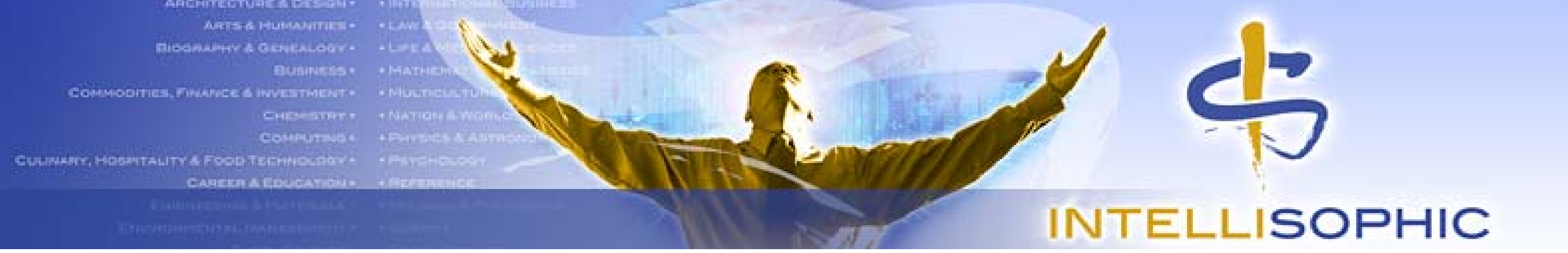

Leveraging Collective Knowledge: Concept Taxonomies from Reference Text

An Intellisophic Proprietary White Paper

Leveraging Collective Knowledge:
Concept Taxonomies from Reference Text

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Abstract

Taxonomies are well accepted tools for large-scale text indexing. But taxonomies in practice are implemented as shallow hierarchies for navigation and categorization, or as controlled dictionaries and thesauri - all using only a string as the terminal concept representation. This paper presents an approach called *orthogonal corpus indexing* (OCI) which generates large scale concept indexes from existing text corpora. A *concept* is a richly multifaceted structure including a title, a signature vector of facet-weights, and links within in a parent-child topic hierarchy. Based on content from reference publishers and public domain sources, Intellisophic is actively building an extensible library of taxonomic content. Currently, this library covers a broad set of subject areas with millions of contextually precise and well articulated concepts. This paper outlines the company's content, methods, and systems.

1 Introduction: Taxonomy for information organization

- *Is it feasible to assemble taxonomic data covering all human knowledge?*
- *What is an appropriate concept representation?*
- *Should concepts be assembled a priori? Or is a dynamic model possible?*
- *How will quality be achieved and maintenance governed?*

Evidence suggests that the loaded cost of developing a taxonomy may be as high as two hundred dollars per node, which seems reasonable when considering the involvement of IT staff, corporate librarians, departmental publishers, commercial information providers, and international standards bodies. The questions above are informed in various ways by *orthogonal corpus indexing* (OCI), the methodology and technology discussed herein for automated development of concept taxonomies from existing reference text corpora. OCI has resulted in a large scale concept catalog and taxonomic library, leveraging existing works for authorship, as a way to reduce taxonomy development costs by orders of magnitude.

1.1 Taxonomies and Concept Indexes

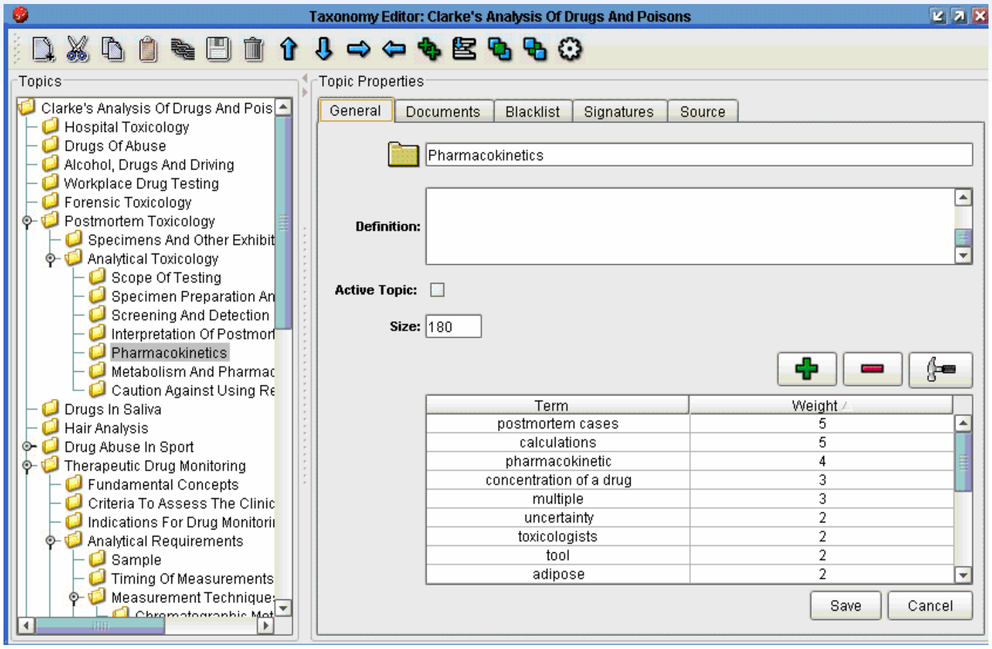
Semantically rich knowledge representations do exist, and several are emerging for semantic interoperability and web services such as W3C's OWL[1] and DARPA's DAML[2]. There is, however, no global ontology of concepts to populate these schematic representations. High degrees of up front design and pre-coordination are required to affix concepts to data. And while taxonomies are intended to enable conceptual access to information - the effort, expertise, and risk involved in manually generating taxonomies results in a lack of rich, deep, and extensible taxonomic data to characterize the conceptual contents of underlying text. Probabilistic information retrieval[3] thus requires up front articulation of each concept space.

