USING A CROP-PEST ONTOLOGY TO FACILITATE IMAGE RETRIEVAL

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2005

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by

Soonho Kim

To my father and mother.

ACKNOWLEDGMENTS

My first thanks go to my adviser, Dr. Howard W. Beck. His kindness, enthusiasm, and support made all the difference in my academic career. I had no background knowledge about agricultural information before I met him. He has been teaching several basic components from scratch that are needed for my research such as Java, concepts of object-oriented database management system, artificial intelligence, and ontologies. Every Friday for 5 five years, Dr. Beck meets me to discuss my research and gives advising to me. I could not finish my dissertation without him.

My thanks also go to Dr. James J. Jones, who served on my committee. I learned how to build a biological system from his course. He taught me a participatory design to develop an application for agricultural users. Whenever I implemented applications on my research, I kept in mind of considering users and communicating with users.

I thank Dr. Fedro Zazueta, who served on my committee. He made my eye to open roles of information technology in agricultural extension service. He introduced current information technology on agricultural extension service in U. S. In addition, he made me to learn how to improve extension service using information technology on South Korea in terms of contribution of my research.

I thank Dr. Tim Momol, who served on my committee. He gave me a big help to understand concepts about crops and pests. He introduced concepts on plant pathology. It was basis on developing a crop-pest ontology which is a major component of my research.

I thank Dr. Joachime Hammer, who served on my committee. He provided guidance on basic concepts of database management system and semantic web.

I also wish to thank the other members of my academic community at University of Florida, particularly Dr. Daniel W. Lee, and Mary Hall. I am deeply grateful to my friends (Mcnair Bostic, Rohit Badal, Yeonchul Jeong, and Chris Davison) for their support during a difficult period for our field.

Outside my academic community, I shared many tears and laughs over with Angela Brammer who corrected my grammar on this dissertation. She did her best for helping me finish it. I thank Inok Kim who takes care of my baby. She cares for my daughter as like her third child. I know I am very lucky to meet her in Gainesville.

The dissertation was a long process, and much has changed in this time. Bonny Koo, my daughter, was born during this period, and she is a sweet hope for the future. Whenever I felt that I was not enough smart to write a dissertation, she made me to keep trying to do. I really thank my husband, Jawoo Koo. He is my best friend, my friend, and my partner. My mother-in-low, Kyungsun Whang, and my father-in-low, Chiwhe Koo, encouraged me to do my Ph.D. degree and gave me lots of help to finish this dissertation.

Finally, I thank my father, Jongko Kim, and my mother, Bokrae Kim. They put all efforts to take care of me through their lives. Unless they did not, I could not become a Ph.D. I thank my brothers, Jaeho Kim and Kwangho Kim as well. I really thank God who makes me to be happy every moment.

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December 2005

Chair: Howard W. Beck
Major Department: Agricultural and Biological Engineering

Professionals in the agricultural field, such as growers, Extension agents, and researchers, need a facility to organize and locate photographic images related to their work, especially as the volume of such images continues to increase. However, current keyword-based image retrieval suffers from relatively low precision and recall. A new approach to image retrieval using an ontology in the agricultural field addresses the limitation of supporting users to find proper images in keyword-based image retrieval, by browsing images associated with formal descriptions of the meanings of words and the relationships between them. Two hundred and ninety-one images were used to develop the approach in the particular domain including crops and related pests. A “crop-pest ontology” was created to represent concepts describing the images. The ontology contains crops and related pests, relationships between them, and environmental factors affecting them. A practical comparison between the crop-pest ontology and the existing National Agricultural Library Thesaurus (NALT) was done to compare and contrast the similarities and differences between the thesaurus and an ontology. The comparison

shows that the crop-pest ontology has better formal representation capabilities avoiding ambiguity as well as supporting inferences which are not possible in a thesaurus such as NALT. To enable browsing of images associated with the crop-pest ontology, images were indexed based on the ontology. The indexing process included manual syntactic and semantic analyses of each image caption, but such an analysis has a high labor cost. Therefore, a process of semi-automatic analysis was designed using natural language-based information extraction techniques which include a parser, a grammar described by phrase patterns, and the crop-pest ontology. A graphical interface was implemented for browsing images associated with concepts in the crop-pest ontology. A usability study indicates that participants met less empty results in the retrieval of images using the crop-pest ontology. Moreover, it shows that the image retrieval using the crop-pest ontology helps users to find relevant images by transferring the domain knowledge to them. The indexing process included manual syntactic and semantic analyses of each image caption, but such an analysis has a high labor cost. Therefore, a process of semi-automatic analysis was designed using natural language-based information extraction techniques which include a parser, a grammar described by phrase patterns, and the crop-pest ontology. This research 1) shows the development of the crop-pest ontology, 2) analyzes the differences and similarity between an ontology and a thesaurus, 3) develops a method of automatic information extraction were explored as a way to reduce the manual labor required for ontology-based indexing and 4) develops a new approach using the ontology to index and browse images so that professionals can retrieve images more easily and accurately in the agricultural field.

CHAPTER 1
INTRODUCTION

Images are a major component of agricultural information systems. As the number of available images increases rapidly, finding relevant images in a timely and efficient manner becomes more difficult. Agricultural professionals such as growers, Extension agents, and researchers need a facility to retrieve images in a collection more easily in the agricultural domain. There are two standard approaches to image retrieval: content-based and text-based. In content-based image retrieval, images are searched using features such as color, texture, shape and spatial location. An example of this approach is the PicSOM system (Koskela, 2000). In text-based retrieval, searches are based on textual descriptions such as image captions. Since content-based retrieval is still not suitable for most applications, online image-retrieval engines such as Google (Google, 2005) employ text-based image retrieval.

Statement of Problems

A typical method of text-based image retrieval employs the use of keywords. Keyword-based image retrieval is an approach that retrieves text such as image captions or descriptions of images by using indexes of words appearing in the text. In its simplest form, a search engine indexes every word occurring in every piece of text associated with images in a collection to be searched. Users describe their interests through one or more keywords. If the keywords appear in indexes, the search engine shows images containing those keywords. This keyword-based image retrieval approach has two general limitations (Hyvonen et al., 2003).

- **Limitation of finding relevant images**: Appearance of a keyword in a text does not necessarily mean that the text is relevant to the user's interest. Relevant text may not necessarily contain the explicit keyword typed by the user.

- **Limitation of helping users to find proper keywords**: the user does not necessarily know what keyword to type to find images. The keyword-based approach is not useful unless the user is familiar with what kinds of images are in a collection and the user know what terms are used to describe relevant images.

Limitation of Finding Relevant Images

The limitation of finding relevant images is formally measured in terms of recall and precision, illustrated in Figure 1-1. Recall is the ratio of the number of relevant documents retrieved to the total number of relevant documents in the collection. Precision is the ratio of the number of relevant documents retrieved to the total number of documents retrieved. Recall and precision are usually expressed as percentages.

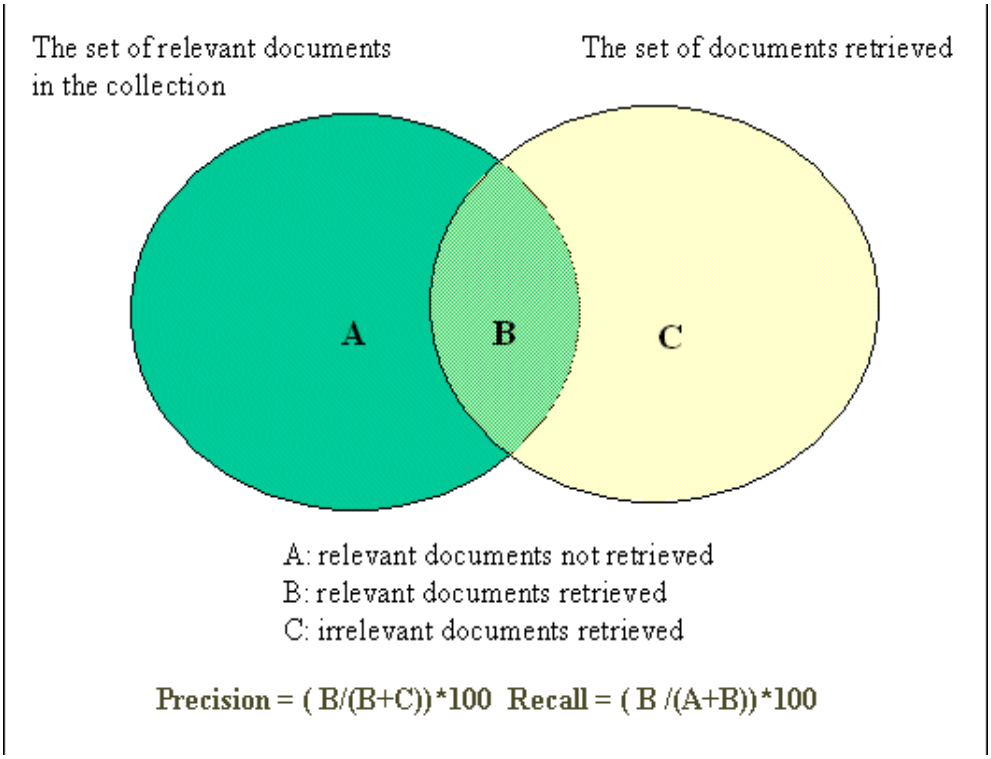


Figure 1-1. An illustration of precision and recall. Precision is expressed as the percentage of retrieved documents that are relevant. Recall is expressed as the percentage of relevant documents retrieved out of all the relevant documents in the collection.

The most desirable retrieval approach would be one with high precision and recall. Such a retrieval approach would find all, and only, the images that are relevant to a user's interest. Blair reported that a practical evaluation of a publication system containing roughly 350,000 pages of text showed the average recall value of the retrieval system to be less than 20 percent of the text relevant to a particular retrieval (Blair et al., 1985). The precision values ranged from 19.6 percent to 100 percent. Blair stated that the recall values were low because keyword-based retrieval is difficult to use when pieces of text are retrieved by subject. Shafi reported that the precision and recall of three search engines, AltaVista (AltaVista, 2005), Google (Google, 2005) and HotBot (HotBot, 2005), were less than 30 %, as shown in the Table 1-1. The search engines were evaluated taking the first ten results pertaining to scholarly information for estimation of precision and recall.

Table 1-1. Mean Precision and Relative Recall of search engines during 2004

	AltaVista	Google	HotBot
Precision	27%	29%	28%
Recall	18%	20%	29%

The design of this approach is based on the false assumption that it is a simple matter for users to predict the exact words and phrases that appear in the texts they would find most useful (and only in those texts). This assumption comes from the basic but flawed idea that one can use the "statistical aspects" of words such as the occurrence, location, and frequency of words to predict their meanings comprehensively. Therefore, one way of getting higher values of precision and recall would be to take the meanings of words into consideration. Understanding the characteristics of words themselves can help the underlying retrieval method adapt to the meanings of words:

- Words can have several meanings. For example, the word "beetle" can mean an insect belonging to a large order characterized by a modified outer pair of wings that forms a hard covering for the inner pair (Encarta, 2005). The word "beetle" can also refer to a car manufactured by Volkswagen that has a shape reminiscent of the insect.

- Different words can have the same meaning. For example, the word “worm” can mean an elongated soft-bodied insect. The word “larval” can mean a wingless and elongated soft-bodied insect that is immature hatching from egg. The different words, “worm” and “larva” point at the same meaning.

- Words can have a wide variety of different associations. For example, the word “beetle” has an association with the word “soybean” because a beetle is a pest of soybeans. In addition, the word “beetle” is associated with the words “egg,” “larva,” “pupa,” and “adult,” which are all names of developmental stages in a beetle’s life.

Limitation of Helping Users to Find Proper Keywords

The limitation of helping users to find proper keywords can be addressed by providing a facility of browsing images associated with well-structured knowledge in a particular field. Yee reported that current keyword-based retrieval such as Google Image Search (Google Image Search, 2005) did not allow users to browse images (Yee, 2003). Markkula reported that professionals in artistic fields such as journalism, design, and art direction use browsing as a basic strategy in searching for images. The reason is that some words describing selected images may be difficult to express freely as search keywords but are easily applied when the images are seen. Similarly, growers and other professionals in the agricultural field would want to be able to browse images as well as search for them with keywords.

A facility to show relationships of an image collection to users can address the limitation of supporting users in the keyword-based image retrieval with providing describing a particular knowledge inferred by images. The result set generated from the keyword-based retrieval would perhaps miss interesting aspect of an image collection; the images in the collection are related to each other in many relationships. For example, an image presenting “stink bug damage on cotton leaf” can be retrieved as a result set of the keyword “stink bug”. However, the interesting relationships between “cotton leaf”

and “damage” can not be shown to the users, even though these relationships might give a clue for users to find relevant images.

Image Retrieval Using a Thesaurus

A thesaurus is a list of terms related to a particular subject and describes related terms for each item. Its primary purposes are indexing documents and helping users retrieve information more easily. It is organized in a hierarchical structure, based on interrelationships of the terms:

Broader Term (BT): A particular term is more general than another term.

Narrower Term (NT): A particular term is more specific than another.

Related Term (RT): Two terms are associated.

Use For (UF): A particular term is the preferred term among a set of synonymous terms.

One of main contributions of a thesaurus in image retrieval can be reformulation of users’ requests and expansion of them to address low precision and recall in the keyword-based image retrieval. A thesaurus could be used to retrieve more relevant images by expanding user’s requests with related terms (RT), which might result in increasing recall. In addition, a thesaurus could be used to avoid retrieving non-relevant information by using narrower term (NT). The approach of retrieving images using a thesaurus has been developed in order to address the low precision and recall of keyword-based image retrieval by considering the interrelationships between terms. Dalmau reported that the integration of thesaurus relationships into search and browse in an online photograph collection significantly improved the user’s discovery experience (Dalmau et al., 2005). When users’ requests were found in the thesaurus, the result page provided search suggestions based on broader term (BT) or narrower term (NT) so that users can broaden

or refine a result set. In addition, the search performed retrieval of all narrower terms of user's requests if they are matched into the thesaurus (Dalmau, 2005). However, Hersh assessed the expansion of users' requests using thesaurus relationships for improving search performance (Hersh et al., 2000). A test collection was expanded using synonym, BT, NT, and RT in the Unified Medical Language System (UMLS) Metathesaurus (UMLS Metathesaurus, 2005). Hersh reported that thesaurus-based query expansion causes a decline in retrieval performance generally.

A thesaurus can be used as a tool to browse images. Dalmau insisted that a thesaurus directed users to more access points available for each image. In addition, he argued that the use of a thesaurus to browse images provides disambiguation. However, Chun stressed that a thesaurus has a limited number of relations, which can result in relatively meager expressiveness of representing specific knowledge, which could result in ambiguity of relations (Chun 2004).

An Approach to Image Retrieval Using an Ontology

A new approach to image retrieval using an ontology is introduced to deal with the two limitation of 1) finding relevant images and 2) helping users to find proper keywords in the keyword-based image retrieval. The word *ontology* is originally from the field of philosophy and referred to the subject of existence.[1] Computer scientists have eventually come to use this term to support the sharing and reuse of formally represented knowledge in computer systems (Gruber 1993). An ontology is defined as a collection of concepts and their relationships which describes knowledge in a particular domain. An ontology is described in a formal way that makes concepts understandable to a machine. A concept is

[1] http://www-ksl.stanford.edu/kst/what-is-an-ontology.html

a set of things that we receive in the world. A concept has a set of property that must be true of each member of the set denoted by the concept A concept can be represented by one of three formal elements in an ontology: an individual, class, or property:

- **Individual**: An individual is defined as a real object in the world.
- **Classes and subclasses**: A class defines a set of enumerated individuals that belong together according to their common properties. Any class can be a subclass of another class that is, whenever satisfying the necessary and sufficient conditions of another. The subclasses are satisfying the requirements of their superclass and adding additional restrictions. Superclasses are generalization of the common properties of the subclasses.
- **Properties**: Properties are defined as relationships between individuals or between individuals and data values (such as strings and integers).
- **Domain**: A domain of a property is defined as a set of individuals to which the property is applied.
- **Range**: A range of a property is defined as a set of individuals that the property has as its value.

Concepts in the crop-pest domain, which include crops and related pests, can be described in a crop-pest ontology. This ontology includes concepts such as plants, pests, relationships between plants and insects such as damage, and environmental concepts such as soil. The concept “plant” is described using the class “plant.” The particular concept “damages” can be represented as a property between “insect” and “plant.” Classes, properties, and individuals are described formal machine-readable form (what does that mean).

The word *ontology* has also become popularly associated with one idea for the next generation of the Web, called the *Semantic Web* (Semantic Web, 2005). The Semantic Web purports to be a universal medium for information exchange by supplying meaning in such a way as to be machine-processable to the content of documents on the Web. Currently, the Web is based on documents written in HTML, a language that describes a

body of structured text, focusing on a desired visual layout. However, HTML has the limitation that it does not describe information contained within the documents themselves. For example, with HTML we can present a page that lists pesticides; accordingly, the HTML code of this page can make simple, document-level statements such as "This document's title is ‘Pesticides.’" But there is no facility within HTML itself to relay more complex concepts, such as "AZOXYSTROBIN” is a pesticide with a unit cost of $1.38." Rather, HTML can only say that the text of "AZOXYSTROBIN" is something that should be positioned near the words "Pesticides" and "$1.38." HTML can not indicate that AZOXYSTROBIN is a type of pesticide or even assert that $1.38 is a unit price. The Semantic Web addresses this limited ability of HTML found within the current Web by using ontologies and by extension of current Web markup languages, all of which will play key roles in describing richer semantics of Web documents by providing sources of shared, precisely defined terms.

The rich semantics of ontologies can provide better retrieval and indexing of images. TextPresso[2] is a biological publication system that uses ontologies to catalog and retrieve literature. In the TextPresso system, using an ontology resulted in a threefold increase of search efficiency in the specific field of biological gene-to-gene interaction (Müller 2004). Hyvonen developed an ontology-based image retrieval system for 600 photographs in the Helsinki University Museum (Hyvonen, 2003). The promotion ontology was used to annotate images and provided a facility to image retrieval. He stressed that image retrieval using the promotion ontology helped the user to find relevant images, even though the user initially lacked knowledge about the domain

[2] http://www.textpresso.org

Related Works in the Agriculture Field

Existing image repositories in agriculture employ either the keyword-based image retrieval or a browsing tool using a few levels of categories, or both. Plant Diagnostic Information System (PDIS, 2005) and Digital Diagnostic and Information System (DDIS, 2005) provides an image search based on keyword-based image search. Therefore, the image search in PDIS and DDIS could have low recall and precision. In both systems, each image has a searchable text that describes image annotations, circumstances and other relevant information. Unless users are familiar with the text, it could be difficult to find proper keywords to retrieve images. Agricultural Research Service provides an image gallery contains more than 2000 images (ARS, 2005). It provides a keyword-based image search. Therefore it has the same limitations of conventional keyword-based search. In addition, it provides nine simple categories to help users to find relevant images: animals, crops, education, field research, fruits & veggies, illustrations, insects, lab research, and plants. Each category shows all images that are classified into the category and there is no subcategory. The nine categories are too general to describe whole contents of images. That means users can miss some contents of images that might be important to them. Insect Images (Insect Images, 2005) provides keyword-image retrieval for insect images and support categories to browse images associated with the insect scientific names. However, Insect Images still has a problem with low recall and precision, since it employs the conventional keyword-based search.

Other image repositories in agriculture provide only browsing facilities images associated with categories. Texas Agricultural Extension Service provides browsing for cotton insect images using a few levels of categories. Those categories are not enough to

represent the content of images. User need a tool to represent contents of images more precisely.

Contributions

The main contributions of this dissertation are summarized as follows:

- A new technology ("ontology") —was adapted to an agricultural information system to address the image retrieval problem.
- An ontology describing crops and related pests, called the crop-pest ontology, was built in the formal Web Ontology Language, OWL. A practical methodology for building the ontology was developed.
- Based on the crop-pest ontology, manual extraction of image information was done with image captions from a scientist who is working on crops and insects as a first step toward image indexing.
- Based on the previous results, images associated with the crop-pest ontology were indexed to enable browsing of the images.
- A new graphical interface was created for browsing images indexed with the crop-pest ontology.
- Methods of automatic information extraction were explored as a way to reduce the manual labor required for ontology-based indexing.

Overview of Chapters

Chapter 2 presents the development of the crop-pest ontology, which covers crops, pests, the relations between them, and the environmental factors surrounding them. Based on early methodologies of ontology building, a practical methodology is introduced for the agricultural field. In addition, validation and evaluation of the created ontology are discussed.

Chapter 3 presents the differences between the crop-pest ontology and another similar approach: "thesaurus." Jacob introduced the argument that a controlled vocabulary is itself an ontology, so long as the standard concept of a controlled vocabulary is similarly redefined (Jacob, 2004). This chapter discusses a comparative

analysis between the crop-pest ontology and the well-known agricultural thesaurus National Agricultural Library Thesaurus (NALT) in order to verify Jacob's argument. The analysis was done according to the representational and inferential abilities that lend more power to information retrieval. The result of this comparative analysis is reported. In addition, the result is discussed in terms of addressing the limitations of keyword-based image retrieval

Chapter 4 presents the process of indexing each image with the crop-pest ontology. This process was based on syntactic and semantic analysis. A graphical interface for browsing images with the crop-pest ontology is introduced. The preliminary evaluation is represented.

Chapter 5 presents the process of information extraction, which aided in the indexing of 150 images that were associated with the crop-pest ontology. Information extraction is a process that identifies useful information from natural language text regarding a domain and converts that information to a structured form, which can be saved into a database. The process uses a parser to map words appearing in each image caption to concepts in the crop-pest ontology. This mapping process helps build indexes of images.

Chapter 6 summarizes conclusions and identifies future directions.

CHAPTER 2
THE CROP-PEST ONTOLOGY

Introduction

An ontology represents domain knowledge using concepts and relationships expressed in a formal, machine-processable language. Building a domain-specific ontology is a process of capturing domain knowledge using this formal language. First defining the purpose and intended uses of an ontology is a crucial step. The crop-pest ontology was built to facilitate image retrieval in an image collection taken by a scientist who is working on crops and pests in the University of Florida. The collection contains 291 images that shows three crops (soybean, peanut, and cotton) and related insects that cause damage on them. The scope of the crop-pest ontology covers at least the domain knowledge contained by the image collection.

This chapter will introduce a methodology for developing the crop-pest ontology and describe it using specific examples in each step. In addition, the created crop-pest ontology will be shown. Then the validation and evaluation of the ontology will be described.

Terminology

Before the procedure of building the ontology can be discussed, components of the crop-pest ontology and some terminology used during the development of the crop-pest ontology must be introduced.

OWL

The OWL is an acronym for **Web Ontology Language**, a semantic markup language for publishing and sharing data using ontologies on the web. OWL has three sublanguages: OWL Lite, OWL DL, and OWL Full. OWL provides machine-processable information on the Web. OWL provides the formality of the crop-pest ontology.

Component of the Crop-Pest Ontology

The crop-pest ontology consists of classes, subclasses, properties, subproperties, domains, ranges and individuals in a hierarchical structure.

- Individual: An individual is defined as things we perceive in the world. For example, when one sees a green plant in a field, the specific green plant observed can be assigned as an individual.

- **Classes and subclasses**: A class defines a set of enumerated individuals that belong together according to their common properties. For example, a class organism can be defined as any individual that has six common properties: movement, feeding, respiration, growth, reproduction and sensitivity to stimuli. Here, these six specific properties are called necessary conditions to be a member of an organism, which keeps this ontology logically consistent. In other words, a virus is not an organism, because a virus cannot reproduce itself without a host. Classes are organized in a hierarchical structure using subclasses. Any class can be a subclass of another class that, whenever satisfying the necessary conditions of another. For example, a class Plant could be defined as a subclass of the class Organism. From this statement, we can deduce that if an individual is a plant, then it is also an organism. The subclasses are satisfying the requirements of their superclass and adding additional restrictions. Superclasses are generalization of the common properties of the subclasses. All classes in the crop-pest ontology are the subclass of Thing, considered the singular root of the crop-pest ontology itself.

- **Properties and subproperties**: Properties are defined as relationships between individuals or between individuals and data values (such as strings and integers). For example, properties of the class Organism can include has parts, locate in, cause damage to, has color, and has age. Properties are divided into two categories: one is a property related to a member of a certain class, and the other is a property related to a data type. For example, the property cause damage to is related to an organism of the class Organism that can be damaged. Likewise, the property has age is related to a integer value such as ten. As with the overall hierarchy of classes, a property can be a subproperty of one or more other properties. For example, the property cause damage to can have a subproperty cause feeding damage to. We can likewise conclude that if a member of a class is related to another by the property

cause feeding damage to, then it is also related to the other by the property causing damage to. The individuals and data types participating in a property can be restricted, using domain and range.

