up sites. NiC tie-up sites are websites that cooperate with NiC. The use state of works used at NiC tie-up sites can be traced. Figure 2 shows the coverage (that is, the relationships among NiC tie-up sites, the Internet, and the real world) of the licenses.

NiC's coverage differs from CC's in that neither SA nor ND are prepared. Users may modify contents with a NiC license and attach any license for derivative works that originate from contents with a NiC license.

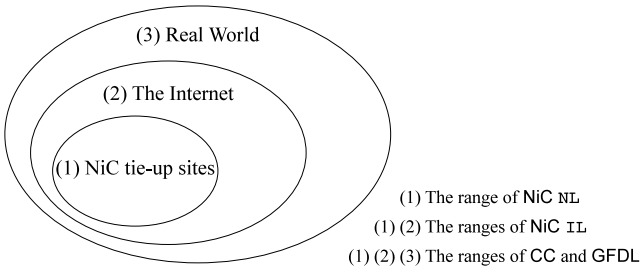

Figure 2: Coverages of licenses.

In NiC, as in CC, there are six possible combinations of license attributes. We call a combination a license as we do for CC. There is a limitation in how attributes can be combined, and six combinations (BY_IL, BY_NL, BY_NC_IL, BY_NC_NL, BY_AC_IL, and BY_AC_NL) can be selected as shown in Table 4. The feature of licenses in NiC is that there are more choices concerning commercial use than there are for CC. NiC adds AC between non-commercial use and commercial use. This may be because of NiC could be aiming to provide more license flexibility than CC does.

3.3 GFDL

GFDL is a copyleft license for free documentation. It is similar to the GNU General Public License (GPL), giving users the rights to copy, redistribute, and modify a content and requiring all copies and derivatives to be available under the same license.

The GFDL was designed for manuals, textbooks, other reference and instructional materials, and documentation which often accompany GNU software. However, it can be used for any work, regardless of subject matter. For exam-

Table 3: License attributes in NiC.

Abbreviation	Term	Definition
BY	Display NiC ID	Users may use works only if they display the NiC ID. (fixed condition)
NC	Non-Commercial	Users may use works only for non-commercial purposes.
AC	Another license for Commercial use	Users may use works for commercial purposes if another license is concluded.
IL	Internet Limitation	Users may use works only on the Internet.
NL	NiC tie-up sites Limitation	Users may use works only on NiC tie-up sites.

Table 4: Two questions to decide what licenses in NiC should be attached to.

		Do you permit commercial use of the work?		
		Yes	Permit only if another license is concluded	No
Which range do you permit of the work?	the Internet	BY_IL	BY_AC_IL	BY_NC_IL
	NiC tie-up sites	BY_NL	BY_AC_NL	BY_NC_NL

ple, the free online encyclopedia Wikipedia used to use the GFDL for all of its text.

Contents licensed under the GFDL can be used for any purpose, as long as the use meets certain conditions. First, all previous authors of the work must be attributed (stipulated in Sections 2 and 4 D in GFDL [6]). Moreover, both copied original works and derivative works must be licensed under the same license (Sections 2 and 4). Furthermore, GFDL is a non-exclusive license like CC and NiC are[1]. Lastly, the condition peculiar to GFDL is that unmodified invariant sections as defined by the author must be maintained (Section 4 L).

3.4 Non-exclusiveness

CC, NiC, and GFDL are *non-exclusive* licenses. In other words, regardless of the license in CC, NiC, and GFDL given to works, authors can offer third parties the works with another license.

4. FORMALIZATION OF LICENSES

In this section, we first define of domains and predicates. Next, we explain the formalization of license attributes and fragments of licenses in CC, NiC, and GFDL in detail. In this paper, we focus on some fragments of licenses because the entire system of licenses is somewhat unwieldy, as our experience in formalizing entire CC licenses shows [8]. We think, however, that it is straightforward to extend our results so that the interoperability between entire systems of licenses can be discussed.

4.1 Definitions

4.1.1 Domains

[1]This condition is provided by copyright law, though it is not explicitly stipulated in GFDL

- $D_{contents}$ denotes the set of contents.
- $D_{contentsTypes}$ denotes the set of content types. It contains elements such as `CRWks` (copyrighted works) and `DerivWks` (derivative works).
- D_{action} denotes the set of actions to contents. It contains elements such as `copy`, `distribute`, `modify`, and `translate`.
- $D_{actionTypes}$ denotes the set of action types. It consists of `OriginalUse` (the type of actions for use of contents as it is) and `DerivUse` (the type of actions for making derivative works). We assume that every action in D_{action} is associated with a unique action type in $D_{actionTypes}$. For example, both `copy` and `distribute` are `OriginalUse`, and both `modify` and `translate` are `DerivUse`.
- D_{agents} denotes the set of agents (e.g., human, program).
- $D^{\mathtt{CC}}_{elements}$ is the set of licenses in CC, that is, $D^{\mathtt{CC}}_{elements} = \{$`BY`, `BY_NC`, `BY_SA`, `BY_NC_SA`, `BY_ND`, `BY_NC_ND`$\}$.
- $D^{\mathtt{NiC}}_{elements}$ is the set of licenses in NiC, that is, $D^{\mathtt{NiC}}_{elements} = \{$`BY_IL`, `BY_NL`, `BY_NC_IL`, `BY_NC_NL`, `BY_AC_IL`, `BY_AC_NL`$\}$.
- $D^{\mathtt{GFDL}}_{elements}$ is the set of a license in GFDL, that is, $D^{\mathtt{GFDL}}_{elements} = \{$`GFDL`$\}$.
- $D_{elements} = D^{\mathtt{CC}}_{elements} \cup D^{\mathtt{NiC}}_{elements} \cup D^{\mathtt{GFDL}}_{elements}$.
- D_{pub} denotes the set of places where contents are used. It consists of `supportedSite` (NiC tie-up sites), `unsupportedSite` (non-Nic tie-up sites) and `outOfInternet` (excluding the Internet). The entire Internet is