Human knowledge naturally covers many domains, ranging from general interest such as entertainment and foods to the sub-sub-topics of specific legal or scientific sub-specialties. OCI is distinctive as a taxonomy generation method in that it leverages structured reference texts for development and extension of an integrated topic space enabling deep yet accurate taxonomies on a scale never before achievable. In a matter of hours or even minutes a source corpus can be converted into taxonomic data through automated methods, and with semi-automated controls for quality enhancement as desired. In general, taxonomy development is akin to data modeling in that a conceptual model is developed to cover the domain of interest. Data modeling is done a priori to meet anticipated application requirements. During taxonomy design for a given industry or segment, if a subject area is not already in our library, we identify relevant and accessible publications to cover the domain of interest.

An *orthogonal reference text* corpus for OCI input can be any body of text that is organized by concept or is otherwise topically prearranged with topic delineations such as chapter headings or a table of contents. Sources used include encyclopedia, reference texts, handbooks and training manuals, gazetteers, on-line directories, or any number of content types and sources satisfying the base requirements. The source reference publications Intellisophic selects usually are alphabetical or have a hierarchical topic graph with distinct and authoritative text portions of length one paragraph or more for each topic. After structure recognition of the source corpus, each delimited text portion from that corpus is processed to derive a single concept in the resulting taxonomy. The source corpus provides three inputs:

a) taxonomic structure (typically largely hierarchical) via an outline structure or other topic delimiting mechanism,
b) a title term as a label for each node, and
c) text describing the topic or concept from which is derived a signature vector containing facets – where a facet may be a word, phrase, entity identifier, concept identifier, or other domain-specific information derived from the source text.

Figure 1 below is an example taxonomy and concept derived from *Clarke's Analysis of Drugs and Poisons*[4]. In print form, this source corpus is a 2100 page reference source on drugs, poisons, and related substances. It is aimed at scientists attempting to determine a drug or poison in a pharmaceutical product, in a sample of tissue or body fluid, from a living patient, or in post-mortem material. *Volume 1* (shown below) has 32 chapters concerning analytical procedures in forensic toxicology. *Volume 2* has more than 1750 substance monographs detailing physical properties, analytical methods, pharmacokinetic data, and toxicity data. The graphic shows the concept of 'Pharmacokinetics' within the reference corpus. The taxonomy below is opened up to this node four levels down in the hierarchy of *Volume 1*. On the left is the concept of 'Pharmacokinetics' in the context of the topic hierarchy around it, showing a navigational path to it.



Taxonomy Editor: Clarke's Analysis Of Drugs And Poisons

Topics

- Clarke's Analysis Of Drugs And Pois
  - Hospital Toxicology
  - Drugs Of Abuse
  - Alcohol, Drugs And Driving
  - Workplace Drug Testing
  - Forensic Toxicology
  - Postmortem Toxicology
    - Specimens And Other Exhibit
    - Analytical Toxicology
      - Scope Of Testing
      - Specimen Preparation An
      - Screening And Detection
      - Interpretation Of Postmor
      - Pharmacokinetics
      - Metabolism And Pharmac
      - Caution Against Using Re
  - Drugs In Saliva
  - Hair Analysis
  - Drug Abuse In Sport
  - Therapeutic Drug Monitoring
    - Fundamental Concepts
    - Criteria To Assess The Clinic
    - Indications For Drug Monitori
    - Analytical Requirements
      - Sample
      - Timing Of Measurements
      - Measurement Technique
        - Chromatographic Met

Topic Properties

General | Documents | Blacklist | Signatures | Source

Pharmacokinetics

Definition:

Active Topic: □

Size: 180

Term	Weight
postmortem cases	5
calculations	5
pharmacokinetic	4
concentration of a drug	3
multiple	3
uncertainty	2
toxicologists	2
tool	2
adipose	2

Figure 1: Example taxonomy and 'Pharmacokinetics' node with term signature facets