- Domain: A domain of a property is defined as a set of individuals to which the property is applied. For example, let us assume the property cause damage to covers the domain of pest. Thus, if A can cause damage to B, then A must be an pest.

- Range: A range of a property is defined as a set of individuals that the property has as its value. For example, the property cause damage to may be assigned the range of plant. Based on deduction, we can reach the conclusion that if A causes damage to B, then B must be a plant.

Methodology for Building the Crop-Pest Ontology

Noy pointed out some fundamental rules in ontology development. First, the best method involves focusing on the intended application. Second, to build an ontology, it is best to redefine the ontology by using it in applications and by discussing it with experts in the field, after defining an initial version of an ontology. Third, concepts in the ontology are physically or logically close to real objects, such as physical objects or logical objects and their relationships. For example, nouns are likely to be objects and verbs are likely to be relationships in sentences that describe domain knowledge in a domain (Noy and McGuinness, 2001). Kalyanpur suggested an outline of developing an ontology using a casual Web ontology development process (Kalyanpur et al., 2004). He emphasized the following process:

- Ontology developers start with certain domain information they want to model, and based on that information, they derive a loose terminology of concepts and relationships in the domain.

- The concepts are structured into a hierarchy and associated with their properties.

- The ontology is refined by browsing and searching concepts.

Uschold proposed a skeletal methodology for building ontologies in more detail (Uschold and Gruninger, 1996). His methodology was as follows:

- Identification of purpose and scope.
- Ontology capture: finding the key concepts and relationships in the domain; description of precise unambiguous text definitions for such concepts and relationships; and identification of terms to refer to? such concepts and relationships.
- Ontology coding: explicit representation of the the ontology in some formal language.
- Integration of existing ontologies.
- Evaluation of the ontology.
- Documentation of the ontology.

Noy outlined a guide to create an ontology as well (Noy and McGuinness, 2001). Her guidelines were similar to Uschold's, but they focused on more practical aspects, using the example of "wine and food." Her simple guidelines for developing an ontology were the following

- Define classes in the ontology.
- Arrange the classes in a taxonomic hierarchy.
- Define properties and describe allowed values for these slots.
- Fill in the values for properties for individuals.

In general, the crop-pest ontology was built according to Noy's methods. The methodology for developing the crop-pest ontology is as following:

1. Development of the purpose and domain of the crop-pest ontology
2. Consideration of Reuse of Existing Ontologies
3. Enumeration of Important Terms in the Crop-Pest Ontology
4. Building Classes and the Class Hierarchy
5. Definition of the Properties of Classes
6. Creating Individuals

Purpose and Domain of the Crop-Pest Ontology

The starting step of the development of the crop-pest ontology was to define its purpose and domain. The purpose of the crop-pest ontology is to use a tool to browse and search 291 images associated with their captions. To fulfill this purpose, the crop-pest ontology needed to cover all concepts in the image captions. Figure 2-1 shows some of those captions.

Thrips damage to peanut leaves.
Closeup of adult thrips on peanut leaf.
Rednecked peanutworm and damage on peanut.
Rednecked peanutorm in peanut bud.
Hopperburn caused by leafhoppers on peanut leaves.
Closeup of hopperburn caused by leafhoppers on peanut leaf.
Overview of hopperburn on peanut caused by leafhoppers.
Adventitious root growth on peanut caused by three-cornered alfalfa girdling.
Lesser cornstalk borer silken feeding tubes on peanut pegs.
Lesser cornstalk borer adult moths (male left, female right).
Closeup of lesser cornstalk borer larva on peanut leaf.
Whitefringed beetle grub in soil at base of peanut plant.
Spotted cucumber beetle (Southern Corn Rootworm adult) on peanut leaf.
Southern corn rootworm (Spotted cucumber beetle larva) on peanut peg.
Sugarcane beetle on finger.
Cutworm on soil curled in C-shape

Figure 2-1. Image captions in the image collection

As shown in Figure 2-1, the content of the image captions includes insects, plants, relationships between them such as damage, and environmental elements such as soil. The domain that this ontology covers is composed of crops, pests, and the relationships between them, as well as the environmental elements surrounding them. Crops (such as soybeans, peanuts, and cotton) are defined as a collection of plants grown by farmers for food or other uses. These crops also offer food or shelter for various developmental stages of insects. The term “pest” refers to any insect that damages a crop by introducing disease or physical and physiological changes. The crop-pest ontology, therefore, supports both the external structure of the crops and insects as well as the internal

processes or events resulting from associations between them. In addition, it reflects the nature of crop-pest relationships and the environmental elements surrounding crops and pests. In addition, the ontology includes concepts that are not directly related to crop and pests. For example, in Figure 2-1, the caption “Sugarcane beetle on finger” contains the concept “finger.” The purpose of the ontology is to support image retrieval. When a user searches for images, often a scale of size is required for comparison, and this example a human body part such as a finger is used for scale.

Consideration of Reuse of Existing Ontologies

One advantage to using ontologies is the possibility of reusing existing ontologies when it is possible to refine and extend existing ontologies built in the same domain for a particular purpose. In the agricultural field, ontologies suitable for the purpose and the crop-pest domain do not yet exist. There is a National Agricultural Library Thesaurus (NALT) called “NALT” that covers agricultural fields including the crop-pest domain. The NALT can be a reference to build the crop-pest ontology. However, the ambiguity of relationships on NALT did not directly allow reusing it to build the crop-pest ontology.

Some general concepts such as “abstract” and “physical” in the upper level of the crop-pest ontology were imported from the Suggested Upper Merged Ontology (SUMO). SUMO is an upper-level ontology that provides definitions for general-purpose concepts and acts as a foundation for more specific domain ontologies (Niles and Pease, 2001). Figure 2-2 shows some concepts from SUMO that comprise the upper level of the crop-pest ontology. Most domain-specific concepts, such as “stink bug” and “peanut,” were created.

Abstract
- attribute
    - internal attribute
    - relational attribute
- quantity
    - content-based quantity
    - physical quantity

physical
- object
    - agent
    - collection
    - self connected object
- process
    - biological process
    - pathological process

Figure 2-2. Concepts from SUMO that compose the upper level of the crop-pest ontology.

Enumeration of Important Terms in the Crop-Pest Ontology

It is useful to list important terms on the domain, because it helps the ontology developers to group terms manually. Image captions are a good source of terms because those captions are directly related to the crop-pest domain and of course they are designed specifically to describe the content of the image. 291 image captions were tokenized and counted on the frequency of each term. 257 terms were listed according to the frequency with which they appeared in the image captions. Ten of the most frequent terms are shown in Figure 2-3. The others are shown in Appendix B. However, these 257 terms are not all of the terms in the domain. Terms not appearing on this list but needed for this domain were added during the development of the ontology. For example, a term “insect” was not contained in the list. However, the term “insect” was needed to

categorize concepts such as “stink bug”, “beetle”, and “armyworm”, so the term “insect” was included into the crop-pest ontology.

On	217[(a)]
Cotton	124
Soybean	82
Leaf	69
Photograph	68
Larva	59
Damage	57
Peanut	47
Of	43
Boll	31

Figure 2-3. The ten most frequently appearing terms in the 291 image captions. Others are shown in Appendix B. (a) indicates the frequency of the word “on” in the 291 image captions.

Building Classes and the Class Hierarchy

Noy introduced these three approaches in developing a class hierarchy (Noy and McGuinness, 2001):

- A top-down development process, which begins with the definition of the most general concepts in the domain and proceeds to subsequent specification of the concepts.
- A bottom-up development process, which begins with the definition of the most specific concepts and continues with the subsequent grouping of these concepts into more general concepts.
- A combination development process, which starts with a few notable top-level concepts and a few salient specific concepts.

The crop-pest ontology was developed based on the combination approach. First, the developing process started with a few notable top-level classes. The root of the crop-pest ontology became the class “thing,” which is a standard rule of building any ontology, according to the standard Web Ontology Language (OWL, 2005). This class “thing” is the most general concept in the ontology. All other classes are subclasses of the class “thing”. Classes imported from SUMO were used as the top-level classes immediately

below the class “thing” (See the figure 2-2). The reason for importing these SUMO classes as top-level classes is these top-level classes from SUMO provided a foundation for more specialized classes. For example, a specific concept “number” was a subclass of class “thing” according to the OWL standard. Then, SUMO provided two subclasses of class “thing”: One is a class “abstract” and the other is a class “physical”. The two classes are disjointed, which means there is no individual of class “abstract” that become an individual of class “physical”. The class “physical” represents a thing has a location in space and time. Since the concept “number” is not located in space and time, the concept can be assigned as a subclass of the class “abstract”. The process of determining which classes belongs to the class “number” was continued through top-level classes to find correct location of the class.

The middle-level classes in the crop-pest ontology are plants, related insects, and environmental objects such as soil. For example, the class “insect” became a middle-level class in the ontology. All upper subclasses of the class “insect” are shown in Figure 2-4.

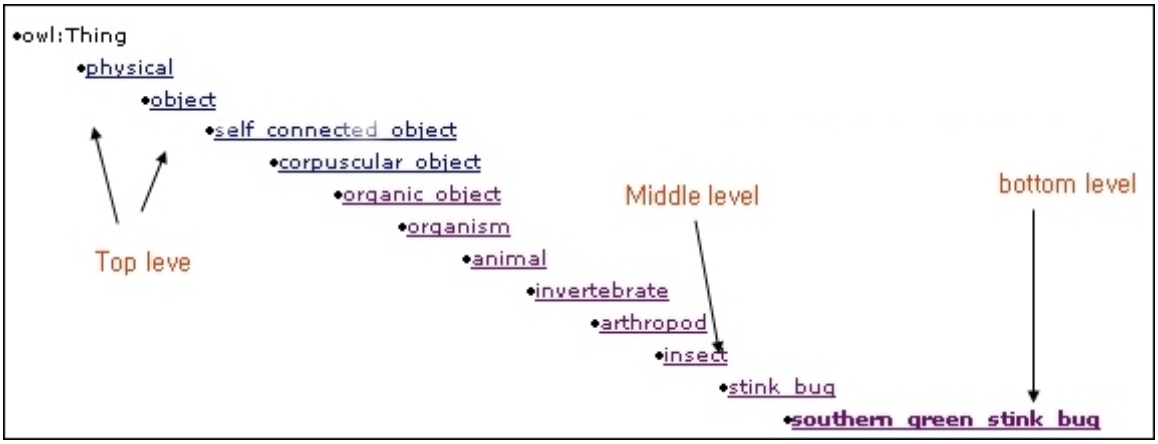


Figure 2-4. Class hierarchy from the root class “thing” down to the class “insect” and its subclass “southern green stink bug,” showing top-level, middle-level and bottom-level classes. Classes in blue were imported from SUMO and classes in purple were created to describe the bottom level classes.

The most specific classes were created using the bottom-up approach to the middle classes. For example, one kind of insect, a concept “the southern green stink bug” (Figure 2-4), appearing on an image caption “southern green stink bug on cotton leaf” was assigned to a subclass of the “insect” class. This bottom-up approach makes assigning subclasses easier because concepts appearing on image captions are clear enough to find which classes belongs to.

Defining Properties

Building a hierarchical structure of classes is not enough to create an ontology because the hierarchical structure itself cannot fully describe any concept. The complete description is accomplished by assigning properties. Properties can be one of two types: object properties or datatype properties, as shown earlier. An object property describes the relationship between two individuals. For example, the property “has_developemtal_stage_of” can show the relationship between an individual of the class “insect” and an individual of one of classes “adult”, “pupa”, “larva”, or “egg”, since an insect has a developmental stage. In this property, the class “insect” becomes a domain and one of classes “adult”, “pupa”, “larva”, or “egg” becomes a range. A datatype property describes the relationship between an individual and a data type, such as string or integer. For example, the datatype property “the_number_of_legs” describes the fact that an insect has six legs by assigning a value of “6” as an integer.

Figure 2-5. The object property “has_developmental_stage_of” and the datatype property “number_of_legs” in the class “insect.”

One of the most difficult decisions to make while developing the crop-pest ontology was determining the lowest level of granularity in the representation in the ontology. Noy gave a guideline for this decision that depends on the potential applications of a particular ontology (Noy and McGuinness, 2001). In other words, the level of granularity is determined by what the most specific concepts are that will be represented in the ontology for a given application. During the development of the crop-pest ontology, the decision of the level of granularity was based on the application—to browse 291 images. Therefore, the crop-pest ontology needed to contain at least all the concepts shown in the image captions. The most specific classes in the ontology represent concepts appearing in the image captions.

Creating Individuals

The last step of building the crop-pest ontology was creating individuals of classes in the hierarchy. Defining an individual of a class involves the following steps:

- Choosing a class
- Creating an individual of the class
- Filling out properties of the individual

For example, the individual “soybean_20” was created to represent a specific soybean.

The class had the following properties defined:

- “locate_place” (Boolean)
- “locate_in_time” (Boolean)
- “is_host_of”
- “has_parts”
- “is_damaged_by”

All properties are filled with each value, as shown in Figure 2-6. The datatype property “locate_place” is filled with a true boolean value, and the object property “is_damaged_by” is filled with the individual “yellow_stripe_armyworm_16.”

Figure 2-6. An individual of class “soybean.” All properties are filled with each value.

Based on the above methodology, 615 classes and individuals were created in the crop-pest domain.

The Crop-Pest Ontology

The crop-pest ontology contains 286 classes, 81 object properties, 36 datatype properties, and 305 individuals. The crop-pest ontology is written in OWL, shown in Appendix D.

Validation of the Crop-Pest Ontology

Validating the crop-pest ontology meant detecting unsatisfiable concepts in conjunction with an OWL reasoner and reporting errors. Unsatisfiable concepts are concepts that cannot be true of any possible individual. Those concepts are usually the result of a basic logic error during ontology development, as they cannot be used to describe any individual. Unsatisfiable concepts are also easy for a reasoner to detect and display (Parsia et al., 2005). Pellet is an open-source Java-based OWL DL reasoner (Pellet OWL reasoner, 2005). Pellet allows utilities to see versions of OWL such as OWL full or DL to check ontology consistency, to classify the taxonomy, and so on. This Pellet OWL reasoner was used to check the consistency of the crop-pest ontology. Figure 2-7 shows the result of the consistency check of the crop-pest ontology.

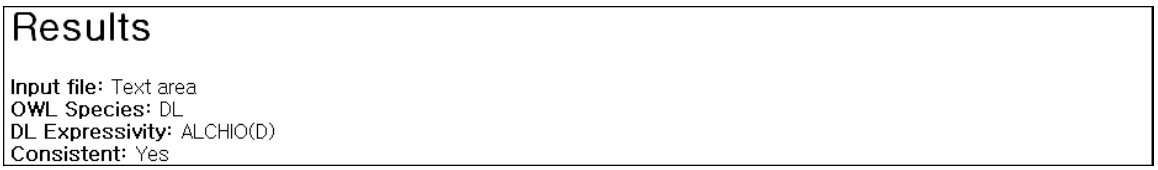


Figure 2-7. Results of the consistency check of the crop-pest ontology using the Pellet OWL reasoner.

Evaluation of the Crop-Pest Ontology

Complete ontologies not only can support their intended applications and function properly but also can be re-used for the development of other ontologies. Therefore, the

evaluation of ontologies is essential. There are two approaches to ontology evaluation: qualitative and quantitative (Brewster et al., 2004).

The qualitative approach would be taken by an ontology developer with knowledge in a particular domain. He/she would be asked to evaluate an ontology using the perspective of the principles. For example, Gomez claimed that the lack of methods for evaluating ontologies could be an obstacle to their use in several application domains (Gomez, 1999). He suggested some ideas to evaluate ontologies technically, especially in the definitions of classes in the ontology. The evaluation of the definitions of classes in the ontology is a technical evaluation that must be performed during the whole ontology development step. The purpose of this evaluation is to discover deficiencies of defined classes, individuals and properties. First, the structure of the ontology should be checked, using the criteria that the definitions should have clear, necessary, and sufficient conditions and should be written in formal language. In addition, the definitions should be logically consistent (Gruber, 1993). Second, the syntax of the definitions should be checked for syntactically incorrect structure, such as loops between definitions. Third, the content of the definitions should be checked to detect what the ontology defines, does not define, or defines incorrectly; what can be, cannot be, or may be inferred; or what may be inferred incorrectly. Finally, he showed three case studies for the evaluation of an ontology: the evaluation of definitions, hierarchy, and properties. Kohler reported an evaluation of existing ontologies in the molecular biological data source (Kohler and Schulze-Kremer, 2002). He checked the stability of the concepts, the validity of the hierarchy, and the wide usage technically.

The quantitative approach is a data-driven approach to ontology evaluation that tests whether the ontology contains domain-specific corpus, which is a collection of domain-related terms. Brewster chose the art and artists domain for which he had developed the ARTEQUAKT ontology and then collected 41 arbitrary texts from the Internet on a numbers of artists. He compared the ARTEQUAKT ontology with the SUMO ontology and the Ontology of Science (Ontology of Science, 2005), even though the SUMO ontology and the Ontology of Science did not cover the same domain as ARTEQUAKT. At the time, he was unable to find any ontology covering the same domain because ontology development research was then in its early stages. He tested them how many corpus to determine how appropriate it is for the representation of the knowledge of the domain represented by the corpus.

The crop-pest ontology evaluation was done using the quantitative approach, testing the coverage of the ontology with a domain-specific corpus. The first step was to find an ontology that covered the same domain. The AGROVOC ontology has a high coverage of the agricultural domain (AGROVOC ontology, 2005), including the crop-pest domain. The crop-pest ontology was compared with the AGROVOC ontology. The second step of this evaluation was the collection of arbitrary domain-specific corpus. As mentioned before, most concepts in the crop-pest ontology were from DDIS image captions that described crops and related pests. Therefore, similar image captions in the same domain would have been good candidates for the domain-specific corpus. Two restrictions were applied to find image captions to test: the captions could not have been used for the development of the crop-pest ontology, and the test captions were all related to cotton and its pests. Texas Agricultural Extension Service provided 95 image captions

that contained a domain-specific corpus (Texas Agricultural Extension Service, 2005). Fifty of those 95 captions were selected randomly, and 138 terms appearing in those 50 captions were used to test the crop-pest ontology, as shown in Appendix C. The coverage of the 138 terms is shown in Table 2-1. The coverage of the crop-pest ontology was higher than AGROVOC's coverage. This result showed that the crop-pest ontology was the closer fit with the selected domain-specific corpus. This indicates how appropriate the crop-pest ontology is for the representation of the knowledge of the domain represented by selected texts.

Table 2-1. The coverage of 138 tested terms in the crop-pest and AGROVOC ontologies.

	The crop-pest ontology	AGROVOC
Coverage (percentage)	44.93%	30.43%

Conclusion and Discussion

The methodology to develop the crop-pest ontology is based on three fundamental rules: 1) the best method involves focusing on the intended application 2) it is necessary step to redefine the ontology by using it in applications and/or by discussing it with experts in the field, after defining an initial version of an ontology and 3) concepts in the ontology are physically or logically close to real objects, such as physical objects or logical objects and their relationships. The procedure for developing the crop-pest ontology was as follows:

- Determination of the purpose and domain of the crop-pest ontology
- Consideration of the reuse of existing ontologies
- Enumeration of important terms in the crop-pest ontology
- Determination of the classes and the class hierarchy
- Definition of properties
- Creation of individuals

According to the procedure, the crop-pest ontology was developed. It contains 286 classes, 81 object properties, 36 datatype properties, 305 individuals. The crop-pest ontology is written in OWL.

The validation of the crop-pest ontology was essential to find unsatisfiable concepts in the ontology. The Pellet OWL reasoner was used to validate the crop-pest ontology. The consistency of the crop-pest ontology was revealed as true. Evaluation as well as validation of the crop-pest ontology was important because in addition to supporting their original applications by functioning properly, complete ontologies also can be re-used for the development of other ontologies. The data-driven approach for evaluation of the crop-pest ontology showed that the crop-pest ontology covers a domain-specific corpus well when compared with AGROVOC, a well-known ontology that covers all agricultural domains. However, the data-driven approach has some limitations compared with the qualitative approach, which checks the definition of classes, properties, and individuals by ontology developers. The data-driven approach cannot check the logical correctness of the definition of classes, properties, and individuals. An OWL reasoner could provide logical correctness, only if the reasoner supports to reason all classes, properties, and individuals. For now, the Pellet OWL reasoner could support consistency checks and some query processes. An evaluation could be designed according to the purpose of the crop-pest ontology. The purpose of the crop-pest ontology is browsing 291 images in a collection. If users agree that browsing images associated with the crop-pest ontology is more convenient than conventional ways of browsing images, which could be another evaluation of the crop-pest ontology as well.

CHAPTER 3
A PRACTICAL COMPARISON BETWEEN THESAURUS AND ONTOLOGY TECHNIQUES AS A BASIS FOR SEARCH IMPROVEMENT

Introduction

Jacob introduced the claim that a controlled vocabulary[3] is itself an ontology, so long as the standard concept of a controlled vocabulary are similarly redefined (Jacob 2003). Chun pointed out that both thesauri and ontologies have common traits: describing domain-specific knowledge; containing terms (or concepts) and relations among those terms; making use of hierarchical structures; being used in information management applications to catalog and retrieve information; and needing to be maintained and revised constantly. Yet he also stressed that they are not the same, for a thesaurus has a limited number of relations, which can result in relatively meager expressiveness of representing specific knowledge (Chun 2004). Another difference is the two systems having different points of emphasis. Whereas ontology builders are primarily concerned with how software and associated machines interact with ontologies in a logical way, thesaurus developers (such as librarians) instead focus on how users retrieve information solely with the aid of a thesaurus (Jibbajabba 2002). The limited number of relations and the different points of emphasis do not cover all differences between thesauri and ontologies, most notably omitting differences based on the characteristics of languages describing domain knowledge. In this paper, we explore additional differences between thesauri and ontologies, not only describing the differences themselves but also providing

[3] A *controlled vocabulary* is the same as a thesaurus.

specific examples that explicitly reveal just how thesauri are not ontologies. We have selected the National Agricultural Library Thesaurus (NALT) as our specific thesaurus of study, because it covers agricultural domains and has performed well in the past as a controlled vocabulary in several well-known agricultural information systems. Likewise, we have developed an ontology which covers crops and related insects, hereafter referred to as the "crop-pest ontology," as a practical domain-specific ontology. We then performed a practical comparison between NALT and the crop-pest ontology.

NALT will be described further. The crop-pest ontology was introduced in the chapter 2. The mechanics of the practical comparison and offer results of the comparison process will be introduced. The conclusion of the comparison will be shown. The respective abilities of NALT and the crop-pest ontology associated with respects to agricultural information systems will be discussed.

The National Agricultural Library Thesaurus

The National Agricultural Library Thesaurus (NALT) is intended for indexing materials and for aiding retrieval in agricultural information systems. The thesaurus was prepared by staff of the National Agricultural Library (NAL) to meet the needs of the United States Department of Agriculture (USDA) and the Agricultural Research Service (ARS) for an agricultural thesaurus (NALT 2005). NALT is the controlled vocabulary of NAL's bibliographic database of citations to agricultural resources, known as AGRICOLA. The Food Safety Research Information Office (FSRIO) and the Agricultural Network Information Center (AgNIC) use NALT as the controlled vocabulary of their information system. NALT is also used for browsing within the ARS and AgNIC web sites (NALT 2005).

NALT is structured into 17 subject categories. These categories are derived from the NAL Agricultural Classification Prototype, originally developed for the Agricultural Information Network.[4] The subject scope of agriculture is broadly defined in NALT and includes terminology related to the supporting biological, physical and social sciences.