expressed by the total of `supportedSite` and `unsupportedSite`.

4.1.2 Predicates

- **Perm**(x, w, act, c) expresses that an agent x permits an agent w to do an action act to a content c.
  Perm : $D_{agents} \times D_{agents} \times D_{action} \times D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **SubWork**(a, c) expresses that a content a is contained in a content c.
  SubWork : $D_{contents} \times D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **DerivWork**(a, c) expresses that a content c is a derivative work based upon a content a.
  DerivWork : $D_{contents} \times D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **CType**(t, c) expresses that a content c has a content type t.
  CType : $D_{contentsTypes} \times D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **AType**(s, act) expresses that an action act has an action type s.
  AType : $D_{actionTypes} \times D_{action} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **Credit**(w, a, c) expresses that an agent w appropriately does a copyright display of a content a on a content c.
  Credit : $D_{agents} \times D_{contents} \times D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **NonCommercial**(w, c) expresses that an agent w uses a content c only for non-commercial purposes.
  NonCommercial : $D_{agents} \times D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **License**(w, c, L) expresses that an agent w gives to a content c a license L.
  License : $D_{agents} \times D_{contents} \times D_{elements} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **Location**(w, c, p) expresses that an agent w uses a content c in a place p.
  Location : $D_{agents} \times D_{contents} \times D_{pub} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **AnotherLicense**(x, w, act, c) expresses that an agent x makes a contract with agent w to permit carrying out an action act to a content c.
  AnotherLicense : $D_{agents} \times D_{agents} \times D_{action} \times D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

- **Modifiable**(c) expresses that a content c is modifiable.
  Modifiable : $D_{contents} \rightarrow \{\textbf{True}, \textbf{False}\}$

4.2 Formalization of CC

4.2.1 Formalization of License Attributes in CC

Here, we describe formalizations of license attributes `BY`, `NC`, `SA`, and `ND` in CC. Each license attribute constitutes some parts of the conditions of a rule $f_1 \wedge \cdots \wedge f_m \rightarrow p$.

- `BY` (Attribution)

Original use (`BY-OU`)

AType(`OriginalUse`, act)
$\wedge$ **SubWork**(a, c)
$\wedge$ **CType**(`CRWks`, a)
$\wedge$ **Credit**(w, a, a)

The formula shown above expresses that an agent w has to display the copyright information appropriately at the original use of a copyrighted work a included in a content c. Original use means to use a copyrighted work as it is. For instance, assume there is an original song c. Examples of original uses would be opening the entire song c to the public as it is on a certain website and pulling out lyrics a and publishing them in a blog.

Derivative use (`BY-DU`)

AType(`DerivUse`, act)
$\wedge$ **SubWork**(a, c)
$\wedge$ **CType**(`CRWks`, a)
$\wedge$ **DerivWork**(a, b)
$\wedge$ **Credit**(w, a, b)

The formula shown above expresses that an agent w has to display the copyright information of an original copyrighted work a on a derivative work b appropriately. Derivative use means to use some adaptation of a copyrighted work. For an original song c, examples of derivative uses would be putting a different melody to the lyrics a and re-arranging song c.

- `NC` (Non-Commercial)

Original use (`NC-OU`)

AType(`OriginalUse`, act)
$\wedge$ **SubWork**(a, c)
$\wedge$ **CType**(`CRWks`, a)
$\wedge$ **NonCommercial**(w, a)

The formula shown above expresses that an agent w has to use for non-commercial purposes at first use of a copyrighted work a in a content c. As for derivative use, it is similar as follows.

Derivative use (`NC-DU`)

AType(`DerivUse`, act)
$\wedge$ **SubWork**(a, c)
$\wedge$ **CType**(`CRWks`, a)
$\wedge$ **DerivWork**(a, b)
$\wedge$ **NonCommercial**(w, b)

- `SA` (Share Alike)

Original use (`SA-OU`)

AType(`OriginalUse`, act)
$\wedge$ **SubWork**(a, c)
$\wedge$ **CType**(`CRWks`, a)
$\wedge$ **License**$(w, a, *\_\texttt{SA})$

When a copyrighted work a in a content c is used as it is, the formula shown above expresses the need to

apply a license attached to the original content c. Here, $*$_SA is either BY_SA or BY_NC_SA.