The concept shown is given context by the path location:

> 1. Clarke's Analysis of Drugs and Poisons
>> 1.6. Postmortem Toxicology
>>> 1.6.2 Analytical Toxicology
>>>> 1.6.2.5 Pharmacokinetics

On the right is shown the set of facets derived by OCI from the corpus source on this topic to describe it. The source text for this concept contains 180 unique words from which OCI text processing derives discriminating facets starting with the term "postmortem cases". Each facet is weighted according to the relative importance (e.g., number of appearances or relative location) of that facet in that topic's source text in the corpus. Signature facets are the words and phrases, hyphenated terms, entities, or other possibly domain-specific elements such as chemical formulas and concepts derived from the text. Facet derivation is achieved using statistical and linguistic processing including phrase generation, parsing rules, lexical filters, and optionally other tools such as entity extraction and categorization.

1.2 Concept Count and Concept Richness

This rich multifaceted representation of an OCI concept is atypical relative to what industry refers to as a node or concept in a taxonomy. Figure 2 below illustrates the position of OCI relative to alternative approaches to taxonomy development – both automated and manual. The left side of the table concerns the richness of a concept: is a concept represented as a single term, e.g., an undifferentiated string, or is a concept multifaceted. Auto-categorization and other concept operations require a rich concept representation in order to go beyond keywords as a proxy for concept matching. The horizontal on the table concerns the number of concepts achievable - low being on the order of tens of thousands or less, while high is above tens of thousands. The higher the number of concepts, the more subject areas and nuances within them are covered, and thus the deeper the taxonomy can be developed into specialized areas.

	Low Node Count – not deep or specific in specialized areas < 10,000	**High Node Count** > 10,000
Low Concept Richness concept is represented as a String	Manually developed thesauri and taxonomies for narrow domains or specific applications	Industry thesauri (several exist with tens of thousands of terms) Library of Congress, Dewey Decimal Yahoo!, Open Directory
High Concept Richness Multidimensional/ multifaceted concept representation	Clustering (e.g., latent semantic indexing / SVD) (inaccurate/unlabeled concepts, methods require redundant sources, irregular taxonomies, limited application) Training sets (must manually define hierarchy	Pre-built, machine aided taxonomies from reference text (millions of multifaceted and accurate concepts, authoritatively organized and described, supports deep and meaningful auto-categorization, extensible concept space)

Figure 2: Rich vs. Deep Taxonomy Creation Methods

Intellisophic believes that no technique besides OCI offers the accuracy and richness of authoritative concepts as well as the depth and breadth of accurate taxonomic hierarchies. The fingerprint of each concept is captured in the signature facets and reflects the authorship and expertise of a subject matter expert (the corpus author). This elaborate articulation of concepts across a large concept space enables:

- enhanced precision and recall in auto-categorization and document filtering
- richer search keys and concept interconnections
- cross-domain research and discovery of intellectual property
- deep tagging and summarization of content with concepts
- cross-referencing of documents, concepts, and people.

Application of such rich and deep taxonomies will be discussed in Section 4**.**

1.3 Taxonomy publishing

OCI processing begins with a corpus source of reference information. Leveraging prior corpus creation by authors, editors, and publishers reduces the direct cost of developing a taxonomy concept by several orders of magnitude while enhancing taxonomy quality in several key dimensions. By selecting corpora from commercially published sources, and complemented by various other sources, Intellisophic has assembled a rich taxonomic library with millions of concepts and facets.

Consider the breadth of reference material available as taxonomy sources. There are several thousand English language encyclopedia published, and there are tens of thousands of professional and technical reference books. Encyclopedia topic areas currently populated range from general knowledge such as *WorldBook Encyclopedia*[5] with twenty-seven thousand topics, to technical and professional specialties such as the *Encyclopedia of Chemical Technology*[6] with its forty thousand topics in a twenty-seven volume set and on to a variety of more specialized areas. OCI has also been applied to public and private corpora of various genres such as patents, legal acts, government reports, on-line information directories, and internal training manuals.

When a topic area is not covered or is not sufficiently elaborated and taxonomy extension is desired, this is achieved through access to new corpora. OCI enables rapid creation of high quality taxonomies on demand. As an example of taxonomy extension, consider again the concept of 'Pharmacokinetics' from Figure 1 above. It is a leaf node in the Clarke drug and poison reference. That topic could be much further elaborated, however, by ingesting for example the *Handbook of Essential Pharmacokinetics, Pharmacodynamics and Drug Metabolism for Industrial Scientists*[7] from Kluwer Academic / Plenum Publishers, and also by *Basic Pharmacokinetics*[8], a web textbook made freely available by several academics in the field. This is an entire textbook for an introductory Pharmacokinetics course that has been made especially for publication on the web.