Relationships between Terms

NALT includes hierarchical, equivalence and associative relationships among concepts. Hierarchical relationships are indicated by Broader Term and Narrower Term designations in the thesaurus. This hierarchical structure of relationships is a distinguishing feature of the thesaurus, in contrast to a simple list of alphabetically ordered terms. Broader terms represent more general concepts than narrower terms:

- Crop yield
- Broader Terms: crop production, yields
- Narrower Terms: grain yield, yield components

"Grain yield" is subordinate to "crop yield" since it is a more specific type of crop yield. Similarly, "crop yield" belongs to a larger concept class of "yields." This relationship suggests that if a searcher is interested in "crop yield" then they would also be interested in specific *types* of crop yields such as "grain yield" and "yield components." Equivalence relationships are designated by *Use* and *Used for* cross-references. Equivalence is made when two or more terms represent the same (or nearly the same) concept, e.g. synonymous terms, common names of organisms and their scientific names, spelling variants, usage variants, and acronyms:

- Mechanical damage
- Use for: mechanical injuries

[4] http://www.agnic.org

As shown here, "mechanical injuries" is a synonymous term for "mechanical damage." The reciprocal relationships appear as follows:

- Beetles
- Use: coleoptera

Here, "coleoptera" is the scientific name or preferred term, while "beetles" serves as a common name to help direct users to a more appropriate term for indexing and retrieval purposes. In general, NALT directs users from non-preferred terms to the more appropriate descriptors for indexing and retrieval using its "Use" and "Used for" designations. Associative relationships are designated by *Related Terms* reciprocal relationships. An associative relationship is made between terms that are conceptually related but are neither hierarchical nor equivalence relationships in nature. Associative relationships serve to alert indexers and searchers that there are other related concepts in the thesaurus that may be of interest to them:

- Insects
- Related Terms: insecticides

Here, "insecticides" is a related concept to "insects," because insecticides are chemical substances used to kill insects.

Comparative Analysis

In this section, we make a comparative analysis between NALT and the crop-pest ontology to further analyze their differences. The main points of comparison are the representation of domain knowledge and faculty of reasoning based on the data representation itself. The representation of domain knowledge is a crucial feature for both systems, because each should extract domain knowledge and describe it using components such as concepts, terms, relations, or properties. We compare NALT and the

crop-pest ontology by showing ways to represent knowledge and then testing their abilities to describe knowledge of domain concepts. Then, we examine reasoning facilities within each of these technologies. Reasoning is the use of logical expressions by agents such as humans or machines to find results or draw conclusions (Encarta 2005). Whenever agents can reach and process well-structured knowledge, the agents alone can make logical inferences and deduce conclusions based on the existing well-structured knowledge. We illustrate specific applications of reasoning such as ontology validation and search.

NALT covers all of agriculture including crops and related insects. But because the ontology only covers crops and associated pests, comparative analysis was performed using only crops and associated pests, called the "crop-pest domain." 631 concepts were generated from the crop-pest ontology database for the comparative analysis. Some of 41,000 preferred terms (terms for indexing and searching) and related terms (terms which have relationships with those preferred terms) covering the crop-pest domain from NALT were examined during this comparison.

Representing Domain Knowledge

Concepts, Semantic Relationships, and Their Logical Consistency

We explored how to best represent domain knowledge using concepts and semantic relationships in both NALT and the crop-pest ontology. We selected a particular concept *Plant*, which is the basic concept in our selected domain of focus (the crop-pest domain), and proceeded to examine the concept *Plant* and its relationships to other concepts on the basis of logical consistency.

In NALT, the term *plants* is represented based on the relationships including *broader term* (BT), *narrower term* (NT), and *related term* (RT) as shown in Figure 3- 1.

```
plants
  BT:  organisms
  NT:  algae and seaweeds
       alpine plants
       .....
       rootstocks
       scions
       .....
       wild flowers
       wild plants
       woody plants
       xerophytes
  RT:  autotrophs
       flora
```

Figure 3-1. Description of a term *plants* in NALT ("…" denotes additional terms not shown)

The crop-pest ontology, however, has a wider variety of types of relationships between concepts. *Superclass* and *Subclass* terms, for instance, indicate a hierarchical structure of a particular concept. In addition, *properties* represent various relationships between concepts or between concepts and data values (such as strings and integers). Representation of a particular concept *Plant* is shown in Figure 2, using the semantic structure of the crop-pest ontology.

There are several highly visible differences in the representations of the same concept Plant between NALT and the crop-pest ontology. First, formality of language in the ontology provides machine-readable information. But, informality of NALT results in a machine not being able to readily process information within the thesuarus itself. Second, subclasses in the ontology should be logically defined using inherited "necessary and sufficient (if possible) conditions" from its superclass, as compared to the assertion of BT/NT relationships in NALT. In Figure 3-2, plant is a specific case of organism, meaning plant should be logically satisfied using its inherited conditions, such as the characteristics of organism as a living thing (replication, metabolism, etc.).

```
<rdf:Description rdf:about="#(a)plant">
  <rdfs:(b)subClassOf rdf:resource="#organism"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a photosynthetic organism that
  has cellulose cell walls, cannot move of its own accord, grows on the earth or in water,
  and usually has green leaves. Kingdom Plantae</rdfs:comment>
  <owl: (c)disjointWith rdf:resource="#protozoan"/>
  <owl:disjointWith rdf:resource="#bacterium"/>
  <owl:disjointWith rdf:resource="#fungus"/>
  <owl:disjointWith rdf:resource="#animal"/>
</rdf:Description>
<rdf:Description rdf:about="#is_host_of">
  <rdfs: (d)domain rdf:resource="#plant"/>
  <rdfs: (e)range rdf:resource="#insect"/>
  <owl: (f)inverseOf rdf:resource="#is_pest_of_"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
</rdf:Description>
<rdf:Description rdf:about="#has_parts">
  <rdfs: domain rdf:resource="#plant"/>
  <rdfs: range rdf:nodeID="A3"/>
  <owl: inverseOf rdf:resource="#is_part_of"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
</rdf:Description>
<rdf:Description rdf:about="#is_part_of">
  <rdfs:domain rdf:nodeID="A2"/>
  <rdfs:range rdf:resource="#plant"/>
  <owl: (g)nverseOf rdf:resource="#has_parts"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
</rdf:Description>
<rdf:Description rdf:about="#grows_on">
  <owl:inverseOf rdf:resource="#give_nutirents_to"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  <rdfs:range rdf:resource="#soil"/>
  <rdfs:domain rdf:resource="#plant"/>
</rdf:Description>
<rdf:Description rdf:about="#has_color">
  <rdfs:domain rdf:nodeID="A4"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  <rdfs:range rdf:resource="#color"/>
</rdf:Description>
<rdf:Description rdf:about="#is_element_of">
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  <rdfs:range rdf:resource="#collection"/>
  <owl:inverseOf rdf:resource="#has_element_of"/>
  <rdfs:domain rdf:nodeID="A3"/>
 <rdf:Description rdf:nodeID="A12">
  <rdf:rest rdf:nodeID="A8"/>
  <rdf:first rdf:resource="#leaf"/>
</rdf:Description>
```

Figure 3-2. Description of a concept *Plant* from the crop-pest ontology, written in Web Ontology Language (OWL) [5]: The concept *Plant* is defined as a class in the OWL. The class *Plant* is a subclass of a class *Organism*. The class *Plant* is disjointed with classes *Animal*, *Fungus*, *Protozoan*, and *Bacterium*. The class *Plant* can have several properties, e.g. property *is_host_of* indicates that a plant is a host of something else. The domain of the property *is_host_of* is the

[5] The precise description of the OWL language is shown at http://www.w3.org/TR/owl-ref/.

class *Plant*. Similarly, the range of the property *is_host_of* is a class *Insect*. The properties *is_host_of* and *is_pest_of* are inverses of each other.

In Figure 3-1, scions are defined as a NT of plant. However, a scion is not a plant but rather a part of a plant used for grafting purposes. It is not logically consistent that a scion is a specific plant. Third, the semantic structure of related terms (RT) in NALT and the corresponding properties in the crop-pest ontology also differ. RT neither explains nor represents what kinds of relationships exist between terms. For example, plant has a RT of flora, but NALT does not explicitly explain the nature of the relationship itself, which could perhaps be “plant is an element of flora.” As shown in Figure 3-2, a property called is_element_of in the crop-pest ontology has limitations of its values: domain, range can further reveal the logical consistency of stored knowledge concepts. These limitations give the crop-pest ontology the additional ability of logic-based consistency validation.

The Ability to Represent Complicated Concepts

In trying to represent knowledge in the crop-pest domain, thesaurus or ontology developers would be confronted with a description difficulty. For example, a concept “large corn earworm larva on peanut leaf” is a relatively complicated concept to represent. Here we explore the ability to represent complicated concepts in NALT and the crop-pest ontology through a process of creating the concept "large corn earworm larva on peanut leaf." To begin with, we state explicit meanings of the given concept:

- The size of corn earworm is large.
- The developmental stage of corn earworm is a larval stage.
- This corn earworm is located in a peanut leaf.

Then, we examine how to describe these meanings in both NALT and the crop-pest ontology. In NALT, terms related to the crop-pest domain are selected from the given

concept, such as corn earworm, larva, peanut, and leaf. For example, peanut and larva would be terms as shown in Figure 3-3.

Corn earworm
Use:
Helicoverpa zea
Related Terms:
Larva
peanut
leaf

peanut

Used for:
*ground nuts (British) **
*groundnuts (British) **

Broader Terms:
legumes
nuts
oilseeds
peanut products

Related Terms:
Arachis hypogaea

larva

Used for:
*caterpillars **
*grubs **
*insect larvae **
*maggots **

Broader Terms:
developmental stages

Narrower Terms:
chiggers
fish larvae
microfilariae
nematode larvae
schistosomula
sporocysts (Trematoda)

Related Terms:
larval development
larvicides

Figure 3-3. Three terms, *corn earworm*, *peanut* and *larva*, in the NALT thesaurus

During the process of selection of terms from the given concepts, explicit meanings within the concept would be absent. For example, we cannot yet determine how big larva is or where the larva is located.

Understanding the words in the example phrase is strongly related to syntactic and semantic understanding of them, which means identifying which parts are main words in a given phrase and which parts are its modifying words. In this example, we found main words (i.e. head) in the given concept, "large corn earworm larva on peanut leaf," as being "corn earworm." The head of ”corn earworm” was therefore represented as a class in the crop-pest ontology. The other words, called modifiers, modified the head of "corn earworm." These modifiers of the corn earworm were created as properties and their domain and range, as shown in Figure 3-4.

Properties	Domain	Range
Size of	Insect	concepts that indicate sizes such as large, medium, and small
Development stage of	Insect	concepts that indicate developmental stages of insects such as egg, larva, pupa, and adult
Locate in	Insect	Plant or Part of Plant

Figure 3-4. Properties assigned a class *corn earworm* for describing the concept “large corn earworm larva on peanut leaf”

Then, an individual of the class “corn earworm” called “corn earworm egg1” was created, with these properties filled out as in Figure 3-5. Finally, we formally generated the given concept "large corn earworm larva on peanut leaf" using the individual of a class “corn earworm” in the crop-pest ontology without any loss of the explicit meanings.

```
Individual(a:corn_earworm_egg1
  type(a:corn_earworm_egg)
  value(a:is_pest_of_ a:peanut1)
  value(a:locate_In a:peanut1)
  value(a:has_size a:large1)
  value(a:has_developmental_stage a:egg1))
 Individual(a:egg1
  type(a:egg))
 Individual(a:large1
  type(a:large))
 Individual(a:peanut1
  type(a:peanut)
  value(a:is_host_of a:corn_earworm_egg1))
```

Figure 3-5. The OWL abstract form for the individual of a class "corn earworm" to represent a complicated concept "large corn earworm larva on peanut leaf" [6]

Reasoning Based on Representation

Reasoning Facilities

In the NALT thesaurus, the relationship between BT and NT could be a simple inference based on generalization and specification. In Figure 3-1, *plants* is treated as a specific organism with regard to BT. *Algae and seaweeds* is likewise treated as a specific plant based on NT, if NALT thesaurus can be converted into a formal language and BT/NT/RT is consistent.. In the crop-pest ontology, however, the ability to process reasoning is well beyond generalization and specification. A concept *beetle* in the crop-pest ontology inherits all properties and associations from its superclass *insect*, based on generalization/specification rules. Here, we explain an inference with the following example from the crop-pest ontology. We first assert three true propositions in the crop-pest domain:

- Corn earworm is an insect that can damage peanut plants.
- An insect is an agent.
- Peanut pest is an agent that can damage peanut plants.

Based on these three propositions, we can infer that corn earworm is also one of the peanut pests, using existential quantification. Following are the steps to perform the same inference in the crop-pest ontology.

We define a class *corn earworm* asserting the first proposition (See Figure 3-6, Part A). A class *agent* is a union of organisms such as insect, bacterium or fungus and non-organisms such as virus or prion that causes events (See Figure 3-6, Part B). Through the hierarchy of classes, we show corn earworm is an insect, invertebrate, animal, organism

[6] "a" denotes a particular namespace, at http://www.owl-ontologies.com/unnamed.owl

and agent, by a process of reasoning. A class *peanut pest* is defined as an intersection of an agent and its property *damage_to_peanut* (See Figure 3-6, Part C). Therefore, we deduce that a class *corn earworm* is a subclass of *peanut pest* automatically, as shown as Figure 3-6, Part D.

```
A)Class(a:corn_earworm partial a:insect)

ObjectProperty(a:damage_to_peanut
  domain(a:corn_earworm)
  range(a:peanut))

B) Class(a:agent complete
  unionOf(a:non_organism a:organism))

  ObjectProperty(a:make_event_of
    domain(a:agent)
    range(a:event))

Class(a:animal partial   a:organism)
Class(a:invertebrate partial   a:animal)
Class(a:insect partial   a:invertebrate)

C) Class(a:peanut_pest complete
  intersectionOf(restriction(a:damage_to_peanut someValuesFrom(a:peanut)) a:agent))
```

D)

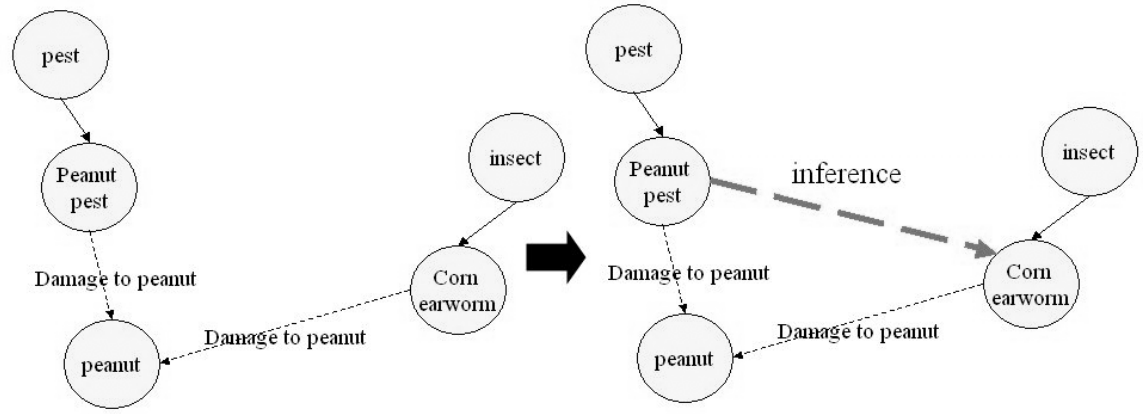


Figure 3-6. The OWL abstract form for an inference “corn earworm is a peanut pest”. A, B, and C show how the ontology describes propositions in the domain. D is a diagram of the result of the inference. A circle indicates a class; a line indicates relationships between classes and subclasses; a dotted line denotes a

property of two classes; and a red line indicates the peanut pest has a new corn earworm, as the result of the inference.

In addition to the above examples, many other logical inferences can be made from entries in the crop-pest ontology.

Searching Documents

The NALT thesaurus brings more relevant documents into a search, providing an overall query expansion. A keyword from end-users first is matched into NALT to find the relevant terms such as those from *Used for*. Once a certain relevant term is selected, it is added to the keyword search of documents in a publication. This query expansion can result in more relevant documents being returned to end-users and leads to improved search ability, but the expansion can also bring in more irrelevant documents. In addition, browsing the controlled vocabulary in NALT provides clues for finding relevant documents to users lacking an exact keyword.

In the crop-pest ontology, the searching process is a reasoning process. Whenever end-users search information using keywords within the crop-pest ontology, the ontology in turn executes a reasoning process to find answers. It can produce better results because the ontology brings relevant information using knowledge not only asserted manually by experts (like NALT does) but also inferred automatically. For example, we detailed a search to find “peanut pest” concurrently in NALT and the crop-pest ontology. As Figure 3-7 explains, we found a preferred term of “plant pest” in NALT that is the closest known term to “peanut pest.” Once experts asserted peanut pests in NALT, the thesaurus then provides relevant terms for the search and brings further relevant information.

We showed how the ontology deduces that corn earworm is a peanut pest. Based on a similar method of deduction, we can get information on all peanut pests, using

deductions for finding all peanut pests as well as any manual assertion such as “A is a peanut pest.”

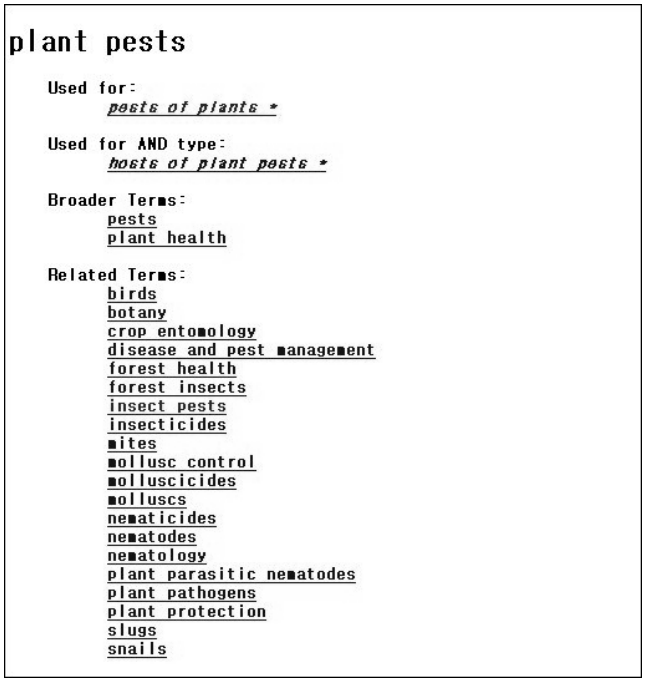


Figure 3-7. Screen shot of the preferred term “plant pests” in NALT

Automatic Validation of Logical Consistency

The validation of NALT and the crop-pest ontology is one of the most important issues in providing better applications of searching information and cataloguing documents. If the thesaurus or the ontology is not established to be logically correct, we can not expect a good result from any application that includes the thesaurus or the ontology.

In NALT, the validation of all terms and relationships is executed by field experts' points of view. For example, throughout the development of the first edition of the NALT thesaurus, Agricultural Research Service (ARS 2005) scientists and specialists in the field of agriculture manually conducted its validation.

In the crop-pest ontology, all classes, properties, domains, ranges and individuals were authenticated by experts. In addition, the deductive ability within the crop-pest ontology can itself assist in the validation process. This deduction is a product of inference executed by a machine. So, once the crop-pest ontology is developed, we can automatically validate the ontology by checking logically correct deductions according to components of the ontology such as classes and properties. Automatic validation of classes and properties was executed by Pellet, which is a reasoner built in Java that was designed specifically for OWL reasoning (Pellet 2005). It checked the crop-pest ontology consistency and reported any unsatisfied classes within it, as demonstrated in Figure 3-8.

A.

B.

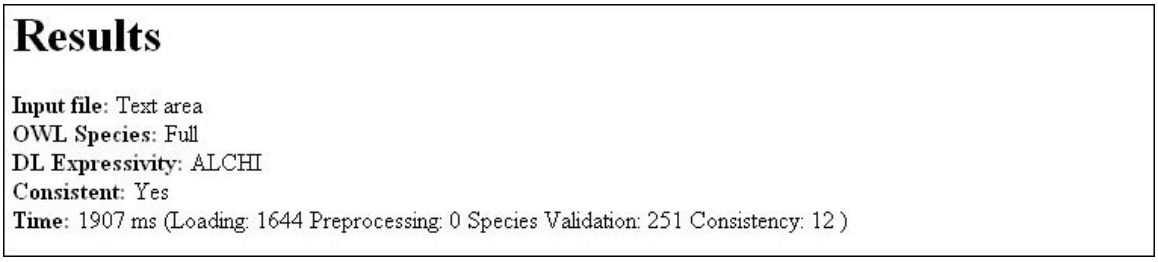


Figure 3-8. Screen shots of OWL consistency checker and the results in Pellet. A shows the front page of the OWL consistency checker. B shows consistency of the crop-pest ontology.

Conclusion

The difference between a thesaurus and an ontology were explored, through a practical comparison between NALT and the crop-pest ontology. The fundamental differences of representing domain knowledge between them were the formality of language in the crop-pest ontology; the logical consistency of concepts and relationships in the crop-pest ontology; and the explicit description of in NALT. Formality in the ontology allowed a machine to more readily process information within the ontology itself.

Some previous research of converting thesauri into formal languages such as Resource Description Framework (RDF) have been studied, though they reported several conversion problems based on relations in the thesauri (Matthews 2002). Logical consistency of concepts and properties brought with it higher faculties of automated reasoning. Ambiguity of relations in the thesaurus was analyzed, in particular those relationships such as broader term (BT) and narrower term (NT), which can inadvertently be used in an ambiguous fashion (e.g. a particular concept is a special case of another concept, or that a particular concept is part of yet another concept).

The differences between the representations of data in both technologies could bring about a different level of power of reasoning within their applications. In the NALT thesaurus, the relationships such as BT or NT become a simple inference based on generalization and specification, assuming the underlying relationships is valid. In the crop-pest ontology, however, the ability to process reasoning is well beyond generalization and specification. It supports the deduction of a conclusion based on true propositions, the search of information as a result of inference, and the automatic validation of logical consistency in the ontology. We conclude that of the two studied

systems, an ontology provides the better representation of domain knowledge and a greater power of reasoning based on the underlying representation, which could improve searching documents in agricultural publications.

CHAPTER 4
BUILDING A DATABASE AND GRAPHICAL USER INTERFACE FOR BROWSING IMAGES BASED ON THE CROP-PEST ONTOLOGY

Introduction

The most common interface for image retrieval is one that allows users to type keywords and see search results in a table ordered by relevance. This type of interface, such as Google Image Search (Google Image Search, 2005), performs well with a large pool of Web images, but it does not allow users to browse images (Yee, 2003). Markkula reported that professionals in artistic fields such as journalism, design, and art direction use browsing as a basic strategy in searching for images. The first reason is that browsing aids in the development of illustration ideas. The second reason is that some words describing selected images may be difficult to express freely as search keywords but are easily applied when the images are seen. The third reason is that image selection depends on a particular work situation, which is difficult to anticipate in indexing. The fourth reason is that artistic professionals feel comfortable with browsing. Similarly, growers and other professionals in the agricultural field would want to be able to browse images as well as search for them with keywords.

Indexing images is vitally important to image browsing. One commonly used approach is using a thesaurus to index images (Hyvonen, 2004). An image can be categorized by a thesaurus that classifies different aspects of images into hierarchical categories. However, a thesaurus turns out to provide only part of the knowledge needed,

when a knowledge-rich description of images is required for indexing them. Wielinga stressed that the structured knowledge-based description of images is much richer than the traditional “set of terms” like a thesaurus (Wielinga, 2001). As shown in the chapter 3, an ontology could improve the deficiencies of a thesaurus in describing domain knowledge by using a formal representation of concepts.

Hyvonen implemented an ontology-based image retrieval system for a photo exhibition using the promotion image database of the Helsinki University Museum (Hyvonen, 2003). In the system, images were annotated according to a promotion ontology. The ontology helped users formulate their queries. Schreiber reported a system of ontology-based photo indexing and searching in an image collection about apes, including chimpanzees, gorillas, and orangutans (Schreiber, 2001). He developed a domain ontology for annotating ape photographs.

As shown in Chapter 2, the crop-pest ontology has been developed for browsing 291 images in a collection. The ontology can be used as a tool for cataloging those images. This chapter describes how images were indexed using the crop-pest ontology. The implement of a graphical interface for browsing the images will be introduced. A usability study will also be presented .

Ontology-Based Image Indexing

Several studies have been done on using ontologies as tools for indexing information. Desmontils explored indexing Web pages using a terminology-oriented ontology. He presented a semi-automatic process for indexing a Web site associated with the ontology (Desmontils, 2002). He insisted that an ontology-based indexing approach could provide more precise retrieval within a given Web sites. Tsinaraki indexed audiovisual information such as images and videos associated with an ontology.

Tsinaraki suggested that indexing multimedia information using the same ontologies across different multimedia standards had the advantage of interoperability across applications (Tsinaraki, 2005). In addition, Tsinaraki pointed out the most interesting aspect of ontology-based indexing, which is that the approach provides not only simple retrieval of audiovisual content with a simple keyword query but also enhanced content-based retrieval with semantic queries such as “give me video clips where the players Ronald or Beckham appear” for audiovisual content through the use of domain-specific ontologies for the knowledge domain. Since user requests within the agricultural fields involve complex concepts as well as simple concepts based on domain knowledge, this ontology-based image indexing is a promising approach to fulfill user needs.