Derivative use (SA-DU)

$$\begin{aligned}&\mathbf{AType}(\texttt{DerivUse}, act)\\ &\quad\wedge\ \mathbf{SubWork}(a, c)\\ &\quad\wedge\ \mathbf{CType}(\texttt{CRWks}, a)\\ &\quad\wedge\ \mathbf{DerivWork}(a, b)\\ &\quad\wedge\ \mathbf{License}(w, b, *\texttt{\_SA})\end{aligned}$$

When a copyrighted work a in a content c is used derivatively in a derivative work b, the formula shown above expresses the need to apply the license attached to the original content c. Here, $*$_SA is either BY_SA or BY_NC_SA.

- ND (No Derivative Works)

  The licenses that contain ND only permit carrying out actions act such that $\mathbf{AType}(\texttt{OriginalUse}, act)$ holds. In other words, ND can be formalized by not adding any formulas that mean conditions for providing permissions for derivative use. We cover this in Subsection 4.2.3 in detail.

4.2.2 Formalization of Non-exclusive Rules

As mentioned in Subsection 3.4, CC is a non-exclusive license. This means that even if a license in CC is attached to works, authors can offer the works to third parties through another license. All licenses in CC contain these non-exclusive rules. We abbreviate the non-exclusive rules as NXp.

- NXp (Non-exclusive)

  NXp can be formalized as follows.

Original use (NXp-OU)

$$\begin{aligned}&\mathbf{AType}(\texttt{OriginalUse}, act)\\ &\quad\wedge\ \mathbf{SubWork}(a, c)\\ &\quad\wedge\ \mathbf{CType}(\texttt{CRWks}, a)\\ &\quad\wedge\ \mathbf{AnotherLicense}(x, w, act, a)\\ &\qquad\rightarrow\ \mathbf{Perm}(x, w, act, a)\end{aligned}$$

Derivative use (NXp-DU)

$$\begin{aligned}&\mathbf{AType}(\texttt{DerivUse}, act)\\ &\quad\wedge\ \mathbf{SubWork}(a, c)\\ &\quad\wedge\ \mathbf{CType}(\texttt{CRWks}, a)\\ &\quad\wedge\ \mathbf{DerivWork}(a, b)\\ &\quad\wedge\ \mathbf{AnotherLicense}(x, w, act, a)\\ &\qquad\rightarrow\ \mathbf{Perm}(x, w, act, a)\end{aligned}$$

4.2.3 Formalization of CC Licenses

The procedure for the formalization of a CC license L is as follows.

1. Take the conjunction of the formulas *-OU, where each $*$ is a license attribute constituting L.
2. Use the conjunction obtained by 1 and form a rule $\bigwedge_{*}$ *-OU $\rightarrow \mathbf{Perm}(x, w, act, a)$.
3. Take the conjunction of the rule obtained by 2 and NXp-OU.
4. Take the conjunction of the formulas *-DU, where each $*$ is a license attribute constituting L, if ND is not contained in L.
5. Use the conjunction obtained by 4 and form a rule $\bigwedge_{*}$ *-DU $\rightarrow \mathbf{Perm}(x, w, act, a)$, if ND is not contained in L.
6. Take the conjunction of the rule obtained by 5 and NXp-DU, if ND is not contained in L.
7. Take the conjunction of 3 and 6, if ND is not contained in L.

For example, the procedure for formalization of BY_SA and BY_NC_ND in CC is as follows.

<BY_SA>

1. BY-OU $\wedge$ SA-OU
2. BY-OU $\wedge$ SA-OU $\rightarrow \mathbf{Perm}(x, w, act, a)$
3. (BY-OU $\wedge$ SA-OU $\rightarrow \mathbf{Perm}(x, w, act, a)) \wedge$ NXp-OU
4. BY-DU $\wedge$ SA-DU
5. BY-DU $\wedge$ SA-DU $\rightarrow \mathbf{Perm}(x, w, act, a)$
6. (BY-DU $\wedge$ SA-DU $\rightarrow \mathbf{Perm}(x, w, act, a)) \wedge$ NXp-DU
7. (BY-OU $\wedge$ SA-OU $\rightarrow \mathbf{Perm}(x, w, act, a)) \wedge$ NXp-OU $\wedge$ (BY-DU $\wedge$ SA-DU $\rightarrow \mathbf{Perm}(x, w, act, a)) \wedge$ NXp-DU

<BY_NC_ND>

1. BY-OU $\wedge$ NC-OU
2. BY-OU $\wedge$ NC-OU $\rightarrow \mathbf{Perm}(x, w, act, a)$
3. (BY-OU $\wedge$ NC-OU $\rightarrow \mathbf{Perm}(x, w, act, a)) \wedge$ NXp-OU

The formula for a CC license L obtained by the above procedure is referred to as $\mathbf{CC}^L(x, w, c, a, b, act)$.

$$\mathbf{CC}^L : D_{agents} \times D_{agents} \times D_{contents} \times D_{agents} \times D_{agents} \times D_{action} \rightarrow \{\mathbf{True}, \mathbf{False}\}$$

As examples, $\mathbf{CC}^{\texttt{BY\_SA}}(x, w, c, a, b, act)$ and $\mathbf{CC}^{\texttt{BY\_NC\_ND}}(x, w, c, a, b, act)$ are shown in Figures 3 and 4, respectively. We can say that for specific constants x_0, w_0, and c_0, $\mathbf{CC}^L(x_0, w_0, c_0, a, b, act)$ means that an agent x_0 permits an agent w_0 to use a constant c_0 through a CC license L. Note that in this formula, a, b, and act act as free variables.