These examples illustrate the massive collective knowledge resource that existing works – both formally and informally published - offer for taxonomy development and extension. This off-the-shelf labor saving model allows taxonomies to be extended as application requirements change and as knowledge grows into virtually any area of human activity. It is based on this model of corpus access that Intellisophic is actively growing its library. In contrast, the effort required for manual pre-coordinated taxonomies forces organizations to choose one concept and term at a time, in the context of a given application - by librarians, subject area experts, and editors who must agree on terminology. This process is tedious, with results that are often rigid, of low coverage, or otherwise of low quality.

2 Development Methods and Topic Coverage

"'Lincoln, the Man, the Car, the Tunnel' was a play about romance"

Keywords are unreliable as indicators of conceptual content as the above example illustrates. This is due to the all-or-nothing keyword approach in which a document either does or does not have a keyword. The mental construct of a "concept", however, rarely corresponds to a single keyword or to a Boolean combination of keywords. A biochemist looking for information on a particular chemical process might search by inventor name, an input compound, a regulatory group, an acronym or common name, or any of a number of possible and probable handles into the conceptual space. Synonyms and alternative wordings further compound the problem. It is ultimately concepts and not words that search keys are targeting. A taxonomy provides a basis for conceptual access and sharing of information as well as enabling mining of textual data for business intelligence, whether that text is in a document repository, newspapers, emails, or embedded in the text fields of a database. A concept within a taxonomy sets context and must provide for a rich multifaceted representation to overcome the naïve model of keyword matching.

2.1 Enumerated and Pre-coordinated Taxonomies

Although a database installation may have hundreds of millions of rows, the set of metadata descriptors required for data integration and mining, such as authoritative terms or controlled vocabularies, is relatively bounded. This is because most database applications are targeted to a well-defined domain of discourse. Thus, metadata models are usually developed by a centralized standards group for structured data. Categorization schemes for unstructured text such as the Library of Congress Classification (LCC)[9] and Dewey Decimal Classification (DDC)[10] are considered *enumerative*, meaning that a notation is assumed to exist to categorize any given publication. The LCC came into being in the early twentieth century and is used in most academic library collections. Indexing elements include: subject, author, date, geography, and genre. Subject is the primary sort key, and the job of the human categorizer is to select a category for the particular information package. In the LCC system, the first letter of a call number refers to the general subject area and the second letter refers to a sub-section within the general subject category. For example, a book on the History of Modern France can be categorized as first level World History and second level France.

Such notations are called *pre-coordinated* because there is prior agreement on the structure and subjects of interest. The centralized process to define and maintain a categorization scheme involves governance and stewardship by committee; a distributed large-scale standards approach. The major drawback to this model is that there is a rigid network of paths leading to rigidly grouped items. The job of the categorizer is to "categorize each book into pre-existing pigeon holes"[11]. While useful for placing books on a shelf, and thus for high-level categorization, schemes such as the DDC or the LCC are not intended to detect and represent the full spectrum of subjects in each information package.

So while pre-coordinated and enumerated taxonomies, thesauri, and lexicons have a place for book identification in library science, their role in automated concept recognition is less clear. Often there is little prior knowledge about the set of topics contained in a document or document pool, and no opportunity for people to read and categorize manually, particularly in a multifaceted context. The goal may be to discover emergent concepts in email, text notes, or a text message stream. The OCI Model for content indexing is not to bound, control, or pre-specify a restricted set of terms and concepts - but rather to allow the space growth in a more organic sense, to use systems to impose organizing structure and for meaning extraction. The resulting rich and deep taxonomic data are high-dimensional indexing structures for connecting to information conceptually.

2.2 Multifaceted Concepts

Ranganathan[12] described the Dewey Decimal system as faulty in its underlying principle of listing all possible subjects, assigning to each a predetermined categorization number, and subsequently fitting everything into existing buckets. Ranganathan saw that human pursuits were growing quickly. New areas of knowledge were being discovered, and new ways to combine existing subjects were emerging as well. Any categorization scheme that attempted to enumerate a finite number of subjects, without proper capability for expansion into new knowledge, could never meet the needs of the future[13]. Ranganathan's seminal work in library and information science formalized *multifaceted concepts* and the *Colon Classification Model* - a model for defining concepts as combinations of other concepts. For example, the Colon system would represent a book about "research in the cure of tuberculosis of lungs by x-ray conducted in India in 1950" with a call number as follows:

L,45;421:6;253:f.44'N5

The notations represent: Medicine,Lungs;Tuberculosis:Treatment;X-ray:Research.India'1950[14]. This is in contrast to the Dewey Decimal and Library of Congress systems which require new concepts to be enumerated individually. The Colon system was a major theoretical development for categorization theory. It acknowledges the various ways that concept facets relate to one another and showed that concepts can be effectively combined to derive new concepts. The rich concepts derived by OCI are multifaceted, as each corpus article is processed to extract the essential facets of that topic. Often twenty or more distinct facets of an article are derived as signature elements.