Creating Concepts for Indexing Images in the Crop-Pest Ontology

New classes, properties and instances were added into the crop-pest ontology to index 291 images associated with the ontology. First, the class “digital photograph” was created in the crop-pest ontology because each real image became an instance of the class “digital photograph.” The class get common properties from upper classes: “thing,” “physical,” “object,” “self-connected object,” “substance,” and “photograph: Figure 4-1 shows the hierarchy from the root class “thing” down to “digital photograph.” The class “digital photograph” has several subclasses, such as “pest photograph,” shown in Figure 4-1.

Second, several properties of this “photograph” class were assigned. After manual analysis of 291 image captions, four common relationships were detected. These relationships were assigned into four properties of the “digital photograph” class:

- damage: any process caused by an agent
- agent (pest): insects that cause damage

- host: plants that are attacked by insects
- location: the place where plants or insects are located

Third, each image was defined as an individual of the class "digital photograph." Based on the content of each image, values of each property for each individual were specified during the process of indexing images, as explained in the next section.

The Indexing Process

This process builds a structured index of images according to the crop-pest ontology. The indexing process can be divided into five steps, shown in Figure 4-2.

Step 1: Syntactic and Semantic Analysis of Each Image Caption

All 291 images have image captions that describe the content of images according to domain experts. The image captions, shown in A, were analyzed both syntactically and semantically. Syntactic analysis is based on the grammatical structure of the captions, and semantic analysis is based on the meaning of each word appearing in a caption and the relationships among word meaning established by the syntax. These analyses extract domain knowledge implied by words or phrases in the image captions as well as the content of the images. For example, the image caption shown in Figure 4-2, "damage caused by three cornered alfalfa hopper on soybean," was analyzed syntactically and semantically.

As shown in Figure 4-3, the word "damage" is a head, or the main word in the phrase. Two modifiers that qualify the meaning of the head follow it: One is the past-participial phrase "caused by three cornered alfalfa hopper," used like an adjective phrase, and the other is the prepositional phrase "on soybean." The semantic analysis was based on the syntactic analysis. The first modifier indicates an agent that causes damage, the specific pest "three cornered alfalfa hopper." The second modifier describes not only the location

of the damage, which is “soybean,” but also implies the host of the pest “three cornered alfalfa hopper” because this content of image is restricted to the crop-pest domain. These syntactic and semantic analyses of the given image caption provided information necessary to index the image into the crop-pest ontology.

Step 2: Creating an Individual of the Image in the Crop-Pest Ontology

Each image becomes an individual of class “digital photograph” in the crop-pest ontology because each image was a real and specific example of the class “digital photograph.” For example, the image with the caption “damage caused by three cornered alfalfa hopper on soybean” was created as an individual of the class “digital photograph.” The individual called “Image – SOY006” represents the image with the caption “damage caused by three cornered alfalfa hopper on soybean.”

Step 3: Filling in the Values of Properties for Each Individual

Each individual created in Step 2 has four properties that must satisfy the properties of the class “digital photograph.” The values of those four properties were filled out with information provided by the syntactic and semantic analyses. For example, the individual in Step 2, “Image – SOY006,” had the following four properties, to which values were assigned in the following way:

- damage: damage
- agent (pest): three cornered alfalfa hopper
- host: soybean
- location: soybean

Step 4: Connecting Assigned Values into Classes/Individuals in the crop-pest ontology

Values assigned to the four properties for each individual were connected with classes and individuals in the crop-pest ontology. This mapping of property values onto the crop-pest ontology provides access to domain knowledge while browsing through

classes/individuals within the ontology. The individual “Image – SOY006,” for example, has “three cornered alfalfa hopper” as the value of the property “agent.” The value “three cornered alfalfa hopper” was mapped into the class “three cornered alfalfa hopper” in the crop-pest ontology. The class then showed 1) what it is and 2) what kinds of relationships there are among other classes or individuals, exposing the domain knowledge. Also the soybean value was mapped to the soybean class.

Step 5: Saving the Individual into the Crop-Pest Ontology

The index of each image from Step 1 through Step 4 was saved into part of the crop-pest ontology as an individual.

An Interface for Browsing Images

Goals

The first goal was to provide an interface to growers, county agents, and other agricultural users that would improve their ability to locate images compared to keyword based search interface. The users do not necessarily know what keyword to type to find images. This keyword-based approach is useful, when the users are familiar with what kinds of images are in a collection and/or when the user know what kind concepts are used to retrieve relevant images. A facility to browse can help users who are not familiar with a certain image collection to retrieve images easily and effectively, even though users must carefully guide themselves using textual or graphical indications of the content reachable via a link (Olston, 2003).

The second goal was to provide the users with the ability to acquire domain knowledge described by the crop-pest ontology while browsing concepts or images. A facility to show the concepts relationships for the domain of an image collection to users

can address the limitations in keyword-based interfaces that do not provide such domain knowledge

Features to be Supported

The graphical user interface has several features and requirements. First, a facility for browsing images is required in this interface for users who are not familiar with the image collection or who have lack of domain knowledge. Second, a facility to support visualization of a hierarchical structure of classes in the crop-pest ontology is required. Classes in the crop-pest ontology are arranged in a hierarchical structure. Therefore, the interface should support the visualization of hierarchy of classes in the crop-pest ontology. Third, a facility to show properties of the crop-pest ontology is required. Properties that show relationships between individuals or between individuals and data values should be shown to users. Fourth, a facility to show relationships of each image with concepts in the crop-pest ontology is required. Each image has relationships to other concepts in the crop-pest ontology. Therefore, the interface should provide concepts related to each image. Fifth, a facility to find all images related to a particular class in the crop-pest ontology is required.

The Graphical Interface

All features to be required to achieve these goals were implemented in the interface. First, the facility to browse images was implemented by modifying TouchGraph, an open source program for data visualization (TouchGraph, 2005). The interface is shown in the figure 4-4. The facility to browse images is shown in the center of the interface. The display contains a graph with nodes including a rectangular, an oval, or a thumbnail of an image; a rectangular node means a class in the crop-pest ontology and an oval node indicates an individual in the ontology. Properties are displayed as

edges shown in the figure 4-4 which are gray lines connecting nodes. When a user click a node, the neighboring nodes are expanded or hidden, enabling users to control the range of nodes to be seen. Users can browse images following to the expansion of nodes shown in figure 4-5. The facility to support visualization of a hierarchical structure of classes in the crop-pest ontology was implemented using colors and shapes of nodes. Classes in the crop-pest ontology were represented by rectangular nodes. Each rectangular node can have three colors. A rectangular in orange represents the selected class. A rectangular in blue is a superclass. A rectangular in green is a subclass. Since the interface is for growers and other professionals who might not be familiar with components of the crop-pest ontology, the interface avoids using technical terminology of the ontology such as class, subclass, and superclass. The meaning of colors ("current selected: orange, more general: blue more specific: green") is defined in the interface in Figure 4-5.

The facility to show properties of the crop-pest ontology was implemented using edges. There are two edges: One is an edge without any label and the other is an edge with a label. An edge with a label represents a property in the crop-pest ontology shown in the figure 4-6. The thick end of each edge with a label indicates the domain of a property and the thin end of it shows the range of the property. For example, in the figure 4-6, a property called "is pest of" is shown the edge with the label "is pest of" in black. The domain of the property is a class "insect" and the range of the property is a class "plant". The thick end of the edge in black indicates the domain, the class "insect", and the thin end of the edge indicates the range represents the range of the property. An example, "is pest of" is highlighted in black.

A facility to show relationships of each image with concepts in the crop-pest ontology was implemented. When an image is selected, all related concepts with the image are shown. The facility provides background knowledge of the image as well as content. In addition, users can expand their retrieval experience in the image collection by following related concepts. For example, related concepts including bean leaf beetle, damage, soybean and related properties are shown, when an image pointed by the black arrow in the figure 4-7.

A facility to find all images related to a particular class in the crop-pest ontology was implemented. In this image collection, users might want to see all images related a particular class without browsing nodes. This facility shows all images related a particular class, given that the user enters the term for that class. For example, in the figure 4-8, a term from the input box located in the left most top of the screenshot “stink bug” was matched into a class “stink bug” in the crop-pest ontology by comparing the given term with names of classes. When users click a button “show all images about stink bug” located in the right most top of the interface, a pop-up window shows all images that were manually assigned into individuals of class “stink bug” and its subclasses.

Usability Study

The graphical interface was designed for growers, county agents, and other agricultural users to improve their ability to locate images compared to keyword based search interface. In addition, this interface was developed in order to provide the users with the ability to acquire domain knowledge by browsing the crop-pest ontology while searching for images. The usability study was planned to evaluate this interface based on these two objectives.

The Keyword-Based Search Interface

To compare this graphical interface with the conventional keyword-based search interface, a keyword-based search interface called “baseline interface” was built using the Egothor (Egothor, 2005), an open source full-featured text search engine written entirely in Java. 291 web pages were generated for indexing those images. Each Web page contains an image file (.jpg) and its image captions as text. Figure 4-9 shows the keyword-based interface and a web page containing an image and its caption. The main page for the baseline interface provides an entry input box for typing in search keyword(s) and one paragraph about the description of the domain. After users enter keyword(s), a linked list of Web pages of search results is shown. When users click a Web page in the list, the Web page shows an image and its caption.

Hypotheses to Be Tested

Based on the two goals of this interface, two hypotheses were tested.

- **Hypothesis 1**: The graphical interface will produce higher precision and recall than the baseline interface.
- **Hypothesis 2** : The graphical interface will help users to learn more about the crops, pests, and relationships between them

Design and Procedure

The hypothesis 1 was tested by evaluating precision and recall of the graphical interface and the keyword-based image interface. The process of this evaluation was carried out in three stages. In the first stage, search terms used to determine precision and recall were drawn. 134 terms were collected from terms that users typed in to search documents in an agricultural information system called Electronic Data Information Source (EDIS). Based on the range of the image database covered by both interfaces, seven search terms were drawn out of the 134 search terms. The selected terms were

shown in the table 4-1. In the second stage, both interfaces were accessed for the selected search terms. Finally, the data was analyzed for results.

The hypothesis 2 was tested by evaluating user satisfaction implemented using a between-subjects design. Data from 20 participants was used in the analysis. 19 participants are in the Department of Agricultural and Biological Engineering in University of Florida and one participant is in the Department of Horticulture in University of Florida. The preliminary study was done with agricultural researchers including 3 faculties, 1 staff, and 16 graduate students. The participants were all users of the Internet, searching for information either everyday or a few times per week. They searched for images online either every day or a few times per week. Each participant used either the baseline interface or the graphical interface. Since there is no explanation before using a interface in practice, participants were not introduced to the features of the interface. But, the fact that they accessed the same image collection about crops and related pests was introduced before starting the evaluation. Either the baseline interface or the graphical interface was randomly assigned. Throughout the study, subjective ratings were reported on a 4-point scale (Strongly agree, agree, disagree, strongly disagree). A sample question is as following:

- Did this interface help you learn more about crops, pests, and relationships between them?

After finishing the retrieval of images in each interface, participants completed an evaluation. All questions to be asked are shown in the Appendix F.

Results

The precision and recall of seven search terms in both interfaces were shown in the table 4-1. The statistical analysis for comparing two precision between the graphical

interface and the baseline interface was shown that precision of the graphical interface is higher than that of the baseline interface(t = -2.11, p = .02). In addition, recall of the graphical interface is higher than that of the baseline interface (t = -2.10, p = .02). Therefore hypothesis 1 was accepted.

The test of hypothesis 2 was done by the analysis of response on the question "Did this interface help you learn more about crops, pests, and relationships between them?". The table 4-2 shows individual response on the question. The statistical analysis shows there is no significant between two interfaces (t = 2.9 p = .46) and the hypothesis 2 was rejected. However, the advanced evaluation would be needed, since responses from participants indicate some difference. The design of this evaluation is based on between-subjects design. This design treats the difference of subjects (i.e. difference of participants) as an error. However, the within-subjects design can deal with the difference of subjects as a variable. In addition, the size of participants is five, which is small. Moreover, the subject ratings based on 4 –point Likert scale might be not sensitive to get the precise response from participants. Therefore, the advanced evaluation would be considered using 1) the within-subjects design, 2) bigger size of participants and 3) a wide range of subject ratings.

Conclusion

Based on the crop-pest ontology, the ontology-based image indexing was done. The new class "digital photograph" was created in the crop-pest ontology to index 291 images. Several properties related with "digital photograph" were assigned. The process of indexing images is as following:

- Syntactic and semantic analysis of each image caption

- Creating an individual of the image in the crop-pest ontology
- Filling in the values of properties for each individual
- Connecting assigned values into individuals in the crop-pest ontology
- Saving the individuals into the crop-pest ontology

After indexing 291 images, a graphical interface for browsing those images was designed to provide a tool to growers, county agents, and other agricultural users that would improve their ability to located images comparing to keyword-based search interface. In addition, this interface was aimed to provide the users with the ability to acquire domain knowledge described by the crop-pest ontology. The graphical interface enables users:

- To browse images
- To support visualization of a hierarchical structure of classes in the crop-pest ontology
- To show properties of the crop-pest ontology
- To show relationships of each image with concepts in the crop-pest ontology
- To find all images related to a particular class

The preliminary usability study was done for this graphical interface. Data from 10 participants was used in this analysis. To compare conventional keyword-based search interface, a keyword-based search interface was built. Hypotheses to be tested are as following, based on the goals of this graphical interface:

- **Hypothesis 1**: The graphical interface will produce higher precision and recall than the baseline interface..
- **Hypothesis 2** : The graphical interface will help users to learn more about the crops, pests, and relationships between them

To test hypothesis 1, seven search terms were drawn from the user inputs from the EDIS and the precision and recall of the graphical interface were higher than those of the baseline interface. Because that precision and recall represent the efficiency of searching

information, the higher precision and recall indicated that growers, county agents, and other agricultural users improve their ability to locate images using the graphical interface, compared to keyword based search interface.

To test hypothesis 2, usability study was implemented using between-subjects design. Each participant used either the keyword-based search interface or the graphical interface using the crop-pest ontology. Throughout the study, subjective ratings were reported on a 4-point Likert scale. The question “Did this interface help you learn more about crops, pests, and relationships between them?” was asked to participants. Eight participants out of ten were that the graphical interface helped them learn more about domain, while five participants out of ten using the keyword-based search interface agreed with that and two participants strongly disagreed. The statistical analysis showed the hypothesis 2 was rejected. But the responses from the participants indicated an advanced study of the evaluation of the graphical interface. The advanced study would be designed using 1) the within-subjects design, 2) bigger size of participants, 3) a wide range of subject ratings, and 4) the retrieval of images by a task.

Table 4-1. The result of evaluating precision and recall in both interfaces

Search terms	Graphical interface		Baseline interface	
	Precision (%)	Recall (%)	Precision (%)	Recall (%)
Aphid	0	0	100	50
Bug	0	0	100	58
Green stink bug	0	0	0	100
Laying egg	0	0	0	0
Plant	50	3	100	11.6
Stink bug	100	100	100	100
White fly	0	0	100	100

Table 4-2. Participant's responses about the question "Did this interface help you learn more about crops, pests, and relationships between them?"

	Interface using keyword	Interface using ontology
strongly agree	0	0
Agree	5	8
Disagree	3	1
strongly disagree	2	0
N/A	0	1
Total	10	10

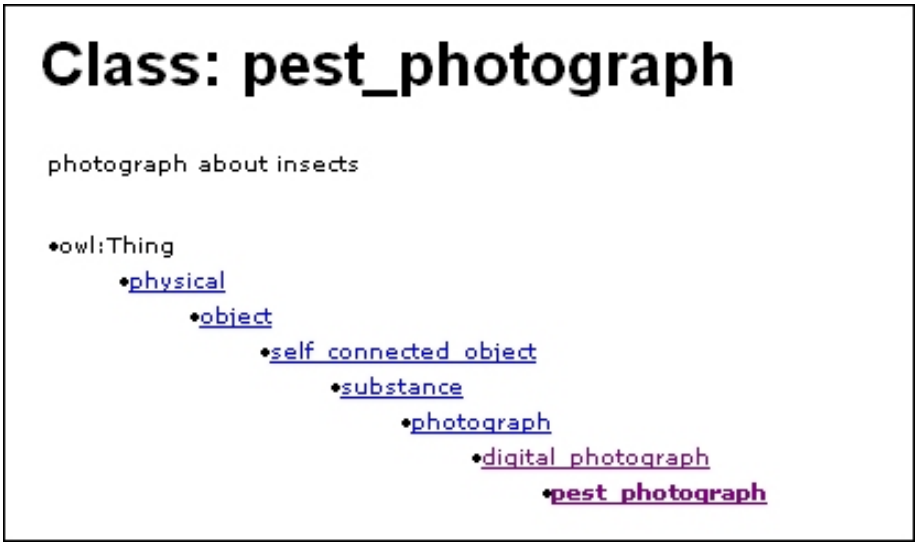


Figure 4-1. Hierarchy from the root class "thing" to "digital photograph."

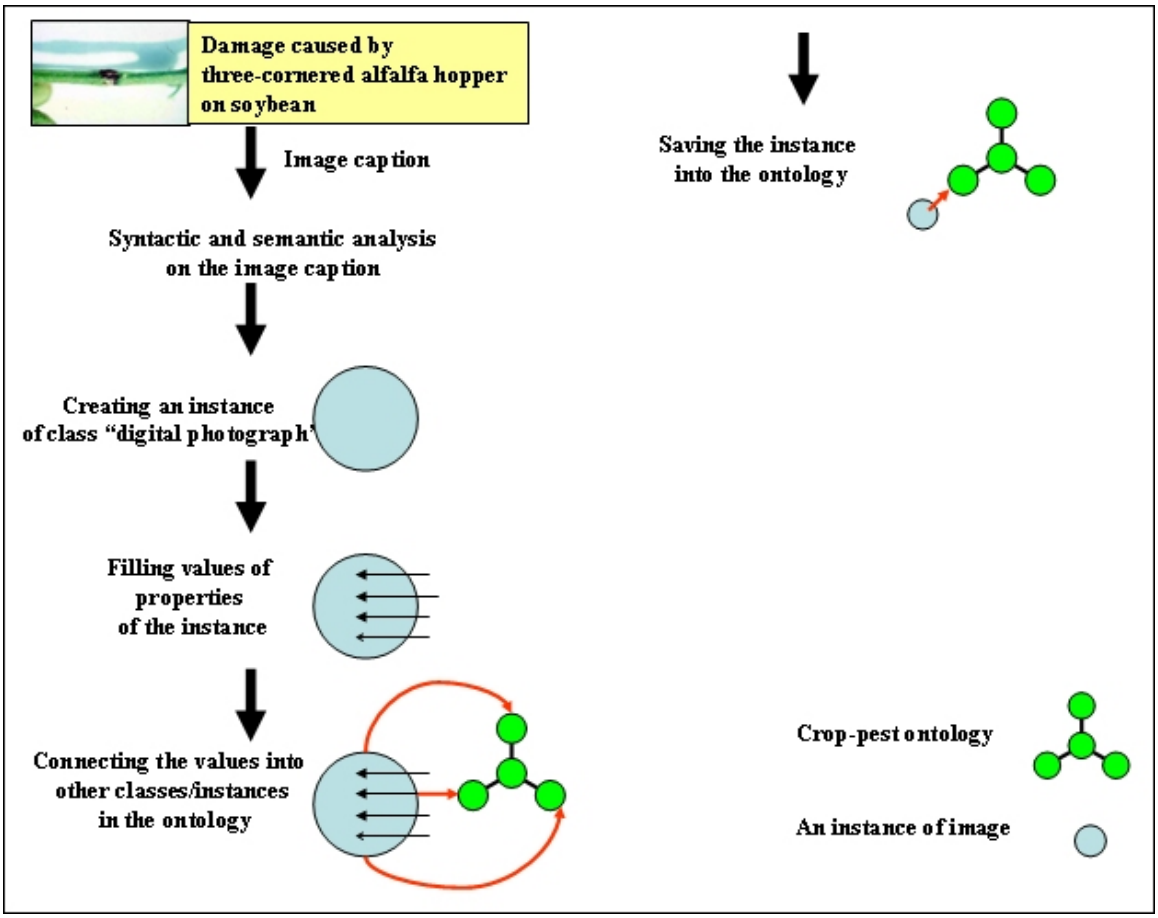


Figure 4-2. Overview of indexing images associated with the crop-pest ontology.

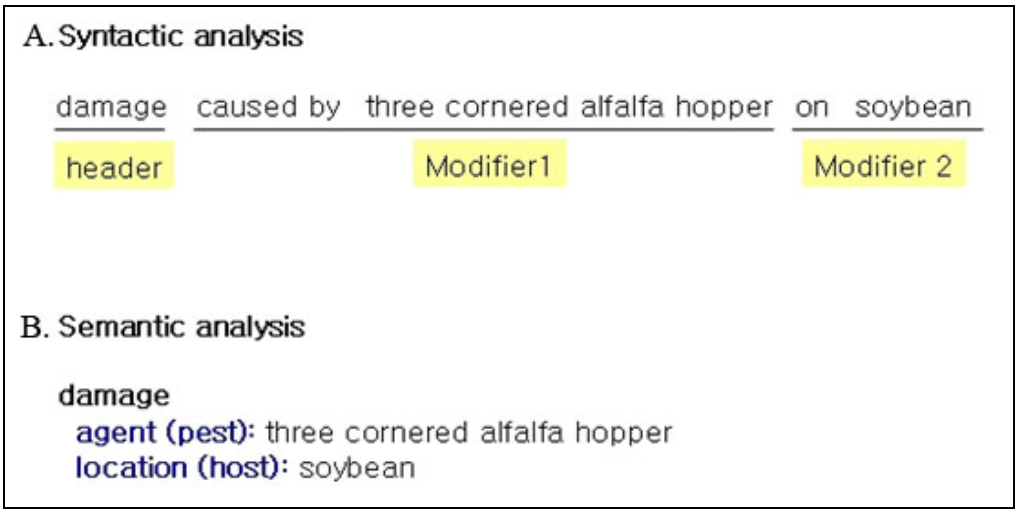


Figure 4-3. Syntactical and semantic analysis of the image caption "damage caused by three cornered alfalfa hopper on soybean." A shows the result of syntactic analysis. B illustrates the result of semantic analysis.

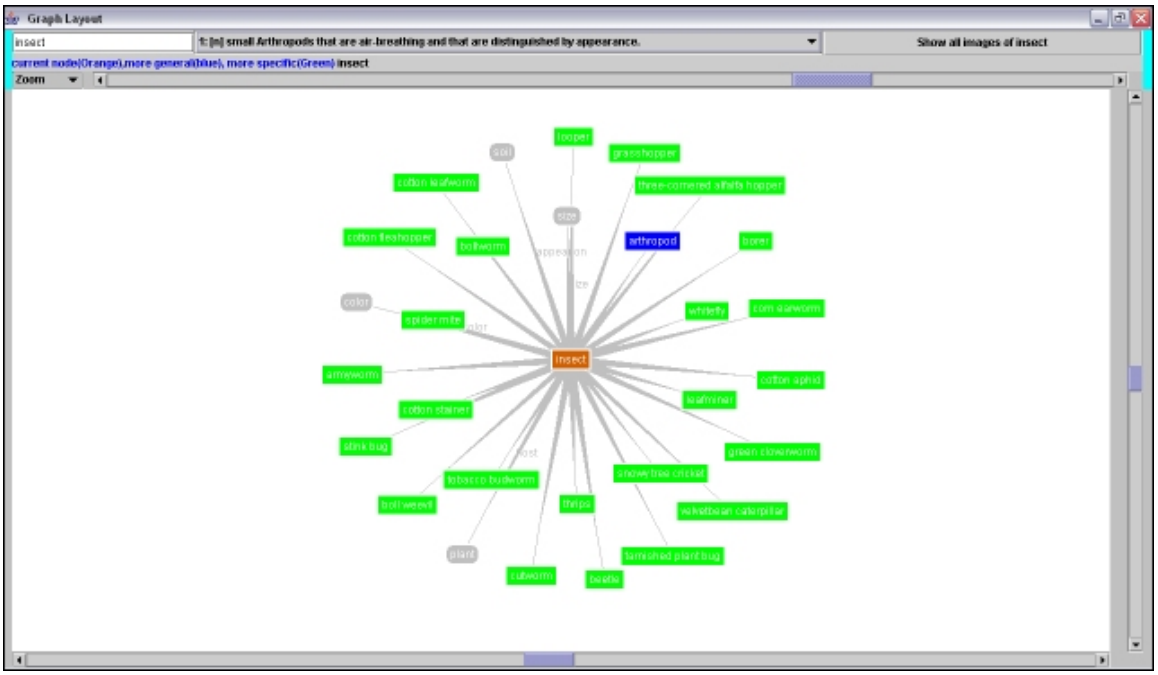


Figure 4-4. The interface that provide a facility to browse 291 images. The browsing facility is located in the center of the interface.