4.3 Formalization of NiC

4.3.1 Formalization of License Attributes in NiC

Here, we describe formalizations of license attributes AC, IL, and NL in NiC. The formalizations of BY and NC are omitted because BY and NC in NiC are same as those in CC.

- AC (Another license for Commercial use)

  Content with this license attribute can basically be used for non-commercial purposes, specially it can be used for commercial purpose by concluding another contract. The non-commercial purpose part is similar to NC. However, the another-contract part has a structure in which the conclusion "permitting for use" is met

$$
\begin{aligned}
&< \mathbf{CC}^{\texttt{BY\_SA}}(x, w, c, a, b, act) > \\
&\quad (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{Credit}(w, a, a) \wedge \mathbf{License}(w, a, \texttt{BY\_SA}) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge\ (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge\ (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{Credit}(w, a, b) \wedge \mathbf{License}(w, b, \texttt{BY\_SA}) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge\ (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a))
\end{aligned}
$$

Figure 3: A formalization of the license BY_SA in CC.

$$
\begin{aligned}
&< \mathbf{CC}^{\texttt{BY\_NC\_ND}}(x, w, c, a, b, act) > \\
&\quad (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{Credit}(w, a, a) \wedge \mathbf{NonCommercial}(w, a) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge\ (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a))
\end{aligned}
$$

Figure 4: A formalization of the license BY_NC_ND in CC.

if the condition "concluding another license" is satisfied. Therefore, the another-contract part expresses the addition of the formula shown below to rules.

Original use (AC-OU)

$$
\begin{aligned}
&\mathbf{AType}(\texttt{OriginalUse}, act) \\
&\quad \wedge\ \mathbf{SubWork}(a, c) \\
&\quad \wedge\ \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge\ (\mathbf{NonCommercial}(w, a) \\
&\qquad \vee\ \mathbf{AnotherLicense}(x, w, act, a))
\end{aligned}
$$

Derivative use (AC-DU)

$$
\begin{aligned}
&\mathbf{AType}(\texttt{DerivUse}, act) \\
&\quad \wedge\ \mathbf{SubWork}(a, c) \\
&\quad \wedge\ \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge\ \mathbf{DerivWork}(a, b) \\
&\quad \wedge\ (\mathbf{NonCommercial}(w, b) \\
&\qquad \vee\ \mathbf{AnotherLicense}(x, w, act, a))
\end{aligned}
$$

These formalizations express that when an agent x grants another permission to an agent w, the use based on the content of another permission is permitted.

- IL (Internet Limitation)

  IL means the condition of permitting use only on the entire Internet. In other words, use outside of the Internet (i.e., in the real world) is not permitted.

Original use (IL-OU)

$$
\begin{aligned}
&\mathbf{AType}(\texttt{OriginalUse}, act) \\
&\quad \wedge\ \mathbf{SubWork}(a, c) \\
&\quad \wedge\ \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge\ (\mathbf{Location}(w, a, \texttt{supportedSite}) \\
&\qquad \vee\ \mathbf{Location}(w, a, \texttt{unsupportedSite}))
\end{aligned}
$$

Derivative use (IL-DU)

$$
\begin{aligned}
&\mathbf{AType}(\texttt{DerivUse}, act) \\
&\quad \wedge\ \mathbf{SubWork}(a, c) \\
&\quad \wedge\ \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge\ \mathbf{DerivWork}(a, b) \\
&\quad \wedge\ (\mathbf{Location}(w, b, \texttt{supportedSite}) \\
&\qquad \vee\ \mathbf{Location}(w, b, \texttt{unsupportedSite}))
\end{aligned}
$$

- NL (NiC tie-up sites Limitation)

  NL means the condition of permitting limited use in NiC tie-up sites. In other words, use excluding NiC tie-up sites is not permitted.

Original use (NL-OU)

$$
\begin{aligned}
&\mathbf{AType}(\texttt{OriginalUse}, act) \\
&\quad \wedge\ \mathbf{SubWork}(a, c) \\
&\quad \wedge\ \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge\ \mathbf{Location}(w, a, \texttt{supportedSite})
\end{aligned}
$$

Derivative use (NL-DU)

$$
\begin{aligned}
&\mathbf{AType}(\texttt{DerivUse}, act) \\
&\quad \wedge\ \mathbf{SubWork}(a, c) \\
&\quad \wedge\ \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge\ \mathbf{DerivWork}(a, b) \\
&\quad \wedge\ \mathbf{Location}(w, b, \texttt{supportedSite})
\end{aligned}
$$

4.3.2 Formalization of Non-exclusive Rules

As mentioned in Subsection 3.4, NiC is a non-exclusive license. This means that even if a license in NiC is attached to works, authors can offer the works to third parties through another license. All licenses in NiC contain these non-exclusive rules. We omit describing the formalization of these rules as they are same as those in CC (cf. Subsection 4.2.2).