2.3 Why Millions of Concepts? "Spectral Content Analysis"

A node within a library categorization scheme is not intended to represent the spectrum of concepts contained in a publication, but rather to reflect the general subject of that publication. A book can be put only one place on the shelves, even if it contains hundreds or thousands of underlying concepts. So how many concepts might be needed? A concept, for OCI purposes, can be interpreted as a domain of discourse and may include either base or aggregate concepts such as:

- a particular event in history
- logistical issues in the transportation and storage of citrus fruits
- taxation on oil production in Europe
- health effects of inhalation of depleted uranium
- a particular famous person
- the general concept of a famous person or of an athlete

Within source corpus text, ideas are represented as strings in a natural language: paragraphs, sections, and section headers are often the only structure imposed on otherwise ambiguous words, phrases and sentences as rendered by the corpus article author. Eventually each facet will be derived via OCI processing from corpus article text. Abstractly, the facets of a concept that OCI extracts are the various entities, attributes, and relationships that would be used to talk about that concept. Facets are not tightly bounded, as they are intended to allow a multi-perspective albeit structured and condensed, description of the concept. Facets can also provide an interconnect model to relate different concepts to one another, and to search and navigate among concepts and documents.

To estimate the number of concepts or facets in the world at large, or as relevant to some particular domain, is only a theoretical exercise. To a child, a rock is something to be thrown, while to a geologist it represents something much more. Nevertheless, many concept labels require multiple terms, for example: *health effects of inhalation of depleted uranium* uses multiple significant terms. Concepts aggregate in a multiplicative way to become more particular or aggregated. Additive as well as subtractive models of concept definition are relevant, for example a concept specification may indicate that someone is interested in *anthrax* the *bacteria* and *industrial hygiene*, but not in the context of the concepts of *cattle* or *livestock vaccination*.

The Oxford English Dictionary[15] contains approximately 500,000 terms, not including another estimated 500,000 scientific terms[16]. Clearly not all combinations of terms and concepts would result in a meaningful aggregate concept. Regardless, the combinatorial aggregations of words into concepts are huge even for highly restricted combinations. WorldBook Encyclopedia has 27,000 topics. The *Encyclopedia of Chemical Technology* has 40,000. *Medical Subject Headings* by the National Library of Medicine[17] has 50,000 terms. The Encyclopedia of Modern Asia[18] has 6,000 topics. The Gale Business Thesaurus[19] has 15,000 terms. Virtually any specialty area, well articulated, can quickly climb into thousands or tens of thousands of concepts. The goal of a concept catalog should be to preserve and represent as much information and detail about a domain as possible, and only through a fine-grained concept index is this possible. The set of concepts relevant across organizations, across document collections, and across applications is clearly too large to manually enumerate into multifaceted representations for automated processing.

Thesauri – often called taxonomies in industry vernacular - are developed for authoritative term sets and for search enhancement. Their entries are what can be called *atomic concepts* - concepts which correspond tightly to the terms of the language. But, as discussed, many concepts are synthesized from multiple underlying or related concepts and thus can never appear in a thesaurus. Comprehensive authorship about virtually any field is not simply itemizing base and related terms; it is the discussing of areas of knowledge in various ways: the components of a system, the steps in a process, the disciplines underlying a scientific challenge.

Consider these example topics from reference corpora Intellisophic has processed:

- Detecting Foodborne Pathogens
- Misinformation On-line
- Anti-fungals for Dermatological Use
- Surveillance of Personnel for Laboratory-Associated Rickettsial Infections
- History of the Federal Bureau of Investigation

Concept taxonomies must be considered dynamic structures which can grow as needed as knowledge evolves and, in a sense, are not even relevant to the thesaurus model. OCI processing has resulted in a rich taxonomy library that has millions of such concepts and underlying facets, articulating the subtlety and interconnectedness among concepts. Intellisophic continues to grow the library into new and more detailed topic spaces.

2.4 OCI Taxonomy Coverage

The breadth and depth of the OCI taxonomy library are driven by two factors - content availability and application demand. The current strategy is to cover general knowledge with multiple general encyclopedias and to build out increasingly targeted taxonomies into more specialized areas. Source corpora range in size from several hundred to as many as 100,000 topics.

Sources have included a variety of genres including encyclopedia, dictionaries, controlled thesauri with definitions, handbooks and manuals, professional and reference textbooks, on-line directories, and patent abstracts. In addition, Intellisophic has processed some less structured (e.g., more narrative) yet still authoritative non-fiction books such as an account of an organization, in which semi-automated markup was included as a pre-processing step to establish topic boundaries.

This content is evolving with a growing set of source materials to meet the demands of new applications, and over time with a growing base of human knowledge. As for quality - if inadequate corpus content is fed to the system (e.g., insufficient text to describe a topic) then quality will suffer, though taxonomy structure and labels may still be robust. The algorithms employed on the content processed to date have shown to be an extremely effective combination. While topics need not be mutually exclusive, it is believed that the taxonomy library assembled thus far is the broadest, deepest and richest in the world.