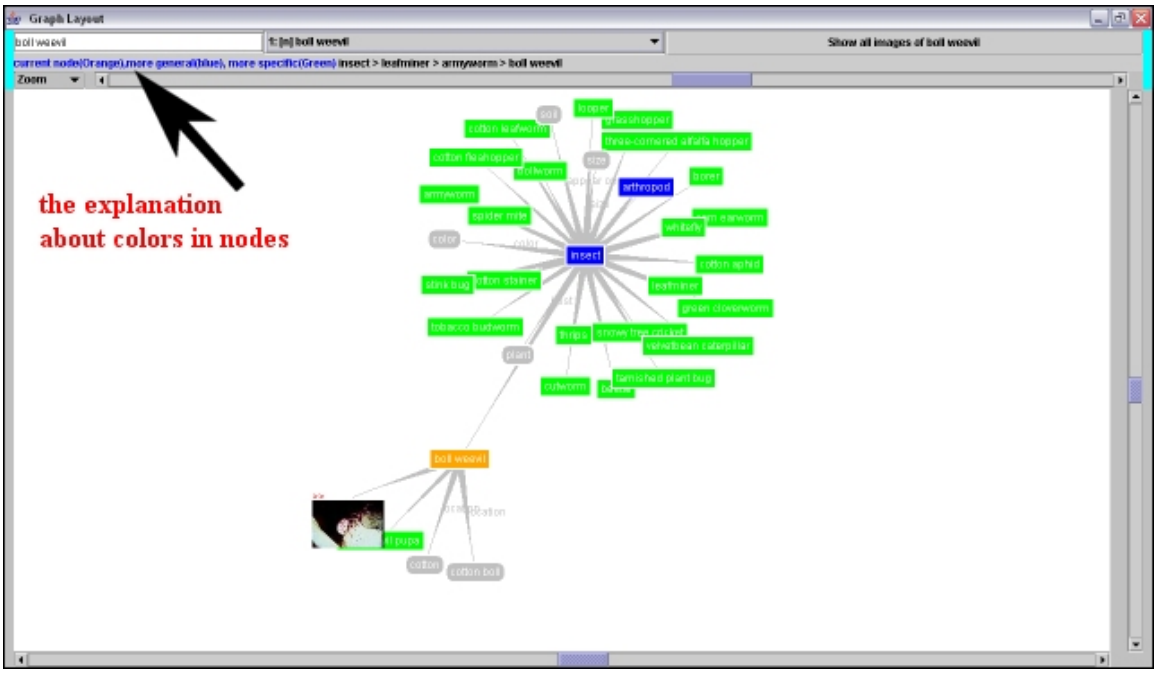


Figure 4-5. Expanding a node (orange rectangle) shows an image. The black arrow (not part of the interface) points at the definition of node colors.

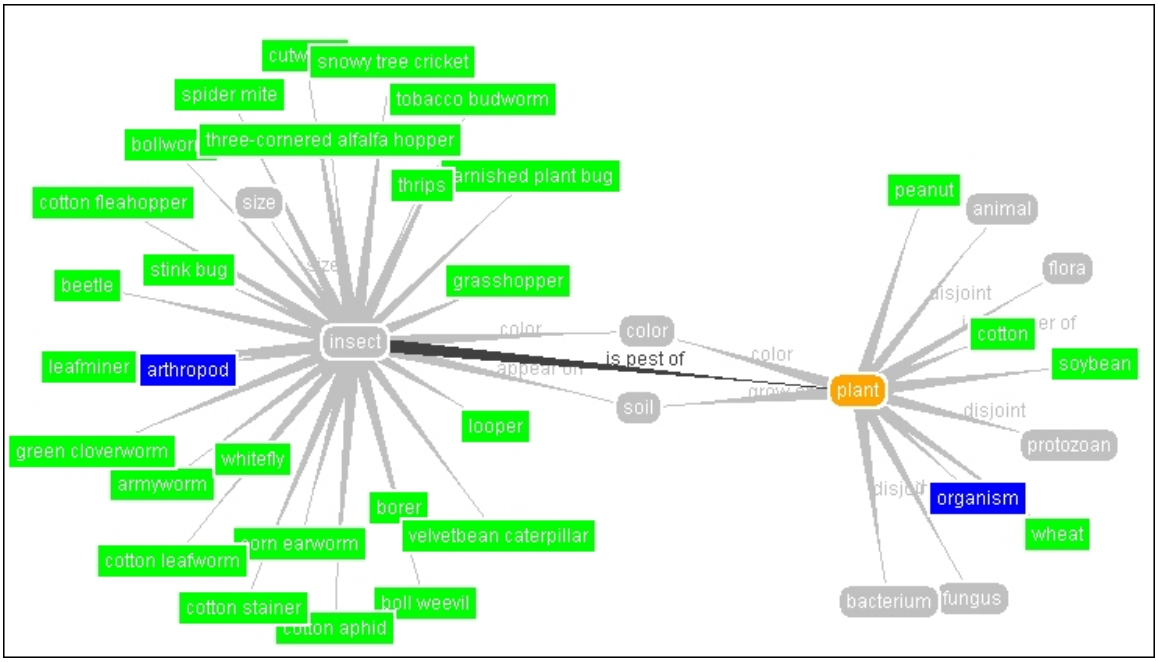


Figure 4-6. A facility for showing properties. A property is shown by an edge with a label. The thick end of each edge represents the domain. The thin end of each edge

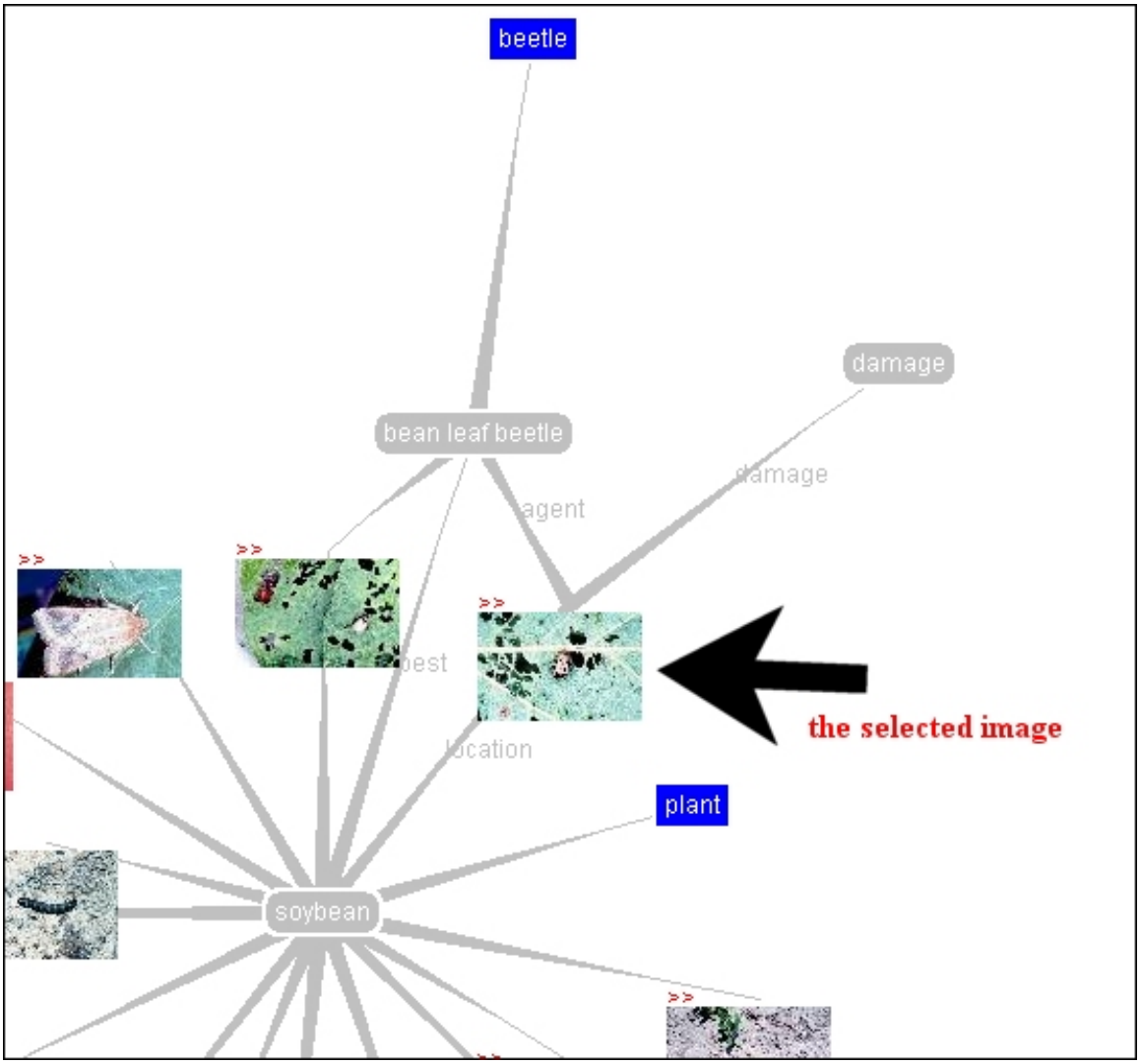


Figure 4-7. The facility to show the selected images with related concepts in the crop-pest ontology.

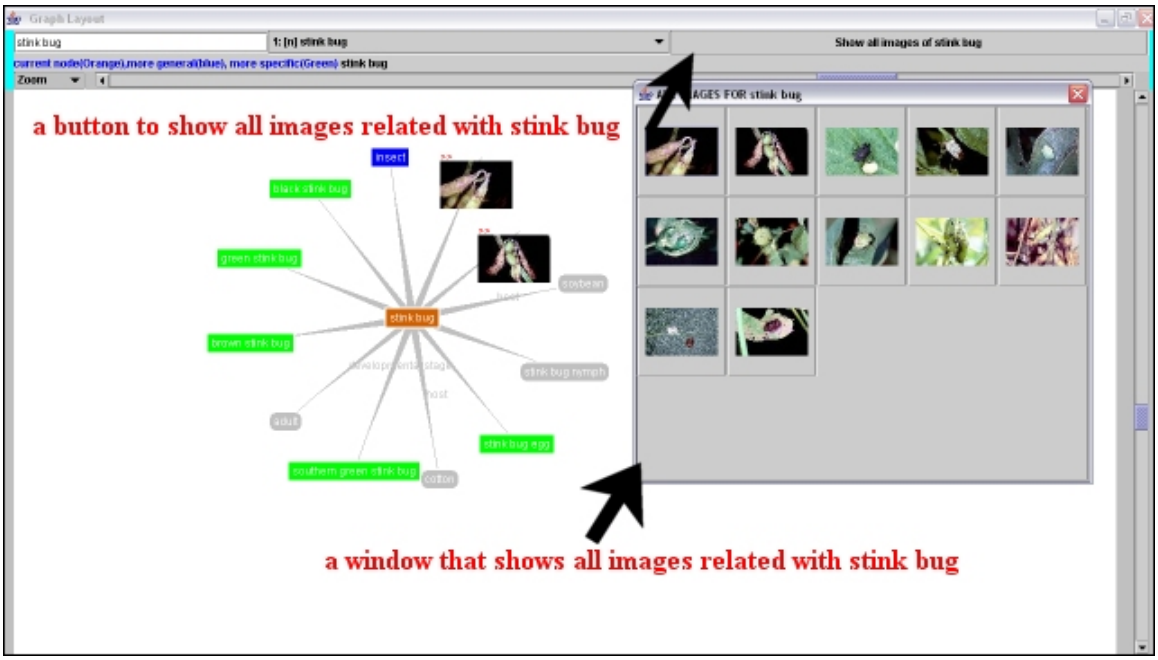
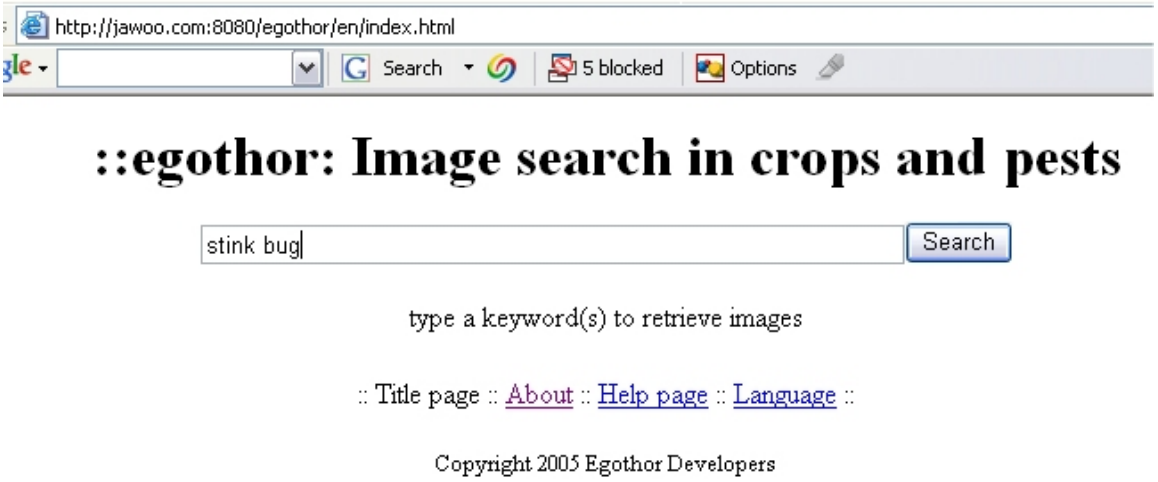


Figure 4-8. The facility to show all images related with a particular class in the crop-pest ontology

A.The main page of the keyword-based search interface



B.A web page containing an image and its caption

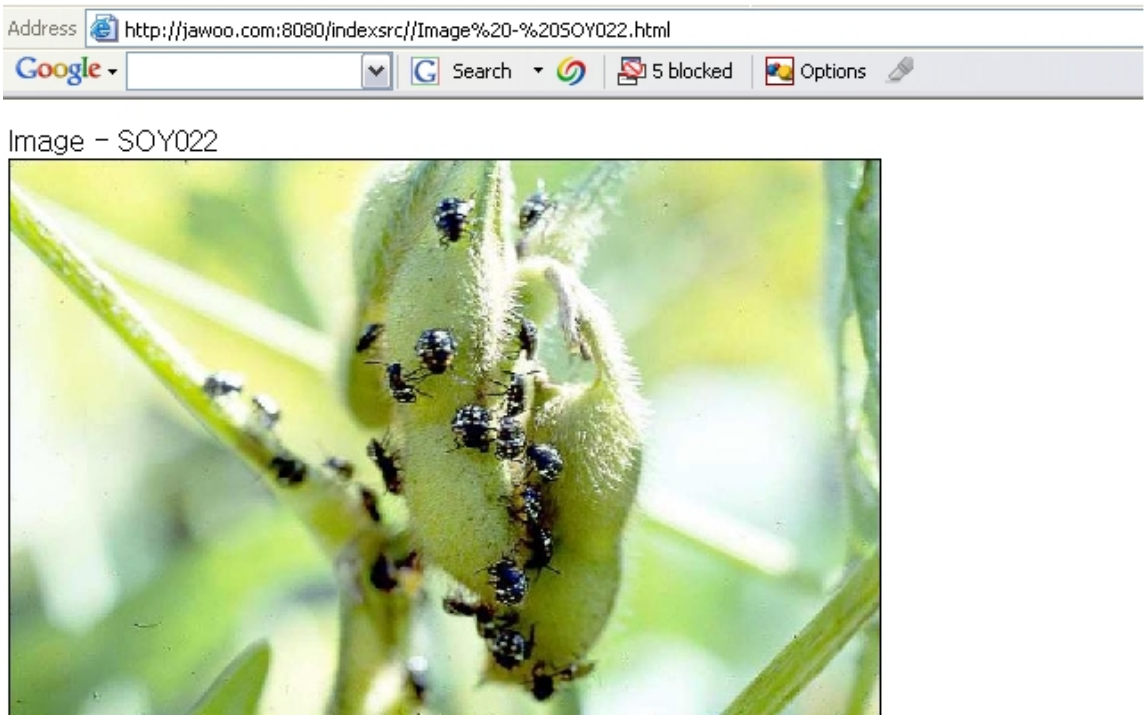


Figure 4-9. The screenshot of keyword-based search interface implemented with Egothor. A shows the main page of searching images B shows the Web page of an image and its caption “stink bug nymphs on soybean pod”. This web page was used for indexing the image

CHAPTER 5
ONTOLOGY-ASSISTED INFORMATION EXTRACTION

Introduction

The indexing of image captions associated with the crop-pest ontology is a process in which important information is extracted from the image captions based on syntactic and semantic analysis and the information then saved into a structural form that enables a reasoner to reach it and apply reasoning processes to it. Chapter 4 described the manual indexing of image captions. This chapter introduces a semi-automatic approach to the creation of indexes based on syntactic and semantic analysis of natural language. The creation of an index can be redefined as the process of extracting relevant information from text and building a formal semantic structure for it. The process is called **information extraction**. Information extraction is a process that identifies useful information from natural language text from a particular domain and converts that information to a structured form which can be saved into a database (Cardie, 1997). In ontology-assisted image retrieval, the structured form that results from the information extraction associated with the ontology is created as an individual of class “image” inside the crop-pest ontology. SMES is one information extraction system that uses domain-specific knowledge from an ontology (Maedche, 2002). SMES maps free text into a domain-specific ontology containing target knowledge structures about crucial information for answering questions such as who, what, whom, when, where or why. The target knowledge structures are predefined by a given ontology.

Manual information extraction incurs a high time and labor cost for syntactic and semantic analysis because domain experts analyze the syntactic and semantic structure of natural language text based on their domain knowledge to create the structure. The semi-automatic approach suggested here is based on a natural language parser, phrase patterns, and the crop-pest ontology. Parsing is defined as the process of analyzing a continuous stream of input such as text in order to determine its grammatical structure with respect to a given set of grammar rules. A parser is a computer program that carries out this task. Phrase patterns provide syntactic and semantic information to the parser. The crop-pest ontology is an ontology that describes crops and related pests in a formal way, as discussed in the chapter 2. The three components function together to analyze natural language text and create the semantic structure automatically. This approach is considered to be semi-automatic rather than automatic since the phrase patterns were created by humans and some manual validation of the automatically created structures is required.

The organization of this chapter is as follows. The components of the information extraction system will be introduced: 1) ontology, 2) phrase patterns and 3) island chart parser. Semantic structures as the outputs of the system will be described as well. The results from the information extraction system are presented and discussed.

Components in Information Extraction System

The information extraction system consists of 1) the crop-pest ontology as a source of domain specific knowledge, 2) an island chart parser which parses given input strings and converts them into semantic structures, and 3) phrase patterns which provide specific grammar for the island chart parser (Figure 5-1). Inputs of the system are untagged natural language text from image captions in the 291 images. Outputs of the system are

semantic structures that contain information about the input text associated with the crop-pest ontology.

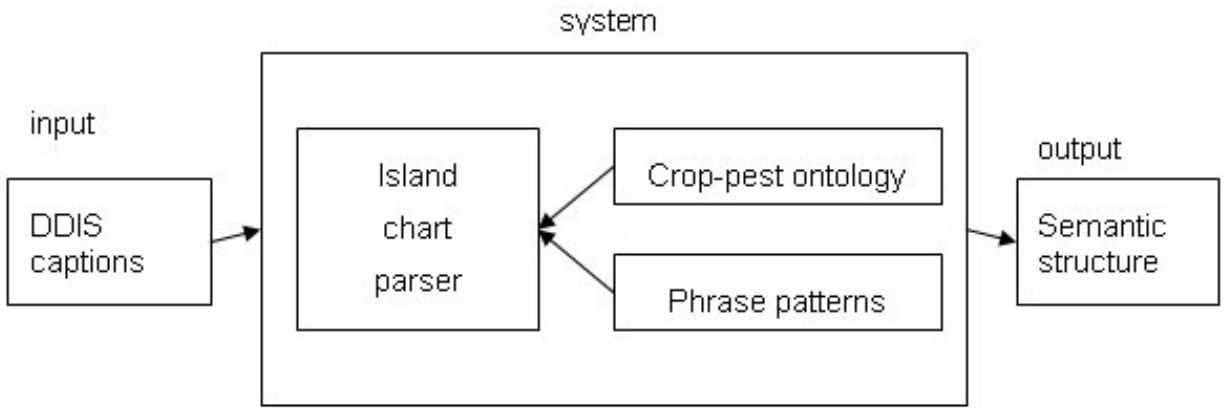


Figure 5-1. The information extraction system in the crop-pest domain. The semantic structure can be classified as an individual of a particular class inside a domain-specific ontology, mapped from the natural language text in a given caption

Ontology

Knowledge of the crop-pest domain is a vital component for building an information extraction system. Domain experts who have extensive experience can build this knowledge. Since every domain expert has a different way of presenting their knowledge, a formalized form is necessary. One such form is an ontology, as was introduced in Chapter 2.

Phrase Patterns

Phrase patterns are domain-specific patterns that represent meaning of phrases (or a word) as well as their syntactic structure. Phrase patterns contain relationships among phrases that are specified as “ATTRIBUTE” and “HEAD.” The HEAD is the main concept appearing as a single word in the phrase being analyzed, and ATTRIBUTE is a modifier of the HEAD. For example, to represent “cotton leaf,” we can create a phrase pattern such as <**np** *plant* ATTRIBUTE: plant, **np** *plant part* HEAD>. In the phrase

pattern, **np** is a category of noun phrase that can be resolved using other patterns for noun phrases. In the case of “cotton leaf”, each **np** in the pattern resolves to a single noun. The phrase pattern also describes the semantic structure of of the phrase and the role of each word in that structure as shown by the labels *plant* and p*lant part*. The phrase pattern explains a relationship between “cotton” and “leaf” with ATTRIBUTE and HEAD, since a leaf is part of cotton. This phrase pattern can be applied for other phrases as well, such as “cotton stem,” “cotton root” and “peanut leaf.” As shown in Figure 5-2, phrase patterns are organized with a hierarchical structure. <n cotton> and <n leaf> become the most specific phrase patterns in the hierarchy. The phrase pattern in the above example is a child of the phrase pattern of <np plant part>, which is a child of <np>.

These phrase patterns can be used a grammar. A grammar is a formal description of the structures acceptable in a language (Allen, 1995). One type of grammar is context-free grammar. Context-free grammar is roughly defined as a grammar in which the left side of the rule has a single symbol. It is effective enough to express most of the structures in natural language (Allen, 1995). However, this grammar is highly ambiguous. Phrase patterns can lessen such ambiguity by using words in context specific to a certain domain.

<np>
<np plant part>
<np plant ATTRIBUTE:plant, np plant part HEAD>
<n cotton ATTRIBUTE:cotton, n leaf HEAD>

Figure 5-2. The hierarchical structure of phrase patterns for a concept “plant part”. A phrase pattern < n cotton ATTRIBUTE:cotton, n leaf HEAD> is more specific pattern than <np plant ATTRIBUTE:plant, np plant part HEAD>, because a cotton is a specific plant and a leaf is a specific plant part.

Island Chart Parser

A chart parser is a parser that utilizes of a set of grammatical rules, and dictionary with each of the possible grammatical senses of each word indicated, and a data structure called a "chart". A chart is a linear list of nodes and retains all edges. The chart parser reads a phrase from the starting point -usually starting from the beginning of a sentence- extending parsing usually in a rightward. However, the chart parser can not recognize fragments of words such as island in a sentence, because it works from the starting point and parse through one way. Therefore, the island chart parser was introduced for parsing bidirectional to recognize fragments of words: the parser can parse in both left and right directions.

The island chart parser parses the syntactic and semantic structure of an input string with domain-specific rules. The phrase patterns are used as domain-specific rules (grammar) for the parser. The parser consists of **nodes**, **edges**, and a **chart**. A node is a point between two words in the input string that is being parsed. One node has information about all the edges that are coming in or going out from it. An edge is a data structure that represents a complete or partial parsing of the input. It applies a particular rule and is labeled by the rule. A chart is a linear list of nodes and retains all edges. Figure 5-3 shows an edge that has a rule and four nodes in a chart.