4.3.3 Formalization of NiC Licenses

The procedure for the formalization of a NiC license L is as follows.

$$
\begin{aligned}
&< \mathbf{NiC}^{\texttt{BY\_NC\_IL}}(x, w, c, a, b, act) > \\
&\quad (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{Credit}(w, a, a) \\
&\qquad \wedge \mathbf{NonCommercial}(w, a) \wedge \mathbf{Location}(w, a, \texttt{supportedSite}) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{Credit}(w, a, a) \\
&\qquad \wedge \mathbf{NonCommercial}(w, a) \wedge \mathbf{Location}(w, a, \texttt{unsupportedSite}) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{Credit}(w, a, b) \\
&\qquad \wedge \mathbf{NonCommercial}(w, b) \wedge \mathbf{Location}(w, b, \texttt{supportedSite}) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{Credit}(w, a, b) \\
&\qquad \wedge \mathbf{NonCommercial}(w, b) \wedge \mathbf{Location}(w, b, \texttt{unsupportedSite}) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a))
\end{aligned}
$$

Figure 5: A formalization of the license BY_NC_IL in NiC.

$$
\begin{aligned}
&< \mathbf{NiC}^{\texttt{BY\_AC\_NL}}(x, w, c, a, b, act) > \\
&\quad (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{Credit}(w, a, a) \\
&\qquad \wedge \mathbf{NonCommercial}(w, a) \wedge \mathbf{Location}(w, a, \texttt{supportedSite}) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{Credit}(w, a, b) \\
&\qquad \wedge \mathbf{NonCommercial}(w, b) \wedge \mathbf{Location}(w, b, \texttt{supportedSite}) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a))
\end{aligned}
$$

Figure 6: A formalization of the license BY_AC_NL in NiC.

1. Take the conjunction of the formulas `*-OU`, where each $*$ is a license attribute constituting L.
2. Use the conjunction obtained by 1 and form a rule $\bigwedge_{*}$ `*-OU` $\rightarrow \mathbf{Perm}(x, w, act, a)$.
3. Take the conjunction of the rule obtained by 2 and `NXp-OU`.
4. Take the conjunction of the formulas `*-DU`, where each $*$ is a license attribute constituting L. Note that the rules for derivative use are contained in all of licenses in NiC because NiC licenses permit modifying contents.
5. Use the conjunction obtained by 4 and form a rule $\bigwedge_{*}$ `*-DU` $\rightarrow \mathbf{Perm}(x, w, act, a)$.
6. Take the conjunction of the rule obtained by 5 and `NXp-DU`.
7. Take the conjunction of 3 and 6.
8. Transform the conjunction obtained by 7 to the formal syntax for licenses defined in Subsection 2.1.

To explain the eighth step of the procedure, we consider the rules of a license containing license attribute `AC`. In the case of original use, the formula `AC-OU` $\rightarrow \mathbf{Perm}(x, w, act, a)$ is as follows:

$$
\begin{aligned}
&\mathbf{AType}(\texttt{OriginalUse}, act) \\
&\quad \wedge \mathbf{SubWork}(a, c) \\
&\quad \wedge \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge (\mathbf{NonCommercial}(w, a) \\
&\qquad \vee \mathbf{AnotherLicense}(x, w, act, a)) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)
\end{aligned}
$$

This formula can be transformed to the following equivalent formula that follows our formal syntax.

$$
\begin{aligned}
&(\mathbf{AType}(\texttt{OriginalUse}, act) \\
&\quad \wedge \mathbf{SubWork}(a, c) \\
&\quad \wedge \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge \mathbf{NonCommercial}(w, a) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge (\mathbf{AType}(\texttt{OriginalUse}, act) \\
&\quad \wedge \mathbf{SubWork}(a, c) \\
&\quad \wedge \mathbf{CType}(\texttt{CRWks}, a) \\
&\quad \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad\quad \rightarrow \mathbf{Perm}(x, w, act, a))
\end{aligned}
$$

Consequently, we can see that this formula is equivalent to the formula $(\texttt{NC-OU} \rightarrow \mathbf{Perm}(x, w, act, a)) \wedge \texttt{NXp-OU}$.