3 Concept Representation and OCI Processing

3.1 Taxonomy and Concept Representation

An OCI concept is a node within a largely hierarchical graph structure of topical parent-child relationships. Other relationships are also possible such as geographic containment, experts within a discipline, etc. These are determined by the semantics of the source corpus and do not necessarily alter the processing performed. A node corresponds to a concept and contains a title, a parent pointer, a signature vector of *concept facets* and their weights, and optionally children and link references. While the term *hierarchy* is used to refer to Intellisophic's graph model, secondary link types are also supported for constructing a new taxonomy from existing ones as well as for typed links besides parent-child such as "see also" links.

The logical concept representation is as follows:

> **CorpusID:** Number
> **NodeID:** Number
> **Title**: String
> **ParentNodeID:** Number
> **Children:** Vector of NodeIDs
> (Includes specially designated "link nodes" for taxonomy interconnections)
> Vector of **Facet Weights**
>
> Facet Weight
> > **FacetID**: Number
> > **Weight:** Number

A *facet* is an aspect of a concept, i.e. a construct used by the corpus author in discussing that concept. At a modeling level, three facet types are relevant:

1. A term, which is a word or phrase lifted from the text with no identified relation to an outside construct (an undifferentiated string). Terms may be pre or post thesaurus processing, pre or post stemming, and may optionally be tagged or enhanced by a parts of speech analyzer.
2. An entity, which is a reference to an instance in an entity extraction and identification system (e.g., ID's of specific people, places, books, organizations, dates, etc.).
3. A concept, which is to say that the corpus article itself contained a specific pre-existing concept (most applicable when deterministic concept matching rules are defined).

The faceted representation of a concept defines each concept as a vector in a multidimensional space of dimension *n*, where *n* is the number of all terms, concepts and entities defined. Our base system implements only the term as a signature facet type, while applications have involved integration of external entity identification systems and extended concept matching rules, so that corpus articles may define facets that are entities and concepts as well as terms. These may be application-specific extensions for finding entities or concepts of interest in a particular domain such as chemical formulas in a chemistry or chemical processing corpus. Similarly, while link nodes are one extended relationship type among concepts, others can be equally defined and identified.

3.2 Corpus Processing

OCI processing looks at a corpus as a whole to determine whether a given element of a text article belongs in the final facet set of the corresponding concept and with what weight. Concept boundaries in the text are defined by the structure of the corpus. As shown in Figure 3, a source corpus is first processed for structure recognition, which may include the processing of a table of contents or the identification of section headers. The text from each section is parsed and processed independently to determine the set of facets that are candidates for assignment to a given concept – these are the words and phrases that appear in the corpus text. The text processing to identify facets includes parsing, phrasing, and elimination of stop words.

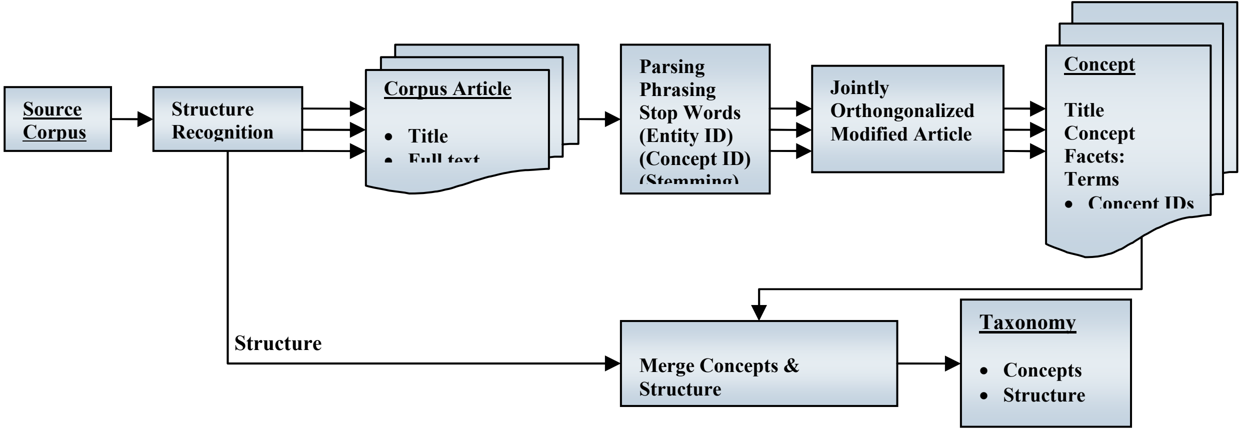


Figure 3: OCI processing

Sparse matrix processing allows for rapid handling of the large multidimensional space of facets and weights to determine which facets are to be assigned to which concepts. The orthogonalization step mathematically identifies a unique signature for each concept to differentiate it from surrounding concepts. As with latent semantic indexing[20] and hierarchical clustering[21] the orthogonalization step looks jointly at a set of surrounding articles from within the source corpus to determine which other corpus articles contain the same candidate terms or facets. The set of facets which is associated strongly with one (or some minority of corpus articles) is assigned to that concept and thus defines the characteristic signature or fingerprint for the derived concept.

