Conceptual Analysis of Resource Meta-information

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Abstract

It's ease of use and the availability of browsers for various platforms have paved the way for the enormous popularity that the World Wide Web currently enjoys. In the near future, by providing not only easy access to information, but also means for conducting business transactions, the Web could form the base technology for the information superhighway. In such a large distributed information system, resource discovery becomes a critical problem.

Recent developments in resource discovery systems, such as HARVEST [BDHMSS94b] and WHOIS++ [DeWe94], provide scalable mechanisms for the identification, location and characterization of networked information resources based upon resource meta-information. However, the Web's vast information space can only be handled effectively, when resources are meaningfully classified into coherent conceptual structures.

The automatic classification of resource meta-information is at the heart of the WAVE system [WAVER], which employs methods from the mathematical theory of concept analysis to analyze and interactively explore the vast information space defined by wide area resource discovery services. In this paper we discuss these methods by interpreting various synoptic and summary interchange formats for resource meta-information, such as the HARVEST SOIF and the WHOIS++ urc, in terms of basic ideas from concept analysis. In so doing, we advocate concept analysis as a principled approach to effective resource discovery.

1 Introduction

The World Wide Web is an Internet based information system for access to distributed hyperlinked documents. Its ease of use and the ability of seamlessly integrating other information services have paved the way for the widespread popularity the Web currently enjoys. Finding specific information however is a difficult task that cannot be accomplished through browsing. To address this problem, various mechanisms for resource discovery have been developed.

A naming scheme, such as the IETF URN, supports the concept of a persistent location-independent resource identifier. Directory resolution services map resource names “back” to actual physical locations (resource instances).
By encapsulating resource meta-information together with resource names, attributes, such as “title”, “author” or “topic”, etc. are available to search engines. In order to implement sophisticated retrieval engines, a means for the automatic interpretation and classification of meta-information must be found. Furthermore, an adequate metaphor for presenting and exploring information structures must be developed.

This paper discusses recent developments in the area of information resource discovery services, and proposes the use of methods from the mathematical theory of concept analysis to process and interactively browse a large information space.

2 Resource Meta-information

2.1 Uniform Resource Characteristics

We here want to apply ideas from Concept Analysis to the on-going discussions in the IETF-IIIR and IETF-URI working groups in general, and the specification by Michael Mealling [Me94a, Me94b] of URCs in particular. We use the following definitions.

- A Uniform Resource Locator (URL) is used for hyperlink markup in Web documents. Since a URL specifies a location and retrieval protocol of a given network resource, it is not a long-lived, stable reference. Moving or even renaming a file causes a URL reference to become stale. Besides, copies of the same document can be located at multiple locations (URLs).

- A Uniform Resource Name (URN) is used to identify a resource. A Uniform Resource Name (URN) is an identifier that uniquely and persistently names an information resource. The URN scheme has been designed in order to solve various problems with the URL. A Uniform Resource Locator (URL) is used to locate an instance of a resource identified by an URN. A Uniform Resource Identifier (URI) is either a URN or a URL.

- A Uniform Resource Characteristic (URC) is used to represent URIs and their associated meta-information. Uniform Resource Characteristics (URCs) [Me94a] are analogous to the bibliographic records of Library Science. URCs encode meta-information about network resources in the form of attribute:value pairs order by precedence. Compare also with IAFA formats, Whois++ templates, SOIF of the HARVEST system for resource discovery, etc.
2.2 IAF A Templates

2.3 Harvest Summary Object Interchange Format

2.4 Bibliographic Records from Library Science

Below, classified according to the eight areas of description of ISBD in Library Science, we list some attributes which might be relevant for a particular purpose:

1. title and statement of responsibility (Title, Author)
2. edition (Version)
3. material (or type of publication) specific details
4. publication, distribution, etc.
5. physical description (Content-Type, Content-Length, Size, Cost, etc.)
6. series (Time To Live)
7. notes (Abstract)
8. standard number and terms of availability (Uniform Resource Names, Uniform Resource Locators)

3 Resource Discovery Services

Due to the rapid growth of the World Wide Web in 1994, resource discovery has become a serious problem. Because of its decentralized architecture, the user experiences the Web as a large information repository without an underlying structure. The process of “surfing” pages by repeatedly following links is the most popular use of the Web. It can however lead to the phenomenon of getting “lost in hyperspace”.