The formula for a NiC license L obtained by the above procedure is referred to as $\mathbf{NiC}^L(x, w, c, a, b, act)$.

$$
\begin{aligned}
\mathbf{NiC}^L : &D_{agents} \times D_{agents} \times D_{contents} \times D_{agents} \\
&\times D_{agents} \times D_{action} \rightarrow \{\mathbf{True}, \mathbf{False}\}
\end{aligned}
$$

As examples, $\mathbf{NiC}^{\texttt{BY\_NC\_IL}}(x, w, c, a, b, act)$ and $\mathbf{NiC}^{\texttt{BY\_AC\_NL}}(x,$

$$
\begin{aligned}
&< \mathbf{GFDL}(x, w, c, a, b, act) > \\
&\quad (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{Credit}(w, a, a) \wedge \mathbf{License}(w, a, \texttt{GFDL}) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge\ (\mathbf{AType}(\texttt{OriginalUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge\ (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{Credit}(w, a, b) \\
&\qquad \wedge \mathbf{License}(w, b, \texttt{GFDL}) \wedge \mathbf{Modifiable}(a) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a)) \\
&\wedge\ (\mathbf{AType}(\texttt{DerivUse}, act) \wedge \mathbf{SubWork}(a, c) \wedge \mathbf{CType}(\texttt{CRWks}, a) \wedge \mathbf{DerivWork}(a, b) \wedge \mathbf{AnotherLicense}(x, w, act, a) \\
&\qquad \rightarrow \mathbf{Perm}(x, w, act, a))
\end{aligned}
$$

Figure 7: A formalization of the GFDL.

w, c, a, b, act) are shown in Figures 5 and 6, respectively. We can say that for specific constants x_0, w_0, and c_0, $\mathbf{NiC}^L(x_0, w_0, c_0, a, b, act)$ means that an agent x_0 permits an agent w_0 to use a constant c_0 through a NiC license L.

4.4 Formalization of GFDL

Contents licensed under the GFDL can be used for any purpose, as long as the use meets certain conditions. First, all previous authors of the work must be attributed. This condition is the same as `BY` in CC and NiC. Moreover, both copied original works and derivative works must be licensed under the same license (GFDL). This condition is same as `SA` in CC. Furthermore, GFDL is a non-exclusive license like CC and NiC are. Lastly, the condition peculiar to GFDL is that unmodified invariant sections as defined by the author must be maintained.

The formula for GFDL is referred to as $\mathbf{GFDL}(x, w, c, a, b, act)$.

$$
\begin{aligned}
\mathbf{GFDL} : D_{agents} \times D_{agents} \times D_{contents} \times D_{agents} \\
\times D_{agents} \times D_{action} \rightarrow \{\mathbf{True}, \mathbf{False}\}
\end{aligned}
$$

As an example, $\mathbf{GFDL}(x, w, c, a, b, act)$ is shown in Figure 7. We can say that for specific constants x_0, w_0, and c_0, $\mathbf{GFDL}(x_0, w_0, c_0, a, b, act)$ means that an agent x_0 permits an agent w_0 to use a constant c_0 by GFDL.

5. DISCUSSION

As shown in Figure 2, NiC has a limited range of effectiveness compared with CC and GFDL. This means the condition

$$
\begin{aligned}
&\mathbf{Location}(w, a, \texttt{supportedSite}) \\
&\quad \vee\ \mathbf{Location}(w, a, \texttt{unsupportedSite})
\end{aligned}
$$

is added to licenses in NiC containing license attribute `IL` and that condition

$$\mathbf{Location}(w, a, \texttt{supportedSite})$$

is added to those containing license attribute `NL`. These conditions are not added in CC. For example, the condition of $\mathbf{NiC}^{\texttt{BY\_AC\_IL}}(x, w, c, a, b, act)$ is tighter than that of $\mathbf{CC}^{\texttt{BY\_NC}}(x, w, c, a, b, act)$. This means that if the conditions of $\mathbf{NiC}^{\texttt{BY\_AC\_IL}}(x, w, c, a, b, act)$ are satisfied, the conditions of $\mathbf{CC}^{\texttt{BY\_NC}}(x, w, c, a, b, act)$ are also satisfied. Thus, we can conclude that $\mathbf{CC}^{\texttt{BY\_NC}}(x, w, c, a, b, act) \rightarrow \mathbf{NiC}^{\texttt{BY\_AC\_IL}}(x, w, c, a, b, act)$, that is, any contents permitted under the license $\mathbf{CC}^{\texttt{BY\_NC}}(x, w, c, a, b, act)$, are also permitted under the license $\mathbf{NiC}^{\texttt{BY\_AC\_IL}}(x, w, c, a, b, act)$ as they are. Oppositely, however, contents licensed with $\mathbf{NiC}^{\texttt{BY\_AC\_IL}}(x, w, c, a, b, act)$ cannot be opened to the public with $\mathbf{CC}^{\texttt{BY\_NC}}(x, w, c, a, b, act)$ because of the restriction of the conditions. In other words, we can say that $\mathbf{CC}^{\texttt{BY\_NC}}(x, w, c, a, b, act)$ has interoperability with $\mathbf{NiC}^{\texttt{BY\_AC\_IL}}(x, w, c, a, b, act)$.

On the other hand, in GFDL, there is a condition that invariant sections cannot be modified even when derivative use is permitted. Therefore, the following condition is added only for GFDL.

$$\mathbf{Modifiable}(a)$$

For this reason, GFDL has no interoperability with any licenses in CC and NiC.

More generally, we can show entire relationships between CC, NiC, and GFDL in Figure 8 concretely. `BY_NC` is interoperable to the license containing license attribute `NC` or `AC` in CC and NiC for the reasons described in Subsection 4.3.2. Contents licensed under licenses containing license attribute `SA` in CC cannot be licensed under any licenses in NiC and GFDL. This is because a license attribute that corresponds to `SA` does not exist in NiC. In addition, contents licensed under license containing license attribute `ND` in CC cannot be licensed under any licenses in NiC because only contents that can be modified can be licensed under NiC.