The parsing procedure of the island chart parser has three steps. The first step is the initialization of a chart with edges. The initialization is done by looking up each term in a given input and retrieving all patterns associated with each term. The second step is cycling on the edges that are generated from the first step. During this step, each edge is checked that it can be expanded by satisfying a rule associated with the edge. If so, the edge becomes a complete edge: the rule associated with the edge is completely satisfied.

Otherwise, it becomes an incomplete edge: the rule associated with the edge is not completely satisfied. The complete edge also can be used for extending other incomplete edges inside a pending edge list. The third step is building parse trees, which are generated from edges parsed completely on the chart. The parser produces one or more parse trees as an output of parsing, since one phrase can be interpreted in several ways due to the ambiguity of natural language (Seiffert, 1987). For each parse tree, a semantic structure is created for representing the meaning of the phrase

Semantic Structure

Semantic interpretation is a process that translates parse trees from outputs of parsing into structured forms. The structured forms are called **semantic structures**. The structure is an object representing a concept that can be automatically classified and added to the ontology. Each semantic structure 1) contains concepts that are associated with the crop-pest ontology, 2) is saved as the instance of the HEAD concept of an input string in the crop-pest ontology, and 3) can be used for retrieving images.

Indexing of images is a process in which important information is extracted from the image captions based on syntactic and semantic analysis. Semantic structures of each image caption, outputs of the information extraction system consisting of phrase patterns, the crop-pest ontology, and the island chart parser, were created based on syntactic and semantic analysis. They provide a rich description of each image. In addition, they are indirectly related to concepts associated with each caption. The semantic structure could be used as indexes of images containing rich information to retrieve images.

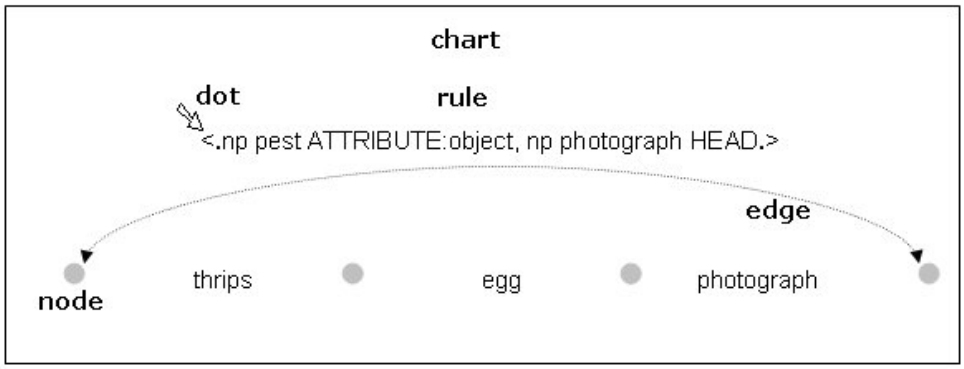


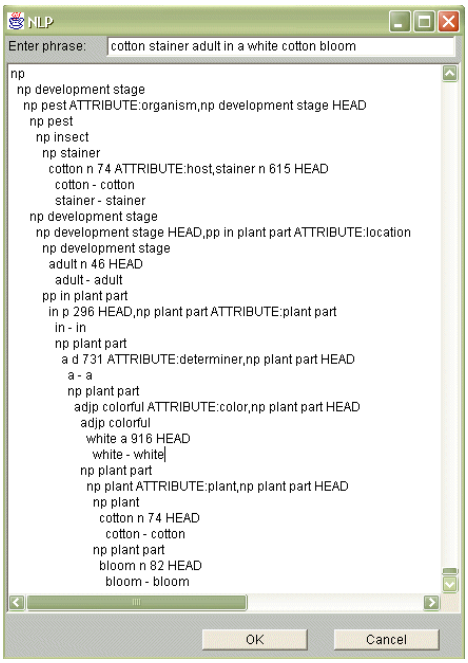
Figure 5-3. Components of the island chart parser with a simple input string. This diagram shows only one edge, but there are many other edges for the phrase being analyzed. An edge has two dots (left and right), which show how many symbols in the pattern are applied: the left dot shows how many symbols have been applied so far in the left direction and the right dot shows how many symbols have been applied so far the right direction

Results of the Information Extraction System

The information extraction system in the crop-pest domain was tested by 150 phrases from image captions. The island chart parser traversed input strings with the crop-pest ontology and phrase patterns. One of parse trees is shown in the left side of Figure 5-4. The parse tree was converted to a semantic structure, as shown in the right side of Figure 5-4. The semantic structure contains 1) words which are associated with the crop-pest ontology (bold), 2) semantic relationships among them (italic), and 3) numbers as an identifier for the synset that represents an appropriate meaning of each word. The HEAD (underlined) of the phrase “cotton stainer adult in a white cotton bloom” is the concept “adult.” Therefore, the semantic structure was saved as an instance the concept “Image” in the crop-pest. The instance of “adult” can be used for searching “adult” directly or related words indirectly.

The result of extracting information was that 130 of 150 phrases were parsed and converted to semantic structures. The island chart parser could not parse the remaining 20 phrases because of the existence of words that were not associated with phrase patterns.

Those words could be categorized into three groups: 1) 13 phrases containing plural nouns (even though the system includes phrase patterns which can determine the singular form), 2) two phrases with conjunctions such as “and,” and 3) 5 phrases that included added parenthetical explanations, such as “wireworm larva (click beetle grubs) on peanut photograph.” The first two categories could be fixed by adding more patterns for detecting conjunctions and plural nouns. Items in the third category could be successfully parsed by modifying the parenthetical phrases using synonyms. Usually the information inside parentheses in the crop-pest domain represents other common names of insect or scientific names. These names are synonyms of the original names (i.e. wireworm larva = beetle grub). The crop-pest ontology can present synonyms. These changes, would improve the information extraction system to parse given all 150 phrases.



adult 46
location: **in** 296
plant part: **bloom** 82
plant: **cotton** 74,
color: **white** 916,
determiner: **a** 731
organism: **stainer** 615
host: **cotton** 74

Figure 5-4. A parse tree (left) and the semantic structure (right) based on the parse tree for the caption “cotton stainer adult in a white cotton bloom.”. The numbers appearing in the right panel indicates that each term was mapped into classes in the crop-pest ontology

Conclusion

An information extraction system was developed with the crop-pest ontology and phrase patterns as domain-specific knowledge sources. This system provides a semi-automatic approach to the creation of indexes based on syntactic and semantic analysis of natural language. The system was then tested with 150 image captions. One hundred and thirty phrases (86.67%) were parsed and converted to semantic structures successfully. Phrase patterns were constructed manually for the information extraction system. This manual building of phrase patterns is very tedious. In future work, automatic building of phrase pattern from existing phrase patterns will be explored in the information extraction system.

CHAPTER 6
CONCLUSION AND FUTURE DIRECTIONS

The new approach of retrieving images associated with an ontology is present here. 291 images describing crops and related pests (called “crop-pest domain”) were used to develop the new approach. An ontology called “crop-pest ontology” was built for retrieving the 291 images, covering concepts in the crop-pest domain. It provides formal description of concepts in the crop-pest domain and supports reasoning processes based on the formal structure such as image search. A practical methodology for developing the crop-pest ontology was suggested according to the principles. Each step of the development was explained with specific examples. The crop-pest ontology contains 286 classes, 81 object properties, 36 datatype properties, and 305 individuals. The top-level of the ontology was imported from the Suggested Upper Merged Ontology (SUMO), which shows a good example of the reusability of existing ontology. The consistency of the crop-pest ontology was checked using the OWL reasoner (open-source Java based OWL DL reasoner) as validation of the ontology. The result of the validation showed that classes, properties and individuals in the crop-pest ontology are logically consistent. Complete ontology not only can support their intended applications and function properly, but also can be re-used for the development of other ontologies. Therefore, the evaluation of the crop-pest ontology is essential process. The crop-pest ontology evaluation was done using the quantitative approach, testing the coverage of the ontology with a domain-specific corpus. 138 terms from a domain-specific corpus were tested to check the coverage of the crop-pest ontology, comparing the well-know agricultural

ontology, AGROVOC. The crop-pest ontology covered 44.93% of tested terms, while AGROVOC covers 30.43% of them. It indicated the crop-pest ontology coverage is better than AGROVOC in the domain-specific corpus. Therefore, the crop-pest ontology can support the ontology-assisted image retrieval in the crop-pest domain.

Jacob's claim about "a controlled vocabulary is itself an ontology" brought a new research of a practical comparison between the National Agricultural Library Thesaurus (NALT) and the crop-pest ontology. In this research, two categories both NALT and the crop-pest ontology were considered to compare. One is representation ability of domain knowledge and the other is reasoning ability based on the representation. NALT represents the domain knowledge based on simple relations such as BT and RT, it occurs ambiguity of relations. In addition, the description of NALT was not written in a formal language, which means that a reasoner can not reach each component of NALT and not do any reasoning process. However, the reasoning ability can give the power of deduction of a new conclusion based on the true statement, since the crop-pest ontology is written in the formal language. In addition, the reasoning ability supports the search of information with high precision and recall. Furthermore, it provides the automatic validation of logical consistency. Therefore, the practical comparison offers the following conclusion; the crop-pest ontology provides the better representation of domain knowledge and a grater power of reasoning based on the underlying representation, which could improve searching technique in the agricultural information system.

Indexing images is a vital importance to support to browse images. Current technique that indexes images by thesaurus can overlook some information inside each image that might be a essential to index it. The crop-pest ontology could improve the

deficiency of describing domain knowledge comparing with thesaurus. So, indexing images associated with the crop-pest ontology was explored in this research. This indexing process is as followings:

- Manual syntactic and semantic analysis of image caption of each image
- Creating an individual of the image in the crop-pest ontology
- Filling the values of properties on the individual
- Concerning assigned values into classes/individuals in the crop-pest ontology
- Saving the individual into the crop-pest ontology

Index of each image from step1 through 5 was saved into part of the crop-pest ontology as an individual. The index can be retrieved for browsing images. Demand of a new interface to browse images associated with the crop-pest ontology brought the work to create the new interface. The goal of this interface is to support the browsing images, avoiding negative consequences like empty result sets or feeling of being lost. In addition, it provides users to acquire domain knowledge described by the crop-pest ontology, during browsing concepts or images. The new interface has several features to support as following:

- To browse images
- To support visualization pf a hierarchical structure of classes in the crop-pest ontology
- To show properties of the crop-pest ontology
- To show relationships of each image with concepts in the crop-pest ontology
- To find all images related to a particular class

The usability study was done using on-line evaluation. The evaluation compares the new interface to retrieve images with the crop-pest ontology to a conventional search interface based on the keyword. A preliminary usability study indicates that participants met less empty results in the retrieval of images using the crop-pest ontology. Moreover,

it shows that the image retrieval using the crop-pest ontology helps users to find relevant images by transferring the domain knowledge to them.

An information extraction system was developed with the crop-pest ontology and phrase patterns as domain-specific knowledge sources. This system provides a semi-automatic approach to the creation of indexes based on syntactic and semantic analysis of natural language. The system was then tested with 150 image captions. One hundred and thirty phrases (86.67%) were parsed and converted to semantic structures successfully. Phrase patterns were constructed manually for the information extraction system. This manual building of phrase patterns is very tedious. In future work, automatic building of phrase pattern from existing phrase patterns will be explored in the information extraction system.

APPENDIX A
291 IMAGE CAPTIONS

1: photograph of insect pest
2: photograph of pest of agronomic crops
3: photograph of peanut pest
4: Thrips on peanut photograph
5: Rednecked Peanutworm on peanut photograph
6: Leafhoppers on peanut photograph
7: Hepperburn from leafhoppers on peanut photograph
8: Three-cornered Alfalfa Hopper on peanut photograph
9: Lesser Cornstalk Borer on peanut photograph
10: Whitefringed Beetle Grub on peanut photograph
11: Southern Corn Rootworm (Spotted Cucumber Beetle Larva) on peanut photograph
12: Wireworm Larva (Click Beetle grubs) on peanut photograph
13: Corn Earworm on peanut photograph
14: Fall Armyworm on peanut photograph
15: Damage caused by fall armyworm on peanut photgraph
16: Stink Bug on peanut photograph
17: Cutworm on peanut photograph
18: Damage caused by cutworm on peanut photograph.
19: Spider Mites on peanut photograph
20: Southern Armyworm on peanut photograph
21: Velvetbean Caterpillar on peanut photograph
22: soybean pest photograph
23: Lesser Cornstalk Borer on soybean photograph
24: Lesser Cornstalk Borer damage on soybean photograph
25: Whitefringed Beetle on soybean photograph
26: Three-cornered Alfalfa Hopper on soybean photograph
27: Three-cornered alfalfa hopper damage on soybean photograph
28: Velvetbean Caterpillar on soybean photograph
29: Looper on soybean photograph
30: Green Cloverworm on soybean photograph
31: Beet Armyworm on soybean photograph
32: Fall Armyworm on soybean photograph
33: Corn Earworm on soybean photograph
34: Stink Bug on soybean photograph
35: Damage by Stink Bug on soybean photograph
36: Bean Leaf Beetle on soybean photograph
37: Soybean Stem Borer on soybean photograph
38: Grasshopper on soybean photograph
39: Yellow-striped Armyworm on soybean photograph

40: Mexican Bean Beetle on soybean photograph
41: Blister Beetle on soybean photograph
42: Snowy Tree Cricket on soybean photograph
43: cotton pest photograph
44: Beet Armyworm on cotton photograph
45: Thrips on cotton photograph
46: Damage by thrips on cotton photograph
47: Tarnished Plant Bug on cotton photograph
48: Damage by tarnished plant bug on cotton photograph.
49: Bollworm on cotton photograph
50: Cotton Aphid on cotton photograph
51: Fall Armyworm on cotton photograph
52: Looper on cotton photograph
53: Cotton Leafworm on cotton photograph
54: Whitefly on cotton photograph
55: Stink Bug on cotton photograph
56: Damage by stink bug on cotton photograph
57: European Corn Borer on cotton photograph
58: Boll Weevil on cotton photograph
59: Cutworm on cotton photograph
60: Spider Mite on cotton photograph
61: Cotton Stainer on cotton photograph
62: White Fringed Beetle on cotton photograph
63: Southern Armyworm on cotton photograph
64: Cotton Fleahopper on cotton photograph
65: Leafminer on cotton photograph
66: Flea Beetle on cotton photograph
67: Sugarcane beetle on cotton photograph
68: Cotton Square Borer on cotton photograph
69: Tobacco Budworm on cotton photograph
70: Thrips damage to peanut leaves.
71: Closeup of adult thrips on peanut leaf.
72: Rednecked peanutworm and damage on peanut.
73: Rednecked peanutworm in peanut bud.
74: Hopperburn caused by leafhoppers on peanut leaves.
75: Closeup on hopperburn caused by leafhoppers on peanut leaf.
76: Overview of hopperburn on peanut caused by leafhoppers.
77: Adventitious root growth on peanut caused by three-cornered alfalfa girdling.
78: Lesser cornstalk borer silken feeding tubes on peanut pegs.
79: Lesser cornstalk borer adult moths (male left, female right).
80: Closeup of lesser cornstalk borer larva on peanut leaf.
81: Whitefringed beetle grub in soil at base of peanut plant.
82: Spotted cucumber beetle (Southern Corn Rootworm adult) on peanut leaf.
83: Southern corn rootworm (Spotted cucumber beetle larva) on peanut peg.
84: Southern corn rootworm (Spotted cucumber beetle larva) damage to peanut pod.
85: Wireworm larva on soil in peanut field.

86: Medium corn earworm larva on edge of peanut leaf.
87: Large corn earworm larva on peanut leaf.
88: Profile of small corn earworm larva on edga of peanut leaf.
89: Fall armyworm egg mass on peanut leaf.
90: Small armyworm larva and minor damage on peanut leaf.
91: Hatching fall armyworm egg mass on peanut.
92: Fall armyworm damage to peanut bud.
93: Stink bug egg mass in peanut leaf.
94: Cutworm damage to peanut pod.
95: Spider mites on peanut leaf.
96: Large southern armyworm larva on peanut leaf.
97: Dark phase of velvetbean caterpillar on peanut stem.
98: Dark phase of velvetbean caterpillar on peanut stem.
99: Lesser cornstalk borer larva with damage on soybean.
100: An adult lesser cornstalk borer moth on the ground beneath a soybean plant.
101: Lesser cornstalk borer larva on soil beneath soybean.
102: Lesser cornstalk borer damage on soybean.
103: Whitefringed beetle grub in soil under soybean plant.
104: Adult whitefringed beetle with damage on soybean.
105: Adult whitefringed beetle on soybean.
106: Three-cornered alfalfa hopper nymph on soybean.
107: Adult three-cornered alfalfa hopper on soybean stem.
108: Damage caused by three-cornered alfalfa hopper on soybean.
109: Small velvetbean caterpillar larvae on soybean.
110: Large velvetbean caterpillar larva on soybean.
111: Looping velvetbean caterpillar larva on edge of soybean leaf.
112: Adult velvetbean caterpillar moth resting on soybean leaf.
113: Velvetbean caterpillar larva on soybean.
114: Adult velvetbean caterpillar moth on soybean.
115: Dark phase of velvetbean caterpillar on soybean.
116: Looper larva on soybean leaf.
117: Large looper larva on soybean leaf.
118: Large looper on soybean leaf.
119: Close-up of large looper larva on soybean leaf.
120: Large green cloverworm larva on soybean leaf.
121: Green cloverworm larva on soybean leaf.
122: Adult green cloverworm moth on soybean.
123: Beet armyworm larva on soybean.
124: Beet armyworm larva curled up on soybean leaf.
125: Adult beet armyworm moth on soybean leaf.
126: Large beet armyworm larva on soybean.
127: Large fall armyworm larva on soybean.
128: Adult fall armyworm moth on soybean.
129: Small corn earworm larva on edge of soybean leaf.
130: Corn earworm larva on soybean foliage.
131: Corn earworm larva on soybean pod.

132: Close-up of adult corn earworm moth on soybean
133: Stink bug nymphs on soybean pod.
134: Stink bug nymphs on dried soybeans.
135: Southern green stink bug on damaged soybean leaf.
136: Close-up southern green stink bug on soybean leaf. Notice the dried soybean laying on leaf for size comparison.
137: Small stink bug nymphs next to egg mass on soybean leaf.
138: Small stink bug nymphs on egg mass on soybean leaf.
139: Southern green stink bug nymph on soybean leaf.
140: Close-up on black stink bug on soybean. Notice the dried soybean for size comparison.
141: Stink bug egg masses on soybean leaf.
142: Adult brown stink bug on soybean.
143: Soybean pod damage caused by stink bug.
144: Soybean pod damage caused by stink bug on soybean.
145: Adult bean leaf beetle with damage on soybean.
146: Bean leaf beetle adult with damage on soybean.
147: Soybean stem borer adult on soybean stem.
148: Soybean stem borer larva in damaged soybean stem.
149: Grasshoppers on soybean leaf.
150: Close-up of grasshopper on soybean stem.
151: Large yellow-striped armyworm on soybean.
152: Mexican bean beetle eggs on underside on soybean leaf.
153: Mexican bean beetle larva on soybean.
154: Pupa of mexican bean beetle on soybean leaf.
155: Adult mexican bean beetle on soybean leaf.
156: Adult blister beetle on soybean leaf.
157: Snowy tree cricket on soybean.
158: Healthy and parasitized beet armyworm larvae with feeding damage on cotton.
159: Large beet armyworm larva behind bract of cotton bloom.
160: Hatching beet armyworm egg mass on cotton.
161: Small beet armyworm feeding in cotton leaf.
162: Beet armyworm larvae feeding in cotton bloom.
163: Beet armyworm pupa on soil at base of cotton plant.
164: Thrips on cotyledon leaf of cotton.
165: Thrips damage to the anthers of a cotton flower.
166: Adult and immature western flower thrips on cotton.
167: Western flower thrips on cotton.
168: Tobacco thrips adult on cotton.
169: Cotton seedling damaged by thrips.
170: Tarnished plant bug on cotton bract.
171: Tarnished plant bug nymph on cotton bract.
172: Two-day old tarnished plant bug egg.
173: Six-day old tarnished plant bug egg.
174: Mid-season plant bug damage to white cotton bloom.
175: Damage caused by a tarnished plant bug on a pinhead square.

176: Bollworm egg at the base of a cotton square.
177: Bollworm egg on cotton leaf.
178: Small bollworm on a small cotton square.
179: Small bollworm on terminal of cotton plant.
180: Four day old bollworm on cotton.
181: Five to six day old bollworm on cotton.
182: Small bollworm in white cotton bloom.
183: 4-day old bollworm larva in dried bloom tag with cotton boll damage.
184: Bollworm damage to small cotton boll under bloom tag.
185: Bollworm egg on brown cotton bloom tag.
186: 6-day old bollworm larva in white cotton bloom.
187: 6-day old bollworm on small cotton boll.
188: Small bollworm on cotton square showing damage.
189: Bollworm feeding through the white bloom into the cotton boll.
190: 4- to 5-day old bollworm larva under the cotton bloom tag with boll damage.
191: Old boll tip feeding damage from a bollworm on a large boll.
192: Old boll tip feeding damage from a bollworm on a mature boll.
193: Bollworm adult moth on cotton leaf.
194: Large bollworm larva on cotton stem.
195: Closeup of head and thorax of a bollworm larva.
196: Large bollworm larva under cotton bloom tag.
197: Bollworm egg on dried cotton bloom.
198: Bollworm eggs on cotton leaf.
199: Cotton bollworm larva on boll in Bt cotton.
200: Bollworm egg on brown bloom tag.
201: Bollworm larva feeding in cotton bloom.
202: Bollworm larva under brown bloom tag.
203: Cotton aphids on cotton leaf.
204: Cotton aphid honey dew and cupped cotton leaves.
205: Cotton aphids with fungus disease.
206: Sooty mold on cotton lint caused by aphid honeydew.
207: Four day old fall armyworm larva feeding on boll bract.
208: Large fall armyworm larva behind the bract of white cotton bloom.
209: 3-day old fall armyworm larva on cotton boll bract.
210: Fall armyworm on small cotton square with damage.
211: Fall armyworm damage to cotton boll bract.
212: Small fall armyworm on cotton square in top of plant.
213: Fall armyworm egg mass on cotton leaf.
214: Small fall armyworm in white cotton bloom.
215: Small fall armyworm larva with feeding damage to cract calyx and boll.
216: Small fall armyworm larva with feeding damage on bract.
217: Bract etching by fall armyworm.
218: Fall armworm larva boring into cotton stem.
219: Fall armyworm larva feeding in white bloom.
220: General view of looper feeding damage on cotton.
221: Soybean Looper on cotton leaf.

222: Soybean looper feeding on cotton leaf.
223: Soybean looper pupa on a cotton leaf.
224: Cabbage looper on cotton leaf.
225: Large soybean looper larva on cotton leaf.
226: Large cabbage looper larva on cotton leaf.
227: Soybean looper pupa on cotton leaf.
228: Soybean looper larva on cotton leaf.
229: Cotton leafworm larva with feeding damage on cotton.
230: Cotton leafworm larva and damage.
231: Cotton leafworm larva with damage.
232: Banded-winged whitefly adults and eggs on cotton.
233: Banded-winged whitefly pupae on cotton leaf.
234: Sweet potato whitefly on the underside of a cotton leaf.
235: Closeup of adults and eggs of the sweet potato whitefly.
236: Closeup of sweet potato larvae and pupae on cotton.
237: Silverleaf whitefly on cotton leaf.
238: Southern green stink bug on cotton leaf.
239: Southern green stink bug on cotton boll with feeding damage.
240: Stink bug injury to cotton boll.
241: no description
242: Wart on inside of cotton boll from stink bug injury
243: Outside boll blemish and brown lint from stink bug damage.
244: Boll rot caused by stink bug feeding.
245: Stink bug damaged boll versus normal open boll.
246: Southern green stink bug nymph and damaged boll.
247: Southern green stink bug nymph on cotton leaf.
248: Adult stink bug feeding on cotton boll.
249: Southern green stink bug adult feeding on cotton boll.
250: Stink bug damage to a 4-day old boll.
251: Dissected 4-day old boll showing internal stink bug damage.
252: no image caption
253: Pinned specimens of adult european corn borer moths.
254: European corn borer egg mass on leaf.
255: European corn borer larva in cotton stem.
256: European corn borer larva in cotton boll.
257: European corn borer larva and boll damage.
258: European corn borer damage to cotton bolls.
259: Boll weevil on cotton boll.
260: Boll weevil pupa in cotton square.
261: Cotton square punctured by boll weevil.
262: Cutworm on soil curled in C-shape.
263: Cutworm in soil at base of cotton plant.
264: Cutworm in soil at the base of cotton planted in wheat stubble.
265: Cutworm in soil with damaged cotton plant.
266: Spider mite damage to cotton leaf.
267: Spider mites on underside of cotton leaf.