3.1 Walking the Web

From the very beginning, approaches have been made to organize information about networked information resources into catalogs and indexes. Index files were originally maintained manually. However, the rapid growth of the Web soon made necessary automatic methods for generating resource directories. Automatic tools called “robots”, “Web wanderers” or “spiders” soon evolved. These are programs which automatically connect to a remote server and recursively retrieve documents. Since spider programs often put heavy loads on Web servers, they have been controversial, and are sometimes disliked by server maintainers.

The main problem with “spiders” is that they are nor “true Web wanderers” — the retrieval program does not transfer itself from the index site to the provider site, but instead transfers in the reverse direction over the network all
the potentially indexable documents. Since document repositories may contain hundreds of megabytes, the bandwidth requirements are enormous. Exacerbating this problem is the fact that current indexing tools gather independently, without sharing information with other indexers.

3.2 Whois++-URC

The WNILS working group in the Internet Engineering Task Force (IETF) is currently defining a standard for creation of a distributed directory service called WHOIS++. It defines the notion of “centroid” as a mechanism for passing index information between index servers. A centroid is a list of records, attributes, and a word list for each attribute. The word list for a given attribute contains one occurrence of every word which appears at least once in any record in the database for the attribute. In order to optimize searching, this abstracted information is passed up a hierarchical tree to other servers. [QUOTE Gargano Proc.Inet’93]

Although WHOIS++ defines a general purpose directory service, it can be employed to provide a Web specific resource discovery service. This can be achieved through a URN to URL mapping directory. By gathering and distributing URC information through a hierarchy of WHOIS++ servers, resource directories based on attributes such as “title” and “keywords” become possible.

3.3 Harvest

Harvest [BDHMS94a, BDHMS94b] is a distributed system for resource discovery and indexing. It separates the task of obtaining and distributing data: A gatherer collects information from a provider, while a broker provides a query interface for index requests. This approach has a variety of advantages. First of all, being able to run the gatherer at the provider site reduces server load and network traffic. Secondly, since a gatherer can feed information to many brokers, some of the redundancy described in the previous section can be avoided. Not only can brokers access more than one gatherer, but they can also be used to cascade indexed views from other brokers, using their query interface.

Not unlike the WHOIS++ approach, HARVEST uses a record consisting of attribute/value pairs as a unit for information indexing. The Summary Object Interchange Format (SOIF) is based on a combination of IETF/IAFA templates and the BibTeX format [La86]. Figure 1 shows an example of an SOIF template [BDHMS94b].

Table 1 lists some analogies between various components of resource discovery services. It provides an orientation towards the specification of resource discovery services in a distributive fashion as a federation of resource discovery software agents.

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1 WHOIS and Network Information Lookup Service
4 Resources are Conceptual Classes

Using ideas from Library Science and Concept Analysis, we are currently developing tools for the conceptual analysis of networked information resources in general, and the World Wide Web in particular. Networked information resources include (1) individual text files, (2) WAIS databases, and (3) starting points for hypertext webs. In this section we argue by example that resources are best thought of, not as objects, but as conceptual classes (concepts). We offer a concept-oriented approach for the description and organization of networked information resources, which will facilitate their subsequent discovery and access. This should not be thought of as yet another object-oriented approach. Although objects generate their own classes, classes are not only more general but also include intensional information. By identifying concepts with classes, this can be regarded as a class-oriented approach — an approach that has been advocated recently by Terry Winograd in the IETF-URI working group discussion on library standards and URI, and supported by Ronald Daniel and Dirk Herr-Hoyman.

4.1 Concept Analysis

Concept Analysis is a relatively new discipline arising out of the mathematical theory of lattices and category theory. It is closely related to the areas of knowledge representation in Computer Science and Cognitive Psychology. Concept Analysis provides for the automatic classification of both knowledge and documents via representation of a users faculty for interpretation as en-
coded in conceptual scales. Such conceptual scales correspond to the facets of synthetic classification schemes, such as Ranganathan’s COLON scheme, in Library Science.

Concept Analysis uses objects, attributes and conceptual classes as its basic constituents. A conceptual class consists of any group of entities or objects exhibiting one or more common characteristics, traits or attributes. A characteristic is a conceptualized attribute by which classes may be identified and separated into a conceptual hierarchy, and further subdivided (specialized) by the facets of topic, form, location, chronology, etc. The “has” relationship between objects and attributes is represented as a binary relation called a formal context.