Weights reflect the relative importance of a facet to a concept and are based on frequency of that facet (term, entity, concept) within the corpus and to its occurrence more generally. Parameterization of the system allows the corpus article to be contextual and achieve a proper relative weighting among different facets. These include position in the article. For example, facets derived from titles can be weighted more heavily than those from article text. The number of bytes considered in a corpus article can be capped if a corpus has articles that are lengthy, in order to create concepts that are well-focused. A child article in the corpus hierarchy may inherit elements of its parent as a means of setting context. An example of this would be if a parent article were "marine biology" and a child article "Hawaii Pacific University" then the concatenation of the two titles would more accurately set the conceptual context of the underlying article.

Other aspects of processing not shown have also been adapted, or have been used for specific applications over time. These include stemming, statistical removal of facets based on probabilistic priors (inverse information gain), and adverb discounting based on parts of speech tagging. These are applied pre or post orthogonalization as part of increasing the accuracy of facets. By associating one or more thesauri with the terms of the facet set – synonyms, broader and narrower term relationships can be leveraged to further tune the concept signature that is output and enhance accuracy in applying the taxonomy for information processing. Results can be stored in a relational database for easy access and connection to other semi-structured and structured data elements within the enterprise. The taxonomic data that OCI generates are delivered in any of several external formats including the XTM Topic Map standard[22] and the W3C Web Ontology Language.

4 Applying Deep Taxonomies with Rich Concepts

A data model represents the structure and vocabulary of data elements for a given database application. Consider ISBN numbers in the publishing world. All applications using this model must commit to the ISBN as a shared representation, without which bookstores could not communicate about books. Of course, ISBN is a narrow domain. To build applications around constructs that have not been pre-established, and may grow rapidly, requires an extended vocabulary and modeling ability. The area of *text mining* concerns the extraction of implicit, unknown (e.g., to the corpus authors), and useful information from large amounts of textual data. Applications enabled by deep taxonomies with rich concepts deal with large bodies of text, concern new or hidden information (e.g., discovery), and involve a domain of concepts that can only be specified for application design at an aggregate subject-area level.

4.1 Categorization, Search and Navigation

The problem of categorizing a document against a set of concepts is to either:

1) determine the single high level concept most relevant to, or representative of, the document (e.g., the library bookshelf / categorization problem),
2) identify a limited set of concepts that are most relevant (e.g., beyond some scoring threshold to capture essential elements of the document), or
3) list all concepts contained within the document (yielding an inventory of the document for auditing or search purposes).

Categorization on the basis of nodes represented as a single undifferentiated string as the concept representation, or with a shallow topic hierarchy and non-specific concepts, would suffer similar problems to keyword search; namely that scoring for relevance would be unstable, unreliable, or simply uninteresting for their generality. False positives and false negatives result from synonyms, homonyms and hyponyms (a word that is more specific than a given word). Categorization against a multifaceted concept allows scoring to be multidimensional and therefore to more closely reflect subtle human judgment about conceptual relevance.

Take into account again the concept of 'pharmacokinetics' from Figure 1. The top-level signature facets are the terms 'postmortem cases', 'calculations', 'concentrations of a drug', 'adipose', 'toxicologists', and the concept label 'pharmacokinetic' itself. In this manifold representation, much more than simply the concept label is surfaced. The author's perspective, as to what is essential to the topic and thus *what the topic means*, comes through in the OCI concept representation. It can be seen from the signature terms that this article was not focusing on other aspects of the topic such as *mechanisms of drug diffusion* or *detection of drugs within a pharmaceutical*. Rather, this article describes 'pharmacokinetics' in terms of concentrations of drugs in body tissue in postmortem cases.

Considering another example, the signature terms in one context for the concept of 'sterilization' are:

> *steam, sterilize, germs, viruses, surgical, killing, medicines, bacteriology, virus-like*

And another context for 'sterilization' (from a different taxonomy) has the terms:

> *procedure, surgical, reversal, tying, tubes, anatomical, blocking, sterilized, castration, spaying, contraception, ovaries, vasectomy*

These divergent signature sets reflect the fact that the term 'sterilization' could refer to the removal or destruction of microorganisms, or it could refer to the act of making an organism infertile. Clearly 'sterilization' alone is ambiguous. The distinct signature terms make very clear the differentiation between these two uses of the term.