Figure 8 shows the result of examining interoperability of all licenses, the public domain, and copyright law. Arrows to themselves are omitted because it is obvious that each license has interoperability with itself. Contents are in the public domain if they are not covered by any rights at all. In other words, there are no conditions for using the contents, so there are interoperabilities from the public domain to any licenses. On the other hand, copyright law generally reserves all of rights concerning contents to authors. Therefore, we expect there are interoperabilities from any license to a copyright law. However, as copyright law is different in each country and the formalization of copyright law is beyond the scope of this paper, we use dotted lines to show the expected interoperabilities.

6. RELATED WORK

We referred to the research in [9], [16], and [10] for the formalization of licenses. Halpern and Weissman provided in [9] formal semantics for DRM like XrML [2]. Pucella and Weissman provided in [16] formal semantics for DRM like ODRL [18]. Both XrML and ODRL are described in formal language. Their research differs from ours in the target of the formal semantics. Halpern and Weissman have also examined a method for expressing access control policies by using first-order logic [10]. Actually, they used a subsystem of first-order logic so that reasoning about access control policies can be efficient and tractable. Their aim is to con-

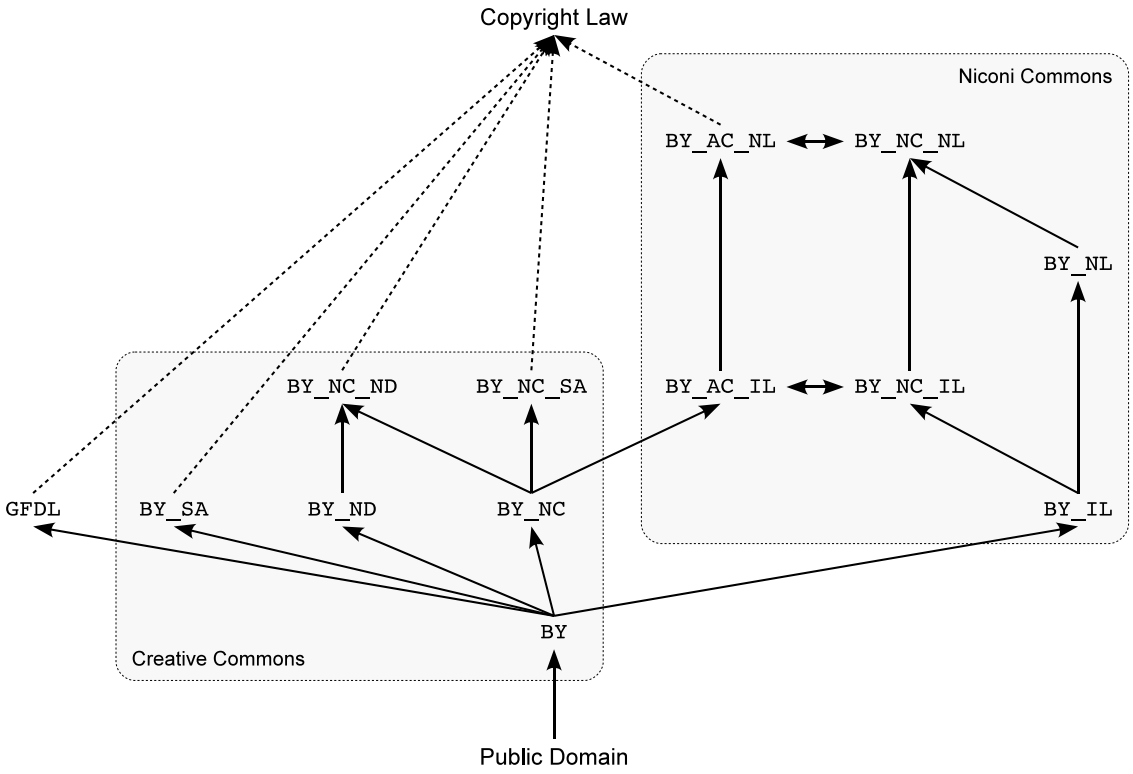

Figure 8: Relationships between CC, NiC, GFDL, the public domain, and copyright law.

struct a general theory, whereas our research is dedicated to analyzing actual licenses from a practical viewpoint.

Bjorner have conducted license formalization in [1]. Generally, licenses are contracts stipulated for permitting the use of copyrighted works. On the other hand, the concepts of a license in [1] have been extended not only to protecting contents but also to describing business obligations and rules formally. The research in [1] is similar to ours in that it provides license formalization. However, the main objective of [1] was to generalize license application, whereas that of our research is to reveal relationships between licenses.

The present research is related to legal reasoning [13] in that the targets are rules described by natural language. However, our research does not pursue generality in rules like legal reasoning does. We provide formal semantics for concrete objects like CC and NiC.