A formal context is a triple \( \langle G, M, I \rangle \) consisting of two sets \( G \) and \( M \) and a binary incidence relation \( I \subseteq G \times M \) between \( G \) and \( M \). Intuitively, the elements of \( G \) are thought of as entities or objects, the elements of \( M \) are thought of as properties, characteristics or attributes that the objects might have, and \( gIm \) asserts that “object \( g \) has attribute \( m \).” In many contexts appropriate for Web documents, the objects are documents and the attributes are any interesting properties of those documents.

The definition of a conceptual class must involve: the common attributes, which are encoded in the superordinate (next higher and more general class), and the distinguishing attributes, which differentiate the defined concept from the superordinate. Conceptual classes are logically characterized by their extension and intension.

- The extension of a class is the aggregate of entities or objects which it includes or denotes.
- The intension of a class is the sum of its unique characteristics, traits or attributes, which, taken together, imply the concept signified by the conceptual class.

The intent should contain precisely those attributes shared by all objects in the

| Library Science | WHOIS++                      | HARVEST                     |
|-----------------|------------------------------|-----------------------------|
| patron          | user                         | user                        |
| photo-copier    | HTTP for resource            | HTTP for resource           |
| reference librarian | client/user-interface  | Broker/Query-Manager       |
| card catalog    | index                        | Broker/Registry             |
| holdings manager| Base-level Server            | Broker/Storage-Manager      |
| interlibrary loan| POLL command                | Broker/Collector            |
| cataloging      | individual publisher         | Gatherer/Extractor(Essence) |
| circulation     | Directory Mesh (?)           | Broker/Caching-and-Replicator|
| library resource list | IANA                     | Harvest Server Registry (HSR) |

Table 1: Analogies between Resource Discovery Services
extent, and vice-versa, the extent should contain precisely those objects sharing all attributes in the intent. Clearly the terms “extension” and “intension” are reciprocally dependent. They complement each other by reciprocally delimiting concepts and explicating definitions. A conceptual class will consist of such an extent/intent pair.

The process of subordination of conceptual classes and collocation of objects exhibits a natural order, proceeding top-down from the more general classes with larger extension and smaller intension to the more specialized classes with smaller extension and larger intension. This order is called generalization-specialization. One class is more specialized (and less general) than another class, when its intent contains the other’s intent, or equivalently, when the opposite ordering on extents occurs. Conceptual classes with this generalization-specialization ordering form a class hierarchy for the formal context. Knowledge is here represented as the hierarchical structure, or complete lattice, known as the lattice of conceptual classes of the formal context. Such lattices of classes can be visualized by line diagrams, where nodes represent conceptual classes and edges represent the subclass (subtype) relationship.

The join of a collection of conceptual classes represents the common attributes or shared characteristics of the classes. The bottom of the conceptual hierarchy (the empty join) represents the most specific class whose intent consists of all attributes and whose extent is often empty. The meet of a collection of conceptual classes represents the conjunction of all the attributes of the classes. The top of the conceptual hierarchy (the empty meet) represents the universal class whose extent consists of all objects. The entire conceptual class hierarchy is implicitly specified by the “has” relationship of the formal context. However, part of the hierarchy of conceptual classes could also be explicitly specified via the following top-down process.

- **Initialization:** The main top-level attribute classes are specified. These are meet-irreducible classes, meaning that they cannot be expressed as the meet of other more general classes.

- **Iteration:** Any collection of (super)classes can be specialized by the specification of differentiating attributes, thus producing subclasses. Each such differentiated (sub)class is subordinate to every (super)class in the collection.

- **Termination:** Continue until further specialization and differentiation is either impossible or impractical.

### 4.2 Specification of Resource Meta-information

Table 2 lists two generic interchange formats which can be used to specify faceted information in conceptually scaled networked information resources. Such faceted information can occur in various interfaces in a resource discovery system. From a mathematical viewpoint, these two representations are equivalent to each other. Software exists for converting between the two forms. The left
side of Table 2 displays the *Formal Context Interchange Format* (FCIF). FCIF is oriented towards the formal contexts of Concept Analysis. FCIF represents order-theoretic formal contexts of networked information resources, consisting of two partially ordered sets, a poset of objects and a poset of single-valued attributes, and an order-preserving incidence matrix which represents the has relationship between objects and attributes. The right side of Table 2 displays the *Concept Lattice Interchange Format* (CLIF). CLIF is oriented towards the concept lattices of Concept Analysis. CLIF provides a storage-optimal representation of order-theoretic lattices of conceptual classes for networked information resource meta-information, consisting of (the inverse relationships for) two generator monotonic functions, from the posets of objects and attributes to the lattice of conceptual classes, and a successor matrix which represents the subtype relationship between conceptual classes.