268: Cotton stainer adult in a white cotton bloom.
269: Cotton stainer nymphs on rotted cotton boll.
270: Cotton stainer nymph on cotton leaf.
271: White fringed beetle grub and damage to cotton seedling.
272: White fringed beetle grub damage to cotton.
273: Closeup of white fringed beetle grub feeding damage to cotton
274: Above ground symptoms of white fringed beetle grub feeding.
275: Southern armyworm egg mass on cotton leaf.
276: Small southern armyworm larvae on cotton leaf with feeding damage.
277: Southern armyworm (early instar) on cotton leaf with damage.
278: Late instar southern armyworm on cotton leaf.
279: Several color variations of late instar southern armyworms.
280: Large southern armyworm larva on cotton leaf.
281: Southern armyworm larva on cotton leaf.
282: Small southern armyworm larvae with damage.
283: Large southern armyworm larvae showing color variations.
284: Cotton fleahopper on cotton leaf.
285: Leafminer damage to cotton leaf.
286: Leafminer damage to cotton.
287: Flea beetle and damage to cotton leaf.
288: Sugarcane beetle larva on boll in Bt cotton.
289: Sugarcane beetle on finger.
290: Cotton square borer larva and damage.
291: Tobacco budworm moth on cotton leaf. possibility of picture frames

APPENDIX B
A LIST OF WORDS APPEARING ON 291 IMAGE CAPTIONS

head	1
calyx	1
silverleaf whitefly	1
internal	1
normal	1
pinhead bollworm	1
parasitized	1
boll cutworm	1
resting	1
tubes	1
above	1
immature	1
field	1
open	1
medium	1
armyworms	1
3-day	1
girdling	1
etching	1
finger	1
planted	1
dew	1
versus	1
stubble	1
laying	1
brown stink bug	1
inside	1
several	1
cupped	1
view	1
soybean.	1
foliage	1
masses	1
disease	1
six	1
right)	1
beet	1
pinned	1
dissected	1

wart	1
boring	1
female	1
six-day	1
large yellow-striped armyworm	1
an	1
top	1
tobacco	1
rot	1
five	1
4-	1
flea	1
fall	1
outside	1
black stink bug	1
cornstalk	1
rotted	1
5-day	1
edga	1
caterpillar	1
c-shape	1
minor	1
cract	1
growth	1
plant bug	1
bolls	1
hepperburn	1
aphid	1
velvetbean	1
next	1
specimens	1
anthers	1
adventitious	1
pegs	1
wheat	1
fall armworm	1
blemish	1
sooty	1

green	1
agronomic	1
leafminer	1
thorax	1
two-day	1
grasshoppers	1
mature	1
left	1
insect	1
overview	1
sweet potato whitefly	1
cotton bollworm	1
early	1
grubs	1
general	1
profile	1
cotyledon	1
terminal	1
weevil	1
punctured	1
three-cornered alfalfa	1
mold	1
male	1
symptoms	1
root	1
through	1
borer	1
crops	1
honey	1
looping	1
fungus	1
mid-season	1
healthy	1
photgraph	1
up	1
honeydew	1
silken	1
lesser	1
soybeans	1
peg	1
flea beetle	1
yellow-striped armyworm	1
moths	2
cotton square borer	2
grasshopper	2
snowy tree cricket	2

cotton fleahopper	2
western	2
beetle	2
variations	2
cotton aphid	2
cotton aphids	2
seedling	2
sweet potato	2
injury	2
pupae	2
spider mite	2
tip	2
comparison	2
into	2
whitefly	2
6-day	2
cotton leafminer	2
beneath	2
tobacco budworm	2
late	2
behind	2
southern	2
bud	2
ground	2
blister beetle	2
lint	2
curled	2
bt	2
wireworm	2
for	2
four	2
banded-winged whitefly	2
color	2
size	2
notice	2
adults	2
cabbage looper	2
hatching	2
rednecked peanutworm	3
phase	3
showing	3
underside	3
spider mites	3
armyworm	3
bean leaf beetle	3
hopperburn	3

APPENDIX C
138 TERMS USING THE EVALUATION OF THE CROP PEST ONTOLOGY AND THE AGROVOC ONTOLOGY

adult
adult bollworm
agrotis spp.
along
Red imported fire ant
associated
attacking
base
beet armyworm
before
big-eyed bug nymph
bluish-green
boll
boll damage
boll feeding
boll rot
boll weevil
bollworm
bollworm damage
bollworm egg
bract
brown cotton
brownish
bud
bug feeding
cabbage looper
caterpillar
caused
causes
cocoon
color variation
coloration
conchuela
convergent
cotton
cotton aphid
cotton fleahopper
cotton leafperforator
cotton leafworm
cotton square
Cotton square borer
curl
cutworm
cycle
damage
damsel bug
dark
dark colored
dark spots
destruction
egg
egg mass
evidence
excrement
excreted
exit
exposed
exposed egg
fall armyworm
feeding
flared
cotton fleahopper
flimsy
foliage damage
forming
free
freshly laid bollworm
grasshopper
green
green lacewing larva
hole
honeydew
immature
inside
lady beetle
large

larva
leaf
leaf mining
leafhopper assassin bug
leafperforator
leafroller
cotton leafworm
left
life
life cycle
lint
mass
midveins
minute
growing
newly
nymph
omnivorous
pale
pink bollworm
pirate bug
plant
plant bug
puncture
pupation
red
reddening
reduced
rot
saltmarsh caterpillar
seeding
severe
showing
skeletonizing
slender
small
small larva
Sooty mold
spider mite
square
stand
stink bug
stink bug adult
cotton strainer
surface
tan moth
tarnished plant bug
tarnished plant bug adult
terminal
thrips
tobacco budworm
tobacco budworm larva
typical
underside
upward
view
white
whitefly
world
yellow
yellow-striped armyworm
yellowing

APPENDIX D
THE CROP-PEST ONTOLOGY WRITTEN IN OWL


```
<?xml version="1.0"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns:owl="http://www.w3.org/2002/07/owl#"
   xmlns="http://www.owl-ontologies.com/unnamed.owl#"
  xml:base="http://www.owl-ontologies.com/unnamed.owl" >
  <rdf:Description rdf:nodeID="A0">
    <rdf:rest rdf:nodeID="A1"/>
    <rdf:first rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:about="#supply_nutrient_to">
    <rdfs:domain rdf:resource="#soil"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <owl:inverseOf rdf:resource="#get_nutrient_from_"/>
    <rdfs:range rdf:nodeID="A2"/>
  </rdf:Description>
  <rdf:Description rdf:about="#rot">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
process or condition of decaying or a decayed area</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#damage"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#noun">
    <rdfs:subClassOf rdf:resource="#word"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">noun</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A3">
    <rdf:first rdf:resource="#cotton"/>
    <rdf:rest rdf:nodeID="A4"/>
  </rdf:Description>
  <rdf:Description rdf:about="#fall_armyworm_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">fall
armyworm on cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

```
  </rdf:Description>
  <rdf:Description rdf:about="#tobacco_thrips">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tobacco
thrips</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#thrips"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_fleahopper">
    <rdfs:subClassOf rdf:resource="#fleahopper"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
fleahopper</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#bud">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a flower
that has not yet opened</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#mining">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#damage"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
process of laying explosive mines</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A5">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#plant_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Ontology"/>
  </rdf:Description>
  <rdf:Description rdf:about="#biological_attribute">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Attributes that apply
specifically to instances of Organism</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#internal_attribute"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#flora">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">plant
group found in a particular country, region, or time</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#collection"/>
  </rdf:Description>
  <rdf:Description rdf:about="#grasshopper">
```

```
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">grasshopper</rdfs:comme
nt>
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A6">
    <owl:unionOf rdf:nodeID="A7"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#physical">
    <owl:disjointWith rdf:resource="#abstract"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a thing
that has a location in space-time. Note that locations are themselves understood to have a
location in space-time</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#tip">
    <rdfs:subClassOf rdf:resource="#part_of_organic_object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the end
of  objects</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#wart">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">growth
on plant: any abnormal growth that looks like a wart and is found on a
plant</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#abnormal_growth"/>
  </rdf:Description>
  <rdf:Description rdf:about="#brown_lint">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#damage"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">brown
lint</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#mexican_bean_beetle_grub">
    <rdfs:subClassOf rdf:resource="#beetle"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">mexican
bean beetle grub</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#looper_pupa">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#looper"/>
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">looper pupa</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#leaf">
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">any of the flat green parts that grow in various shapes from the stems or branches of plants and trees and whose main function is photosynthes</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#plant_has_parts">
    <rdfs:domain rdf:resource="#plant"/>
    <owl:inverseOf rdf:resource="#is_a_part_of_plant"/>
    <rdfs:range rdf:resource="#plant_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:subPropertyOf rdf:resource="#has_parts"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A8">
    <rdf:rest rdf:nodeID="A9"/>
    <rdf:first rdf:resource="#wheat"/>
  </rdf:Description>
  <rdf:Description rdf:about="#sweet_potato_whitefly_larva">
    <rdfs:subClassOf rdf:resource="#whitefly"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">sweet potato whitefly larva</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#preposition">
    <rdfs:subClassOf rdf:resource="#word"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a member of a set of words used in close connection with, and usually before, nouns and pronouns to show their relation to some other part of a clause. </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#finger">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">any of the digits of the hand, sometimes excluding the thumb </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#human_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A10">
    <rdf:first rdf:resource="#fungus"/>
    <rdf:rest rdf:nodeID="A11"/>
  </rdf:Description>
  <rdf:Description rdf:about="#health_attribute">
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">atribute
about organism's health</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#biological_attribute"/>
  </rdf:Description>
  <rdf:Description rdf:about="#color_variation">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">color
variation</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#variation"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#life">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
period between birth and the present time</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#time_interval"/>
  </rdf:Description>
  <rdf:Description rdf:about="#small">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">of a
relatively little size</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#size"/>
  </rdf:Description>
  <rdf:Description rdf:about="#insect_developmental_stage">
    <rdfs:subClassOf rdf:resource="#developmental_stage"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">developmental stage of
insect, usually egg,larva, pupa and adult</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#self_connected_object">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">any
Object that does not consist of two or more disconnected parts</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_element_of">
    <owl:inverseOf rdf:resource="#has_elements"/>
    <rdfs:range rdf:resource="#object"/>
    <rdfs:domain rdf:resource="#object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#content_bearing_object">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any Sel
fConnected Object that expresses information</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

```
    <rdfs:subClassOf rdf:resource="#self_connected_object"/>
  </rdf:Description>
  <rdf:Description rdf:about="#corn_earworm_moth">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">corn
earworm moth</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#corn_earworm"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#velvetbean_caterpillar_egg">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">velvetbean caterpillar
egg</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#velvetbean_caterpillar"/>
  </rdf:Description>
  <rdf:Description rdf:about="#reproductive_body">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#anatomical_structure"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Reproductive structure of
Organisms. Consists of an Embryonic Object and a nutritive/protective envelope. Note
that this class includes seeds, spores, and FruitOrVegetables, as well as the eggs produced
by Animals. </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#symptom">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">any
change in bodily function that is experienced by a patient and is associated with a
particular disease </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#phathological_process"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#pod">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the long
narrow outer case holding the seeds of a plant such as the pea, bean, or vanilla.
</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#soybean_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#fleahopper">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_aphid_with_disease">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
aphid with disease</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_aphid"/>
```

```
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#flea_beetle_on_cotton_photograph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">flea
beetle on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#agent">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Something or someone
that can act on its own and produce changes in the world</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#object"/>
  </rdf:Description>
  <rdf:Description rdf:about="#time_measure">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#constant_quantity"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">The
class of temporal durations (instances of TimeDuration) and positions of TimePoints and
TimeIntervals along the universal timeline (instances of TimePosition). </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#agronomic_crop_pest_photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">agronomic crop pest
photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#peanut_pest_photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#agronomic_crop_pest_photograph"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">pest
photograph on peanut</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#flea_beetle">
    <rdfs:subClassOf rdf:resource="#beetle"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">flea
beetle</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#stink_bug">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">stink
bug</rdfs:comment>
```

```
  </rdf:Description>
  <rdf:Description rdf:about="#honey_dew">
    <rdfs:subClassOf rdf:resource="#byproduct"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a sweet
sticky substance deposited on leaves by aphids and certain other insects as a by-product
of the juices they suck from plants</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_fleahopper_on_cotton_photograph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
fleahopper on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A12">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:datatype="http://www.w3.org/2001/XMLSchema#int">6</rdf:first>
  </rdf:Description>
  <rdf:Description rdf:about="#western_flower_thrips">
    <rdfs:subClassOf rdf:resource="#thrips"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">western
flower thrips</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#cutworm">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cutworm</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A13">
    <rdf:first rdf:resource="#fungus"/>
    <rdf:rest rdf:nodeID="A14"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A15">
    <owl:unionOf rdf:nodeID="A16"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#plant">
    <owl:disjointWith rdf:resource="#protozoan"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#bacterium"/>
    <owl:disjointWith rdf:resource="#virus"/>
    <rdfs:subClassOf rdf:resource="#organism"/>
    <owl:disjointWith rdf:resource="#fungus"/>
    <owl:disjointWith rdf:resource="#animal"/>
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">An
Organism having cellulose cell walls, growing by synthesis of Substances, generally
distinguished by the presence of chlorophyll, and lacking the power of locomotion.
</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_previous_stage_of_pupa">
    <owl:inverseOf rdf:resource="#is_a_next_stage_of_pupa"/>
    <rdfs:range rdf:nodeID="A17"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#larva"/>
  </rdf:Description>
  <rdf:Description rdf:about="#fall_armyworm_larva_boring">
    <rdfs:subClassOf rdf:resource="#boring"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">fall
armyworm larva boring</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#body_part">
    <rdfs:subClassOf rdf:resource="#anatomical_structure"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
collection of Cells and Tissues which are localized to a specific area of an Organism and
which are not pathological</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#green_cloverworm">
    <rdfs:subClassOf rdf:resource="#cloverworm"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">green
cloverworm</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#three-cornered_alfalfa_hopper">
    <rdfs:subClassOf rdf:resource="#hopper"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">three-
cornered alfalfa hopper</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#silverleaf_whitefly">
    <rdfs:subClassOf rdf:resource="#whitefly"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">silverleaf
whitefly</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#spider_mite_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
```

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    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">spider
mite on cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#abdomen">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
elongated portion of the body of an arthropod, located behind the thorax. It is usually
segmented</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#insect_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A18">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#plant_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A19">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#adult"/>
  </rdf:Description>
  <rdf:Description rdf:about="#feeding_on_plant_part">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">feeding
on plant part</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#feeding"/>
  </rdf:Description>
  <rdf:Description rdf:about="#stem_9">
    <rdf:type rdf:resource="#stem"/>
    <is_a_part_of rdf:resource="#soybean_20"/>
  </rdf:Description>
  <rdf:Description rdf:about="#boll_tip">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#tip"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">end of
cotton boll</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A20">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:unionOf rdf:nodeID="A3"/>
  </rdf:Description>
  <rdf:Description rdf:about="#southern_green_stink_bug_nymph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">southern
green stink bug nymph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#southern_green_stink_bug"/>
  </rdf:Description>
  <rdf:Description rdf:about="#animal_body_part">
```

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    <rdfs:subClassOf rdf:resource="#body_part"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">bodyPart in
animal</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_previous_stage_adult">
    <rdfs:range rdf:resource="#adult"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#pupa"/>
  </rdf:Description>
  <rdf:Description rdf:about="#phathological_process">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#internal_process"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
process which make injury or damage </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#spider_mite">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">spider
mite</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#feeding">
    <rdfs:subClassOf rdf:resource="#biological_process"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">process
of  eat something </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#boring">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#damage"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the act
of drilling</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#attribute">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Qualities which we cannot
or choose not to reify into subclasses of Object</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#abstract"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#spinalColumn">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#human_body_part"/>
```

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    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the axis
of the skeleton of a vertebrate animal, extending from the head and consisting of a series
of interconnected vertebrae that enclose and protect the spinal cord</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#plant_bug">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#color">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">The
Class of VisualAttributes relating to the color of Objects</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#visual_attribute"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_stem_borer_larva">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
stem borer larva</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#soybean_stem_borer"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_aphid_on_cotton_photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
aphid on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A21">
    <rdf:rest rdf:nodeID="A5"/>
    <rdf:first rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:about="#linguistic_expression">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#content_bearing_object"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
subclass of Content Bearing Objects which are language-related</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#head">
    <rdfs:subClassOf rdf:resource="#insect_body_part"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
topmost part of a insect body, where the brain, eyes, nose, ears, mouth, and jaws are
situated</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#sugarcane_beetle_larva">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

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    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">sugarcane beetle
larva</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#beetle"/>
  </rdf:Description>
  <rdf:Description rdf:about="#ObjectProperty_2">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#velvetbean_caterpillar_pupa">
    <rdfs:subClassOf rdf:resource="#velvetbean_caterpillar"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">velvetbean caterpillar
pupa</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#substance"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">an
image produced on light-sensitive film inside a camera or digital camera</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#physical_quantity">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
PhysicalQuantity is a measure of some quantifiable aspect of the modeled world, such as
'the earth's diameter' </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#quantity"/>
  </rdf:Description>
  <rdf:Description rdf:about="#sweet_potato_whitefly_egg">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">sweet
potato whitefly egg</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#whitefly"/>
  </rdf:Description>
  <rdf:Description rdf:about="#stink_bug_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">stink
bug on cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#beetle">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">beetle</rdfs:comment>
  </rdf:Description>
```

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  <rdf:Description rdf:nodeID="A22">
    <rdf:rest rdf:nodeID="A23"/>
    <rdf:first rdf:resource="#larva"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_part_of_human">
    <rdfs:domain rdf:resource="#human_body_part"/>
    <rdfs:range rdf:resource="#human"/>
    <rdfs:subPropertyOf rdf:resource="#is_a_part_of"/>
    <owl:inverseOf rdf:resource="#human_has_parts"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#peanut">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a low-
growing annual plant of the legume family whose seeds are contained in pods that are
forced underground as they grow.</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#plant"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A24">
    <rdf:rest rdf:nodeID="A25"/>
    <rdf:first rdf:resource="#bacterium"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A26">
    <rdf:first rdf:resource="#larva"/>
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
  </rdf:Description>
  <rdf:Description rdf:about="#animal">
    <rdfs:subClassOf rdf:resource="#organism"/>
    <owl:disjointWith rdf:resource="#protozoan"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#bacterium"/>
    <owl:disjointWith rdf:resource="#fungus"/>
    <owl:disjointWith rdf:resource="#virus"/>
    <owl:disjointWith rdf:resource="#plant"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">An
Organism with eukaryotic Cells, and lacking stiff cell walls, plastids, and photosynthetic
pigments.</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#anatomical_structure">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
normal or pathological part of the anatomy or structural organization of an Organism.
This class covers BodyParts, as well as structures that are given off by Organisms, e.g.
ReproductiveBodies</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#organic_object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
```

```
  <rdf:Description rdf:nodeID="A27">
    <rdf:rest rdf:nodeID="A10"/>
    <rdf:first rdf:resource="#virus"/>
  </rdf:Description>
  <rdf:Description rdf:about="#thrips_on_cotton_photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">thrips
on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bud_7">
    <rdf:type rdf:resource="#bud"/>
    <is_a_part_of rdf:resource="#soybean_20"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_one_of_life_cycle_of_insect">
    <rdfs:subPropertyOf rdf:resource="#is_one_of_lifecycle"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_body_part">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">body
part in cotton</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#green_cloverworm_larva">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">green
cloverworm larva</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#green_cloverworm"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A28">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#egg"/>
  </rdf:Description>
  <rdf:Description rdf:about="#object">
    <rdfs:subClassOf rdf:resource="#physical"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Corresponds roughly to
the class of ordinary objects. Examples include normal physical objects, geographical
regions, and locations of Processes, the complement of Objects in the Physical
class</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#process"/>
  </rdf:Description>
  <rdf:Description rdf:about="#pest_photograph">
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    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">photograph about
insects</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#digital_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#human_body_part">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">human
body part</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#animal_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#perceptual_attribute">
    <rdfs:subClassOf rdf:resource="#internal_attribute"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
Attribute whose presence is detected by an act of Perception. </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A29">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:unionOf rdf:nodeID="A30"/>
  </rdf:Description>
  <rdf:Description rdf:about="#developmental_process">
    <rdfs:subClassOf rdf:resource="#biological_process"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">process
of the process of developing, developing something, or of being developed, for example,
by growth or metamorphosis </rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A31">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#fungus"/>
  </rdf:Description>
  <rdf:Description rdf:about="#european_corn_borer_moth">
    <rdfs:subClassOf rdf:resource="#european_corn_borer"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">european corn borer
moth</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A32">
    <rdf:rest rdf:nodeID="A19"/>
    <rdf:first rdf:resource="#pupa"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A33">
    <rdf:rest rdf:nodeID="A34"/>
```