Jamkhedkar and Heileman examined the interoperability between Rights Expression Languages (RELs) in DRM systems [11]. Their research defines a core-rights model that is abstracted from components of RELs and describes how a concrete example of rights can be expressed in the models of XrML, ODRL, and CC. This research is similar to ours in that it provides a formal approach to rights management. The main objective of [11] was to offer a core-rights model, whereas our research is empirical.

7. CONCLUSIONS AND FUTURE WORK

We constructed a framework to formally examine license interoperability. We defined the framework for formalizing licenses using many-sorted first-order logic to analyze them.

On the framework, we provided a formalization for CC, NiC, and GFDL licenses, which are frameworks for supporting content distribution written in natural language. We verified the interoperability between CC, NiC, and GFDL and its validity based on the formalization. As a result, we defined the interoperability between CC, NiC, and GFDL.

Our study provides a theoretical basis for addressing the following issues.

Formalizing the entire NiC and GFDL In [8], formal semantics for the entire CC are provided. All of the text in the legal codes of CC were translated into formal language using many-sorted first-order logic. On the other hand, we have examined only a fragment of NiC for license attributes and GFDL in this paper. Strictly speaking, all of the text in the legal codes of NiC and GFDL should be translated in its entirety.

Automatic decision of license interoperability We plan to implement a system that can decide whether each formalized license has interoperability with other specific licenses or not. The system will be implemented on an automated theorem prover.

Other future work includes interoperability analysis of more examples of licenses. We also investigate possibilities of applying our result to different scenarios that relate to content circulation such as multiple licenses, superdistribution, and mashups.

8. ACKNOWLEDGMENTS

We would like to thank the reviewers for their comments that help improve the manuscript. We thank Yuko Noguchi and Dominique Chen of Creative Commons Japan, Kenji Taguchi of National Institute of Advanced Industrial Science and Technology, Nobukazu Yoshioka and Fumihiro Kumeno of National Institute of Informatics, Satoshi Tojo of Japan Advanced Institute of Science and Technology, and Dines Bjorner, for their accurate comments and advice. We thank Yoshifumi Manabe, Ken Mano and Hideki Sakurada of NTT Communication Science Laboratories for their valuable comments on earlier versions of this work.

9. REFERENCES

[1] D. Bjorner. *Domain Engineering: Technology Management, Research and Engineering*. JAIST Press, 2009.

[2] Content Guard. XrML: eXtensible rights Markup Language (online). Available at `http://www.xrml.org/`.

[3] Creative Commons. Creative Commons (online). Avaliable at `http://creativecommons.org/`.

[4] E. Diehl. A four-layer model for security of digital rights management. In *8th ACM Workshop on Digital Rights Management (DRM 2008)*, pp. 19–28, 2008.

[5] G. Doërr and T. Kalker. Design rules for interoperable domains. In *8th ACM Workshop on Digital Rights Management (DRM 2008)*, pp. 39–50, 2008.

[6] Free Software Foundation (FSF). GNU Free Documentation License (online). Available at `http://www.gnu.org/licenses/fdl.html`.

[7] K. Fujita, H. Endo, and Y. Tsukada. A formal approach to interoperability between licenses for content protection. In *4th International Workshop on Security 2009 (IWSEC 2009)*, pp. 81–98, 2009.

[8] K. Fujita and Y. Tsukada. A formal foundation for Creative Commons legal codes (in Japanese). *IPSJ Journal*, vol. 49, no. 9, pp. 3165–3179, 2008.

[9] J. Y. Halpern and V. Weissman. A formal foundation for XrML, *J. ACM*, vol. 55, no. 1, pp. 1–42, 2008.

[10] J. Y. Halpern and V. Weissman. Using first-order logic to reason about policies. *ACM Trans. Inf. Syst. Secur.*, vol. 11, no. 4, pp. 1–41, 2008.

[11] P. A. Jamkhedkar and G. L. Heileman. A formal conceptual model for rights. In *8th ACM Workshop on Digital Rights Management (DRM 2008)*, pp. 29–38, 2008.

[12] R. H. Koenen, J. Lacy, M. MacKay, and S. Mitchell. The long march to interoperable digital rights management. *Proceedings of the IEEE*, vol. 92, no. 6, pp. 883–897, 2004.

[13] K. Nitta, M. Shibasaki, T. Sakata, T. Yamaji, W. Xianchang, H. Ohsaki, S. Tojo, I. Kokubo, and T. A. Suzuki. New HELIC-II: a software tool for legal reasoning. In *5th International Conference on Artificial Intelligence and Law*, pp. 287–296, 1995.

[14] Niwango, inc. Nico Nico Douga (online, in Japanese). Available at `http://www.nicovideo.jp/`.

[15] Niwango, inc. Niconi Commons (online, in Japanese). Available at `http://www.niconicommons.jp/`.

[16] R. Pucella and V. Weissman. A formal foundation for ODRL. In *Workshop on Issues in the Theory of Security (WITS 2004)*, 2004.

[17] N. P. Sheppard and R. Safavi-Naini. On the operational semantics of rights expression languages. In *9th ACM Workshop on Digital Rights Management (DRM 2009)*, pp. 17–28, 2009.

[18] W3C. Open Digital Rights Language (ODRL) version 1.1. (online). Available at `http://www.w3.org/TR/odrl/`.