In this section we demonstrate that FCIF and CLIF subsume both the Uniform Resource Characteristics of WHOIS++ and the Summary Object Interchange Format of HARVEST. These interchange formats are more general mechanisms than either URCs or SOIFs, and allow for the specification of more complex conceptually structured systems of resources. Actually, as Figure 2 points out, both FCIF and CLIF are better thought to occur after conceptual scaling, whereas both URC and SOIF specify “raw meta-information” which exists before conceptual scaling [GaWi89]. From the philosophical viewpoint of Concept Analysis, conceptual scaling is an act of interpretation, which maps raw uninterpreted data, such as occurs in URC or SOIF, to a user’s view. URC and SOIF represent entity relations, whereas FCIF and CLIF represent incidence data between objects and attributes. These attributes are simple structured queries of the form tag#value, where # is any relational operator +, ≤, etc. The equality operator represents nominal scaling, whereas the inequality operator ≤ represents ordinal scaling [GaWi89]. Through conceptual scaling, which often is just nominal or ordinal scaling, we can compare FCIF and CLIF with URC and SOIF.

The OBJECT section of the FCIF specifies, in a transposed fashion, a required ordering relationship between resources:

\[ O_{i_1} \leq O_{i_2} \text{ iff } O_{i_1} \text{ is listed in the row indexed by } O_{i_2} \]

This OBJECT section can specify both generalization-specialization and part-whole relationships between resources. When parts are typed, part-whole relationships can be embedded as generalization-specialization relationships — the whole is a special case of an object which has that part. An important example of generalization-specialization relationships occurs in WHOIS++-URC. Here the instantiation relationship between an URN and its URL instances \( \{\text{URL}_1, \text{URL}_2, \ldots, \text{URL}_n\} \) is a generalization-specialization relationship. This instantiation relationship can be specified by adding a row indexed by the URN to the OBJECT section of the FCIF:
An important example of whole-part relationships occurs in \texttt{Harvest SOIF}. Here the \textit{embedded} relationship that occurs between an archived directory structure and one of its summarized files is a whole-part relationship. This directory-file whole-part relationship can be specified in an analogous way in the \texttt{OBJECT} section of the FCIF.

![Conceptual Scaling with Various Interchange Formats](image)

### 4.3 Examples

- The interchange formats FCIF and CLIF subsume the Uniform Resource Characteristics (URCs) of the IETF working group on Uniform Resource Identifiers URIs. The structural information in these interchange formats subsume Mitra’s precedence rules, which were used by Michael Mealling\cite{Me94b}. As Mealling points out, precedence rules allow for the creation of simple URCs that can be easily parsed and created by novice users.

The example in the left side of Table 3 of a URC is taken from the Internet Draft document \cite{Me94b} of the IETF. This URC contains two instances of the resource whose title and author are given below the URN attribute. It describes the resource entitled “Intro to FTP and Telnet” by author Adam Arrowood, and is available via anonymous ftp in postscript form and via http as an HTML document. After suitable analysis and interpretation via conceptual scaling of this bibliographic record data, a conceptual structure such as in the right side of Table 3 might be visualized. Here the lattice order from the URL object concepts to the URN object concept represents the precedence order in the URC. The conceptual class labeled by the author attribute is distinct from the URN object concept, since it represents all the resources which Adam Arrowood has created or authored. As is appropriate, the location is an attribute for the URLs, but not the URN. Table 4 demonstrates how the URC data on the left side in Table 3 might be represented in FCIF.

From the viewpoint of Concept Analysis, both resources represented by URNs and instances of resources represented by URLs are objects, whereas
meta-information in the form of (multi-valued attribute, value) pairs are (single-valued) attributes. Using precedence rules URCs represent two kinds of relationships: the “has” or “having” relationship between a URI and its meta-information: and the “instantiation” relationship between a resource represented by an URN and one of its instances represented by a URL.

- The interchange formats FCIF and CLIF subsume the Summary Object Interchange Format (SOIF) stream protocol of the Harvest system. SOIF specifies the interface between the Harvest Gatherer and Broker components. SOIF specifies single object summaries. FCIF specifies a typed collection of SOIF. Since SOIF specifies only single objects, it is a special case of the FCIF format, and is not able to specify order information either between objects or between attributes. Table 5 demonstrates this fact. On the left side of Table 5 is SOIF of some type TYPE. On the right side of Table 6 is the corresponding FCIF format for this SOIF. The attributes here are the ones used to query the broker(s). The objects here are object summaries in the returned query results. We see that the SOIF specifies mainly the incidence matrix.