Relevance scoring of documents against a multifaceted concept is a mathematically based alternative to complex Boolean queries and has been shown to increase both precision and recall significantly. Government labs testing based on the TREC Q&A track material[23] have indicated significant improvements relative to competing content and categorization models. Based on a multidimensional relevance scoring algorithm, not only would the term sterilization be used, but a joint vector cosine score and signature coverage score can be applied. Multidimensional scoring against a concept signature is a robust way around keyword indexing with its complex and contrived Boolean combinations of terms and query design issues.

This same multifaceted representation also aids in search and navigation, in that multiple paths and interconnections can be identified. An extended keyword search on signature terms may aid in a discovery process for a researcher investigating toxicology, drugs, forensics, etc.

Having the concept term 'pharmacokinetics' placed in the context of

Clarke's Analysis of Drugs and Poisons > Postmortem Toxicology > Analytical Toxicology > Pharmacokinetics

enables fast disambiguation of faceted terms and concepts, as well as introducing further navigation opportunities. Similarly, 'sterilization', is easily disambiguated or discovered based on navigational paths.

> *General Knowledge > Life Science > Bacteriology > Sterilization*
> *vs.*
> *Health > Reproductive Health > Birth Control > Surgical > Sterilization*

A final aspect of multifaceted concepts for search and categorization is in summarization. When a document is categorized against a multifaceted concept, a document gist can display the sentences and phrases around signature elements as a means of focusing the summary. This highlights the portions of the document that are related to this concept, explains reasoning behind categorization and summarizes the document in the context of a given concept.

4.2 The Narrative

Another take on multifaceted concepts is our *narrative*. A narrative is a document selected by a user to represent some area of knowledge or discourse, i.e. a subject of interest. For a government analyst this might be a multi-page intelligence report describing how to build and deploy a particular class of weapon. By categorizing such a threat narrative document against a set of taxonomies (say covering several hundred thousand topics in medicine, physics, chemistry, and warfare), the underlying set of concepts contained in that document immediately become clear. The concept decomposition of this narrative provides a review of the conceptual contents of the document. When many such threat scenarios have been identified, the conceptual breakout of each document can be individually obtained quickly through categorization. The structured data set, in the form of a concept inventory detected within the narrative, is now a basis for discovering and identifying more information about that same narrative constituting a conceptual "more like this" feature. The set of concepts that the narrative categorize into is in fact a multifaceted conceptual representation of that narrative, in a representation and form amenable to further automated processing and inference. This narrative model for categorizing resumes, papers, or emails offers a model for finding individuals relative to areas of expertise (authorship) and interest (readership).

4.3 Concept Query Language

As a final example application of our taxonomies and concepts, Intellisophic has implemented the *concept query language* (CQL). CQL is an SQL-like language that operates over taxonomies, concepts and documents. It can also be easily extended to connect to other entities in the enterprise such as customers or employees. Connections of structured data sets with concepts are a rich area for data warehouse development and text analytics (e.g., skill-set identification, interest-group registration, call center administration, claims processing, etc.).

CQL allows complex Boolean querying over the joint document space and concept space (including hierarchy such as 'in a concept or under it'). Fulltext features include thesaurus, stemming, and proximity search, among others. Given a set of documents that have been categorized (or are otherwise associated with) taxonomy nodes, an example query is:

```
SELECT <DOCUMENT> WHERE
signatureword LIKE '%hydrogen%'
and ( nodetitle LIKE 'carbon'  OR nodeid UNDER 42332 )
and ( corpus_name LIKE 'chemistry' corpus_name LIKE 'chemical')
and fulltext NOT LIKE 'bone'
and datelastfound = SYSDATE
ORDER BY author
```

This query finds documents that are associated with a corpus and nodes as specified in the where clause, and having the fulltext and metadata characteristics as further specified. Specifically, this query seeks documents *associated with nodes having hydrogen as a signature element and having carbon in the title or else being a descendant of nodeid 42332 in a corpus having chemistry or chemical in the name, but not if the document has the term bone and must have been found as a document today*. Document information and metadata are returned in an XML data structure. A large set of underlying concepts to apply in such a query enables a kind of "semantic slicing and dicing" - lifting the level of abstraction in document and concept identification from keywords (as in traditional Boolean full text search) to one of concepts. In a sense, each CQL query can be thought of as synthesizing a new concept. Alerts on these queries can indicate when new documents come into the system, which conform to this new CQL-defined "concept".

5 Conclusion

This paper has introduced Orthogonal Corpus Indexing as a model for efficient production of high quality taxonomies, and described several applications for the kinds of taxonomies that OCI produces. Existing vetted sources impose structure and identify concept labels and facets resulting in rich, deep and meaningful taxonomies achievable through automation. Spurious or unlabeled "concepts" that may arise from automated approaches such as clustering are not an issue in this approach. The quality of the resulting taxonomies is high along core dimensions such as breadth, depth, accuracy, balance, consistency, extensibility, and interconnection. As the publishing world develops into new on-line publication types and genres, such semantic knowledge acquisition models are only further enabled.

6 Resources

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