- At the December 1994 meeting of the IETF-URI working group in San Jose, Stuart Weibel reported on “Existing Library Standards and the Evolution of Uniform Resource Characteristics”, where he suggested the use of Text Encoding Initiative (TEI) headers as a possible candidate for the specification of URCs. The Text Encoding Initiative is a multilingual, international project which has developed guidelines for the preparation and interchange of electronic texts for scholarly research. Each TEI-conformant text is prefixed by a header, which documents the electronic text. The use of the TEI-header as a basis for electronic text cataloging would allow digital libraries and traditional libraries to interoperate by integrating electronic resource discovery with existing paper resource discovery and retrieval.

In the follow-up discussion of the IETF-URI working group Dirk Herr-Hoyman created the simple example in Table 5 for the specification of a URC using TEI-like syntax. The nesting here verifies the simple fact that URLs are objects with their own attributes. Table 7 demonstrates how the the URC data in Table 6 might be represented in FCIF.

- Each resource is of a particular type. That type may be standardized by the conventions of some group. Or, that type might be dependent upon the individual user’s purpose and current viewpoint. The individual user may wish to customize the resource meta-information in order to construct their own personal information space.

Stuart Weibel, in the charter for the OCLC-NCSA metadata workshop in March 1995, has discussed the desirability of a taxonomy of resource
types. The complexity of resource meta-information depends upon its intended use. Too little information will fail to meet some purposes; too much information is a burden for systems and is costly to generate and maintain. This suggests the desirability, or even the necessity, for the development of a hierarchy of resource meta-information types. As Weibel suggests, resource meta-information might be promoted from a simple to a more complex level as the result of user demand or attention from a cataloging or archival agency. Levels of such a hierarchy might be defined by several criteria: purpose, cost, origin, etc.

BibTeX [Le79] provides a very simple example for a taxonomy of types of resource meta-information. Different types of publications require different information: journal article meta-information has a volume, but book meta-information does not. For each resource type in BibTeX, attribute tags are divided into required, optional, and ignored. Table 8 represents the BibTeX formal context, whose objects are the BibTeX entry types, and whose attributes are the required BibTeX fields (required BibTeX attribute tags). Figure 8 displays the line diagram of the lattice of classes for this BibTeX formal context.

Here, the “misc” BibTeX entry type labels the top lattice node, since it is the most general type in terms of required tags (fields) — it has none. The BibTeX “article” entry type is more specialized than the BibTeX “proceedings” entry type, since in addition to “year” and “title” tags, it also requires “journal” and “author” tags. All absolutely non-required tags (tags not required by any type) label the bottom lattice node. This BibTeX concept lattice line diagram reveals an important idea: the discovery by conceptual analysis of new resource types — the unlabelled lattice node in the center of the diagram represents an interesting but unspecified type, whose required tags are “author”, “title”, and “year”.

5 Conclusions

In this paper we have demonstrated that Concept Analysis provides a solid foundation for the development of a principled approach towards the specification of networked information resource meta-information. We have discussed in particular, how the meta-information in two well-known resource discovery services, WHOIS++ and HARVEST, can both be subsumed in a more general and well-structured approach which uses ideas from Concept Analysis.

References

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- $O_i$ and $O_{i,o}$ are object names (strings).
- $A_i$ and $A_{j,a}$ are attributes $tag\#value$, where $#$ is $=$, $\leq$, etc.
- $C_k$ and $C_{k,s}$ are indexes (natural numbers) of conceptual classes.
- $x_i$ and $y_j$ are coordinates (natural numbers) of conceptual class nodes.

Table 2: Interchange Formats for Faceted Resource Meta-information

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[BeMoKa94] Beck, Howard; Mobini, Amir; Kadambari, Viswanath: *A Word is Worth 1000 Pictures; Natural Language Access to Digital Libraries*, Proceedings of the Second International WWW conference, pp. ??, Chicago, October 1994.

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[DeEm94] Deutsch, Peter; Entage, Alan: *Publishing Information on the In-
Table 3: **Conceptual Scaling of a URC**

| Specification of a URC | Conceptual Structure of a URC |
|------------------------|-------------------------------|
| URN:IANA:623:oit:cs:ftp-and-telnet | ![Diagram of Conceptual Structure] |
| Title: Intro to FTP and Telnet |  |
| Author: Adam Arrowood |  |
| URL: file://ftp.gatech.edu/pub/docs/ftp.telnet.ps |  |
| Content-Type: text/ps |  |
| Size: 1MB |  |
| URL: http://www.gatech.edu/oit/info/ftp.telnet.html |  |
| Content-Type: text/html |  |
| Size: 600K |  |
| Cost: US$0.25 |  |

*ternet with Anonymous FTP*, Bunyip Information Systems Inc., May 1994.

[DeWe94] Deutsch, Peter; Schoutz, Rickard; Faltstrom, Patrik; Weider, Chris: *Architecture of the Whois++ Service*, internet draft document draft-ietf-wnils-whois-arch-01.txt, July 25, 1994.

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[Me94a] Mealling, Michael: *Specification of Uniform Resource Characteristics*, Internet Draft draft-ietf-uri-urc-00.txt (April 5, 1994) of the Internet Engineering Task Force (IETF).
Table 4: Formal Context Interchange Format for a URC

[Me94b] Mealling, Michael: Encoding and Use of Uniform Resource Characteristics, Internet Draft draft-ietf-uri-urc-spec-00.txt (July 1, 1994) of the Internet Engineering Task Force (IETF).

[Wy80] Wynar, B.S.: Introduction to Cataloging and Classification, 6th ed., Libraries Unlimited, Littleton, Colorado 1980.

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Table 5: **SOIF and the corresponding FCIF**

| Summary Object Interchange Format | Formal Context Interchange Format |
|----------------------------------|----------------------------------|
| @ UPDATE {                       | TYPE $T$                         |
| $T$ { $URL_1$ $A_{1,1}$ $A_{1,2}$ · · · $A_{1,i_1}$ } | OBJECT $URL_1$ ()               |
| $T$ { $URL_2$ $A_{2,1}$ $A_{2,2}$ · · · $A_{2,i_2}$ } | $URL_2$ ()                      |
| · · ·                        | · · ·                           |
| $T$ { $URL_n$ $A_{n,1}$ $A_{n,2}$ · · · $A_{n,i_n}$ } | $URL_n$ ()                      |

| ATTRIBUTE $A_1$ ()               |               |
|···$A_m$ ()                      |               |
| INCIDENCE $URL_1$ { $A_{1,1}$ $A_{1,2}$ · · · $A_{1,i_1}$ } |               |
| $URL_2$ { $A_{2,1}$ $A_{2,2}$ · · · $A_{2,i_2}$ } |               |
| · · ·                        |               |
| $URL_n$ { $A_{n,1}$ $A_{n,2}$ · · · $A_{n,i_n}$ } |               |

Table 6: **Specification of a URC**

```xml
<TEL-SGML>
  <url>urn:mysite.uri/myauth/11122233</url>
  <title>My really good resource</title>
  <author>Ima Nutt</author>
  <date>December 22, 1994</date>
  <locationGroup>
    <list>
      <item><url>http://www.mysite.com/myresource</url>
        <extent>24567 bytes</ext>
        <format>text/html</format>
      </item>
      <item><url>ftp://ftp.mysite.com/pub/myresource.txt</url>
        <extent>12543 bytes</ext>
        <format>text/plain</format>
      </item>
    </list>
  </locationGroup>
</TEL-SGML>
```
Table 7: Specification of a URC

| objects | incidence | attributes |
|---------|-----------|------------|
| 1 article | 1 × × × × | 1 author |
| 2 book | 2 × × × × | 2 title |
| 3 booklet | 3 × × × × | 3 journal |
| 4 inbook | 4 × × × × × | 4 booktitle |
| 5 incollection | 5 × × × × × | 5 volume |
| 6 inproceedings | 6 × × × × | 6 number |
| 7 manual | 7 × × × × | 7 series |
| 8 mastersthesis | 8 × × × × | 8 edition |
| 9 misc | 9 × × × × | 9 publisher |
| 10 phdthesis | 10 × × × × | 10 address |
| 11 proceedings | 11 × × × × | 11 howpublished |
| 12 techreport | 12 × × × × | 12 month |
| 13 unpublished | 13 × × × × | 13 year |

Table 8: formal context for BibTeX types and required tags
Figure 3: lattice of classes for BibTeX types and required tags