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    <rdf:first rdf:resource="#bacterium"/>
  </rdf:Description>
  <rdf:Description rdf:about="#tag">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">body
part of the bottom of bloom in cotton</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#developmental_stage">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">developmental
stage</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#phase"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bt_cotton">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
which has Bt toxins for insect tolerance</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton"/>
  </rdf:Description>
  <rdf:Description rdf:about="#large">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#size"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">comparatively big in size,
number, or quantity, or bigger in size, number, or quantity than is usual or
expected</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#early_phase">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">early
phase</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#developmental_stage"/>
  </rdf:Description>
  <rdf:Description rdf:about="#content-based_quantity">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">quantity
which are based on content such as </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#quantity"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A35">
    <rdf:rest rdf:nodeID="A22"/>
    <rdf:first rdf:resource="#egg"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_element_of_crop">
```

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    <rdfs:range rdf:resource="#crop"/>
    <rdfs:domain rdf:nodeID="A20"/>
    <owl:inverseOf rdf:resource="#has_elements_of_plant"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:subPropertyOf rdf:resource="#is_a_element_of"/>
  </rdf:Description>
  <rdf:Description rdf:about="#adverb">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a word
that modifies a verb, an adjective, another adverb, or a sentence, for example, ?happily,?
?very,? or ?frankly?</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#word"/>
  </rdf:Description>
  <rdf:Description rdf:about="#fungus_disease">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">disease
caused by fungus</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#disease"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#brightness">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
intensity of light reflected or given off by something</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#visual_attribute"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A9">
    <rdf:first rdf:resource="#peanut"/>
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
  </rdf:Description>
  <rdf:Description rdf:about="#foliage">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
leaves of a plant or tree</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#collection"/>
  </rdf:Description>
  <rdf:Description rdf:about="#hatching">
    <rdfs:subClassOf rdf:resource="#developmental_process"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
developnental process to cause a young organism in insect  to emerge from its
egg</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#egg">
    <owl:disjointWith rdf:resource="#larva"/>
    <owl:disjointWith rdf:resource="#pupa"/>
    <owl:disjointWith rdf:resource="#adult"/>
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    <rdfs:subClassOf rdf:resource="#insect_life_cycle"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#human_has_parts">
    <owl:inverseOf rdf:resource="#is_a_part_of_human"/>
    <rdfs:range rdf:resource="#human_body_part"/>
    <rdfs:domain rdf:resource="#human"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:subPropertyOf rdf:resource="#has_parts"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A16">
    <rdf:rest rdf:nodeID="A18"/>
    <rdf:first rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:about="#white_fringed_beetle">
    <rdfs:subClassOf rdf:resource="#beetle"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">white
fringed beetle</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#boll_weevil_on_cotton_photograph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">boll
weebil on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#base">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
bottom or lowest part</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#part_of_organic_object"/>
  </rdf:Description>
  <rdf:Description rdf:about="#worm">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
  </rdf:Description>
  <rdf:Description rdf:about="#white_fringed_beetle_on_cotton_photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">white
fringed beetle on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#internal_process">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Processes which involve
altering an internal property of an Object, e.g. the shape of the Object, its coloring, its
structure, etc. Processes that are not instances of this class include changes that only
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affect the relationship to other objects, e.g. changes in spatial or temporal location.
</rdfs:comment>
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
<rdfs:subClassOf rdf:resource="#process"/>
</rdf:Description>
<rdf:Description rdf:about="#cutworm_on_peanut_photograph">
<rdfs:subClassOf rdf:resource="#peanut_pest_photograph"/>
<rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cutworm on peanut
photograph</rdfs:comment>
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
</rdf:Description>
<rdf:Description rdf:about="#tarnished_plant_bug_egg">
<rdfs:subClassOf rdf:resource="#hopper"/>
<rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tarnished plant bug
egg</rdfs:comment>
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
</rdf:Description>
<rdf:Description rdf:about="#top">
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
<rdfs:subClassOf rdf:resource="#part_of_organic_object"/>
<rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
highest part or point </rdfs:comment>
</rdf:Description>
<rdf:Description rdf:about="#variation">
<rdfs:subClassOf rdf:resource="#organic_object"/>
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
<rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">living
organism that differs: a living organism that differs from the normal form for its
kind</rdfs:comment>
</rdf:Description>
<rdf:Description rdf:about="#view">
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
<rdfs:subClassOf rdf:resource="#internal_process"/>
<rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">inspecting something
</rdfs:comment>
</rdf:Description>
<rdf:Description rdf:about="#brown_stink_bug">
<rdfs:subClassOf rdf:resource="#stink_bug"/>
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
<rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">brown
stink bug</rdfs:comment>
</rdf:Description>
<rdf:Description rdf:about="#earworm">

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    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#byproduct">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">something produced as a
secondary result of production of something else</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#artifact"/>
  </rdf:Description>
  <rdf:Description rdf:about="#tobacco_budworm_on_cotton_photograph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tobacco
budworm on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#objectProperty_34">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bacterium">
    <owl:disjointWith rdf:resource="#fungus"/>
    <owl:disjointWith rdf:resource="#virus"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"> a
single-celled, often parasitic microorganism without distinct nuclei or organized cell
structures. Various species are responsible for decay, fermentation, nitrogen fixation, and
many plant and animal diseases.</rdfs:comment>
    <owl:disjointWith rdf:resource="#protozoan"/>
    <rdfs:subClassOf rdf:resource="#organism"/>
    <owl:disjointWith rdf:resource="#animal"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:about="#support_to_stand_up_">
    <rdfs:domain rdf:resource="#soil"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:range rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_host_of">
    <rdfs:domain rdf:resource="#plant"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:range rdf:nodeID="A36"/>
    <owl:inverseOf rdf:resource="#is_pest_of"/>
  </rdf:Description>
  <rdf:Description rdf:about="#arthropod">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
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    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">an
invertebrate animal that has jointed limbs, a segmented body, and an exoskeleton made of
chit</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#invertebrate"/>
  </rdf:Description>
  <rdf:Description rdf:about="#substance">
    <rdfs:subClassOf rdf:resource="#self_connected_object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">An
Object in which every part is similar to every other in every relevant respect. More
precisely, something is a Substance when it has only arbitrary pieces as parts - any parts
have properties which are similar to those of the whole. Note that a Substance may
nonetheless have physical properties that vary. For example, the temperature, chemical
constitution, density, etc. may change from one part to another. An example would be a
body of water. </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#biological_process">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
Process embodied in an Organism</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#internal_process"/>
  </rdf:Description>
  <rdf:Description rdf:about="#wheat">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">an
annual grass, native to southwestern Asia and the Mediterranean, some types of which
are widely cultivated in temperate regions for their edible grains. The numerous varieties
of cultivated wheat are based on three main species: bread wheat, durum or hard wheat,
and emmer. Genus Triticum.</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:about="#appears_on">
    <rdfs:range rdf:nodeID="A37"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#phathological_process"/>
  </rdf:Description>
  <rdf:Description rdf:about="#leaf_8">
    <is_a_part_of rdf:resource="#soybean_20"/>
    <rdf:type rdf:resource="#leaf"/>
  </rdf:Description>
  <rdf:Description rdf:about="#larva">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#egg"/>
    <owl:disjointWith rdf:resource="#adult"/>
    <rdfs:subClassOf rdf:resource="#insect_life_cycle"/>
    <owl:disjointWith rdf:resource="#pupa"/>
```

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  </rdf:Description>
  <rdf:Description rdf:about="#visual_attribute">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">The
Class of visually discernible properties</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#perceptual_attribute"/>
  </rdf:Description>
  <rdf:Description rdf:about="#stink_bug_feeding">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">feeding
caused by stink bug</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#feeding_caused_by_pest"/>
  </rdf:Description>
  <rdf:Description rdf:about="#vertebrate">
    <rdfs:subClassOf rdf:resource="#animal"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">An
Animal which has a spinal column. </rdfs:comment>
    <owl:disjointWith rdf:resource="#invertebrate"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_body_part">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
body part</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#process">
    <rdfs:subClassOf rdf:resource="#physical"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">anything
that lasts for a time but is not an Object</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#object"/>
  </rdf:Description>
  <rdf:Description rdf:about="#feeding_caused_by_pest">
    <rdfs:subClassOf rdf:resource="#feeding"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">feeding
caused by pest</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#life_cycle">
    <rdfs:subClassOf rdf:resource="#biological_process"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
series of changes of form and activity that a living organism undergoes from its
beginning through its development to sexual maturity</rdfs:comment>
  </rdf:Description>
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  <rdf:Description rdf:about="#plant_body_part">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">body
part of plant</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#stem">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the main
axis of a plant that bears buds and shoots. It is usually above ground, although some
plants have underground stems </rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A38">
    <rdf:first rdf:resource="#soybean"/>
    <rdf:rest rdf:nodeID="A39"/>
  </rdf:Description>
  <rdf:Description rdf:about="#green_stink_bug">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">green
stink bug</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#stink_bug"/>
  </rdf:Description>
  <rdf:Description rdf:about="#looper_on_cotton_photograph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">looper
on cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#positional_attribute">
    <rdfs:subClassOf rdf:resource="#internal_attribute"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Attributes characterizing
the orientation  or position of an Object</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#integer">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
negative or nonnegative whole number.</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#rational_number"/>
  </rdf:Description>
  <rdf:Description rdf:about="#object_10">
    <rdf:type rdf:resource="#object"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bollworm_on_cotton_photograph">
```

```
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">bollworm on cotton
photograph</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A40">
    <rdf:first rdf:resource="#larva"/>
    <rdf:rest rdf:nodeID="A28"/>
  </rdf:Description>
  <rdf:Description rdf:about="#size">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
amount, scope, or degree of something, in terms of how large or small it
is</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#internal_attribute"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#has_elements">
    <rdfs:domain rdf:resource="#object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:range rdf:resource="#object"/>
    <owl:inverseOf rdf:resource="#is_a_element_of"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bloom">
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
flower, especially on a plant cultivated chiefly for its flowers</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#anther_5">
    <rdf:type rdf:resource="#anther"/>
  </rdf:Description>
  <rdf:Description rdf:about="#square">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">square
in cotton</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#cotton_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#corn_earworm">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">corn
earworm</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#earworm"/>
  </rdf:Description>
  <rdf:Description rdf:about="#puncture">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">to
sustain or cause a small hole or wound in something such as the skin</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#damage"/>
  </rdf:Description>
  <rdf:Description rdf:about="#create_process_to">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#agent"/>
    <rdfs:range rdf:resource="#physical"/>
  </rdf:Description>
  <rdf:Description rdf:about="#damage">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">injury or
harm from agent </rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#phathological_process"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A41">
    <rdf:first rdf:resource="#plant"/>
    <rdf:rest rdf:nodeID="A33"/>
  </rdf:Description>
  <rdf:Description rdf:about="#beet_armyworm_feeding">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">beet
armyworm feeding</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#feeding_caused_by_pest"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#feeding_damage">
    <rdfs:subClassOf rdf:resource="#damage"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">feeding
damage</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#sugarcane_beetle_on_cotton_photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">sugarcane beetle on cotton
photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#european_corn_borer">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#borer"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">european corn
borer</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#cloverworm">
```

```
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#mexican_bean_beetle_egg">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#beetle"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">mexican
bean beetle egg</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A42">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:unionOf rdf:nodeID="A43"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A23">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#pupa"/>
  </rdf:Description>
  <rdf:Description rdf:about="#fall_armyworm_feeding">
    <rdfs:subClassOf rdf:resource="#feeding_caused_by_pest"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">fall
armyworm feeding</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A44">
    <rdf:first rdf:resource="#protozoan"/>
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
  </rdf:Description>
  <rdf:Description rdf:about="#insect">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">small
Arthropods that are air-breathing and that are distinguished by appearance.
</rdfs:comment>
    <rdfs:subClassOf rdf:nodeID="A45"/>
    <rdfs:subClassOf rdf:resource="#arthropod"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_part_of">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#body_part"/>
    <owl:inverseOf rdf:resource="#has_parts"/>
    <rdfs:range rdf:resource="#organism"/>
  </rdf:Description>
  <rdf:Description rdf:about="#internal_attribute">
    <rdfs:subClassOf rdf:resource="#attribute"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
Attribute of an Entity that is an internal property of the Entity, e.g. its shape, its color, its
fragility, etc. </rdfs:comment>
```

```
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#locate_place">
    <rdfs:domain rdf:resource="#physical"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#boolean"/>
  </rdf:Description>
  <rdf:Description rdf:about="#collection">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Collections have
members.They have a position in space-time and members can be added and subtracted
without thereby changing the identity of the Collection. Some examples are toolkits,
football teams, and flocks of sheep. </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#object"/>
  </rdf:Description>
  <rdf:Description rdf:about="#closeup">
    <rdfs:subClassOf rdf:resource="#view"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
detailed view or examination of something</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#stainer">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:about="#age_attribute">
    <rdfs:subClassOf rdf:resource="#biological_attribute"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">attribute
of organism's age</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#time_duration">
    <rdfs:subClassOf rdf:resource="#time_measure"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
measure of length of time, with or without respect to the universal
timeline</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#disease">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
process that alters or interferes with a normal process, state or activity of an
Organism</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#phathological_process"/>
  </rdf:Description>
```

```
  <rdf:Description rdf:about="#soybean_looper_pupa">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
looper pupa</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#looper_pupa"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A34">
    <rdf:first rdf:resource="#fungus"/>
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
  </rdf:Description>
  <rdf:Description rdf:about="#the_number_of_legs">
    <rdfs:domain rdf:resource="#insect"/>
    <rdfs:range rdf:nodeID="A46"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#pod_4">
    <is_a_part_of rdf:resource="#soybean_20"/>
    <rdf:type rdf:resource="#pod"/>
  </rdf:Description>
  <rdf:Description rdf:about="#snowy_tree_cricket">
    <rdfs:subClassOf rdf:resource="#cricket"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">snowy
tree cricket</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A47">
    <rdf:rest rdf:nodeID="A8"/>
    <rdf:first rdf:resource="#cotton"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A36">
    <owl:unionOf rdf:nodeID="A0"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_20">
    <is_damaged_by rdf:resource="#yellow_striped_armyworm_16"/>
    <has_parts rdf:resource="#bloom_6"/>
    <has_parts rdf:resource="#pod_4"/>
    <locate_in_time
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</locate_in_time>
    <has_parts rdf:resource="#bud_7"/>
    <has_parts rdf:resource="#leaf_8"/>
    <locate_place
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</locate_place>
    <has_parts rdf:resource="#stem_9"/>
    <rdf:type rdf:resource="#soybean"/>
    <is_host_of rdf:resource="#yellow_striped_armyworm_16"/>
```

```
  </rdf:Description>
  <rdf:Description rdf:about="#is_pest_of">
    <rdfs:domain rdf:nodeID="A48"/>
    <rdfs:range rdf:resource="#plant"/>
    <owl:inverseOf rdf:resource="#is_host_of"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#blister_beetle">
    <rdfs:subClassOf rdf:resource="#beetle"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">blister
beetle</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#phase">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a clearly
distinguishable period or stage in a process, in the development of something, or in a
sequence of events</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#time_interval"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#insect_body_part">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#body_part"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">body
part of insect</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#borer">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">borer</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A49">
    <owl:unionOf rdf:nodeID="A21"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#real_number">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#number"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
Number that can be expressed as a (possibly infinite) decimal</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#tobacco_budworm_moth">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tobacco
budworm moth</rdfs:comment>
```

```
    <rdfs:subClassOf rdf:resource="#tobacco_budworm"/>
  </rdf:Description>
  <rdf:Description rdf:about="#european_corn_borer_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">european corn borer on
cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#egg_19">
    <locate_place
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</locate_place>
    <is_a_previous_stage_of_larva rdf:resource="#egg_19"/>
    <locate_in_time
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</locate_in_time>
    <rdf:type rdf:resource="#egg"/>
    <is_a_next_stage_of_larva rdf:resource="#egg_19"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A7">
    <rdf:first rdf:resource="#soybean"/>
    <rdf:rest rdf:nodeID="A47"/>
  </rdf:Description>
  <rdf:Description rdf:about="#leafworm">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#make_damage_to">
    <owl:inverseOf rdf:resource="#is_damaged_by"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:range rdf:nodeID="A15"/>
    <rdfs:domain rdf:resource="#agent"/>
  </rdf:Description>
  <rdf:Description rdf:about="#locate_in_time">
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#boolean"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
    <rdfs:domain rdf:resource="#physical"/>
  </rdf:Description>
  <rdf:Description rdf:about="#dark_phase">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">dark
phase</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#developmental_stage"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#calyx">
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
group of sepals, usually green, around the outside of a flower that encloses and protects
the flower bud</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#relational_attribute">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#attribute"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
Attribute that an Entity has by virtue of a relationship that it bears to another Entity or set
of Entities</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_stainer_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
stainer on cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#protozoan">
    <owl:disjointWith rdf:resource="#fungus"/>
    <owl:disjointWith rdf:resource="#plant"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#virus"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a single-
celled organism such as an amoeba that can move and feeds on organic compounds of
nitrogen and carbon.</rdfs:comment>
    <owl:disjointWith rdf:resource="#animal"/>
    <owl:disjointWith rdf:resource="#bacterium"/>
    <rdfs:subClassOf rdf:resource="#organism"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A11">
    <rdf:rest rdf:nodeID="A44"/>
    <rdf:first rdf:resource="#bacterium"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_stem_borer_egg">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#soybean_stem_borer"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
stem borer egg</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_previous_stage_of_larva">
    <owl:inverseOf rdf:resource="#is_a_next_stage_of_larva"/>
    <rdfs:range rdf:resource="#egg"/>
    <rdfs:domain rdf:nodeID="A50"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
```

```
  </rdf:Description>
  <rdf:Description rdf:about="#soybean">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
southeastern Asian plant cultivated around the world for its nutritious seeds, for soil
improvement, and to provide grazing for animals</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#plant"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#abnormal_growth">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">abnormal
growth</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#phathological_process"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#objectProperty_44">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#corpuscular_object">
    <rdfs:subClassOf rdf:resource="#self_connected_object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
SelfConnectedObject whose parts have properties that are not shared by the
whole</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#instar">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">in the
life cycle of an arthropod such as an insect, a stage between two successive
molts</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#time_interval"/>
  </rdf:Description>
  <rdf:Description rdf:about="#rational_number">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
RealNumber that is the product of dividing two Integers</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#real_number"/>
  </rdf:Description>
  <rdf:Description rdf:about="#tarnished_plant_bug_nymph">
    <rdfs:subClassOf rdf:resource="#hopper"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tarnished plant bug
nymph</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A51">
```

```
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#protozoan"/>
  </rdf:Description>
  <rdf:Description rdf:about="#tobacco_budworm">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tobacco
budworm</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#budworm"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#has_elements_of_plant">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#crop"/>
    <owl:inverseOf rdf:resource="#is_a_element_of_crop"/>
    <rdfs:subPropertyOf rdf:resource="#has_elements"/>
    <rdfs:range rdf:nodeID="A6"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A2">
    <owl:unionOf rdf:nodeID="A24"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#sugarcane_beetle">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">sugarcane
beetle</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#beetle"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A45">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Restriction"/>
    <owl:onProperty rdf:resource="#the_number_of_legs"/>
    <owl:hasValue
rdf:datatype="http://www.w3.org/2001/XMLSchema#int">6</owl:hasValue>
  </rdf:Description>
  <rdf:Description rdf:about="#CropPestOntology.rdf-xml_Class_9">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect_developmental_stage"/>
  </rdf:Description>
  <rdf:Description rdf:about="#get_nutrient_from_">
    <rdfs:domain rdf:nodeID="A52"/>
    <owl:inverseOf rdf:resource="#supply_nutrient_to"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:range rdf:resource="#soil"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_looper">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
looper</rdfs:comment>
```

```
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#looper"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cricket">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:about="#objectProperty_38">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bollworm_feeding">
    <rdfs:subClassOf rdf:resource="#feeding_caused_by_pest"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">feeding
caused by bollworm</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#insect_age">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
length of time that insect has existed, usually expressed in days</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#age"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#shape">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
outline of something?s form</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#visual_attribute"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_leafworm_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
leafworm on cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#environmental_object">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">object
which consists of environment</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#object"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cocoon">
    <rdfs:subClassOf rdf:resource="#insect_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the silky
covering with which a caterpillar or other insect larva encloses itself during its transition
to an adult state</rdfs:comment>
```

```
  </rdf:Description>
  <rdf:Description rdf:about="#stink_bug_egg">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">stink
bug egg</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#stink_bug"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#time_position">
    <rdfs:subClassOf rdf:resource="#time_measure"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
TimePoint or TimeInterval along the universal timeline from NegativeInfinity to
PositiveInfinity</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#has_developmental_stage_of">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#insect"/>
    <rdfs:range rdf:nodeID="A29"/>
  </rdf:Description>
  <rdf:Description rdf:about="#blemish">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#damage"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a mark
or imperfection that spoils the appearance of something</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#aphid">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#green_cloverworm_moth">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">green
cloverworm moth</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#green_cloverworm"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A14">
    <rdf:first rdf:resource="#bacterium"/>
    <rdf:rest rdf:nodeID="A51"/>
  </rdf:Description>
  <rdf:Description rdf:about="#head_18">
    <is_a_part_of_insect rdf:resource="#yellow_striped_armyworm_16"/>
    <rdf:type rdf:resource="#head"/>
  </rdf:Description>
  <rdf:Description rdf:about="#age">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
length of time that somebody or something has existed</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#constant_quantity"/>
  </rdf:Description>
  <rdf:Description rdf:about="#insect_has_parts_">
    <rdfs:range rdf:resource="#insect_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:subPropertyOf rdf:resource="#has_parts"/>
    <owl:inverseOf rdf:resource="#is_a_part_of_insect"/>
    <rdfs:domain rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A17">
    <owl:unionOf rdf:nodeID="A32"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#yellow_striped_armyworm">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">yellow
striped armyworm</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#armyworm"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cabbage_looper">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#looper"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cabbage
looper</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#black_stink_bug">
    <rdfs:subClassOf rdf:resource="#stink_bug"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">black
stink bug</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#banded-winged_whitefly_egg">
    <rdfs:subClassOf rdf:resource="#banded-winged_whitefly"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">banded-
winged whitefly egg</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#non-organism_pest">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">pest
which is not an organism such as virus and prion</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#organism"/>
    <rdfs:subClassOf rdf:resource="#pest"/>
    <rdfs:subClassOf rdf:nodeID="A53"/>
```

```
  </rdf:Description>
  <rdf:Description rdf:about="#yellow_striped_armyworm_16">
    <insect_has_parts_ rdf:resource="#head_18"/>
    <locate_place
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</locate_place>
    <locate_in_time
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</locate_in_time>
    <has_developmental_stage_of rdf:resource="#larva_17"/>
    <make_damage_to rdf:resource="#soybean_20"/>
    <is_pest_of rdf:resource="#soybean_20"/>
    <rdf:type rdf:resource="#yellow_striped_armyworm"/>
  </rdf:Description>
  <rdf:Description rdf:about="#velvetbean_caterpillar_moth">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#velvetbean_caterpillar"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">velvetbean caterpillar
moth</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#budworm">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#abstract">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#physical"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Properties or qualities as
distinguished from any particular embodiment of the properties/qualities in a physical
medium. Instances of Abstract can be said to exist in the same sense as mathematical
objects such as sets and relations, but they cannot exist at a particular place and time
without some physical encoding or embodiment</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_square_borer_on_cotton_photograph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
square borer on cotton photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#etching">
    <rdfs:subClassOf rdf:resource="#biological_process"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the act
of etching</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_pest_photograph">
```

```
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#agronomic_crop_pest_photograph"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">pest
photograph on soybean</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_stem_borer">
    <rdfs:subClassOf rdf:resource="#borer"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
stem borer</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A39">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#wheat"/>
  </rdf:Description>
  <rdf:Description rdf:about="#has_parts">
    <rdfs:range rdf:resource="#body_part"/>
    <rdfs:domain rdf:resource="#organism"/>
    <owl:inverseOf rdf:resource="#is_a_part_of"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A48">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:unionOf rdf:nodeID="A54"/>
  </rdf:Description>
  <rdf:Description rdf:about="#number">
    <rdfs:subClassOf rdf:resource="#quantity"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
measure of how many things there are, or how much there is, of a certain kind. Numbers
are subclassed into RealNumber, ComplexNumber, and ImaginaryNumber.
</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_part_of_insect">
    <owl:inverseOf rdf:resource="#insect_has_parts_"/>
    <rdfs:domain rdf:resource="#insect_body_part"/>
    <rdfs:range rdf:resource="#insect"/>
    <rdfs:subPropertyOf rdf:resource="#is_a_part_of"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#virus">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">An non-
Organism consisting of a core of a single nucleic acid enclosed in a protective coat of
protein. A virus may replicate only inside a host living cell. A virus exhibits some but not
all of the usual characteristics of living things. </rdfs:comment>
    <owl:disjointWith rdf:resource="#animal"/>
```

```
    <rdfs:subClassOf rdf:resource="#non-organism_pest"/>
    <owl:disjointWith rdf:resource="#fungus"/>
    <owl:disjointWith rdf:resource="#bacterium"/>
    <owl:disjointWith rdf:resource="#protozoan"/>
    <owl:disjointWith rdf:resource="#plant"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#european_corn_borer_larva">
    <rdfs:subClassOf rdf:resource="#european_corn_borer"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">european corn borer
larva</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_aphid">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
aphid</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#aphid"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cycle">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
sequence of events that is repeated again and again, especially a causal
sequence</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#internal_process"/>
  </rdf:Description>
  <rdf:Description rdf:about="#southern_armyworm_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">southern
armyworm on cotton photograph</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#whitefly">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">whitefly</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A54">
    <rdf:first rdf:resource="#insect"/>
    <rdf:rest rdf:nodeID="A27"/>
  </rdf:Description>
  <rdf:Description rdf:about="#insect_life_cycle">
    <rdfs:subClassOf rdf:resource="#life_cycle"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">egg-
larva-pupa-adult
</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#cutworm_on_cotton_photograph">
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cutworm on cotton
photograph</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#three-cornered_alfalfa_hopper_egg">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#three-cornered_alfalfa_hopper"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">three-
cornered alfalfa egg</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#anther">
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a male
flower part, the top part of a stamen, that bears the pollen in pollen sacs.
</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#feeding_on_cotton_body_part">
    <rdfs:subClassOf rdf:resource="#feeding_on_plant_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">feeding
on cotton body part</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A52">
    <owl:unionOf rdf:nodeID="A41"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A55">
    <owl:unionOf rdf:nodeID="A56"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#organic_object">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"> objects
which encompass Organisms and CorpuscularObjects that are parts of
Organisms</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#corpuscular_object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#banded-winged_whitefly">
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">banded-
winged whitefly</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#whitefly"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A1">
    <rdf:first rdf:resource="#virus"/>
    <rdf:rest rdf:nodeID="A13"/>
  </rdf:Description>
  <rdf:Description rdf:about="#three-cornered_alfalfa_hopper_nymph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">three-
cornered alfalfa nymph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#three-cornered_alfalfa_hopper"/>
  </rdf:Description>
  <rdf:Description rdf:about="#invertebrate">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">An
Animal which has no spinal column</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#animal"/>
    <owl:disjointWith rdf:resource="#vertebrate"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#leafminer">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">leafminer</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#armyworm">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">armyworm</rdfs:comment
>
    <rdfs:subClassOf rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:about="#banded-winged_whitefly_larva">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">banded-
winged whitefly larva</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#banded-winged_whitefly"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_stem_borer_pupa">
    <rdfs:subClassOf rdf:resource="#soybean_stem_borer"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
stem borer pupa</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

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  </rdf:Description>
  <rdf:Description rdf:about="#bollworm_egg">
    <rdfs:subClassOf rdf:resource="#bollworm"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">bollworm
egg</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A56">
    <rdf:rest rdf:nodeID="A26"/>
    <rdf:first rdf:resource="#egg"/>
  </rdf:Description>
  <rdf:Description rdf:about="#time_interval">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#time_position"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">An
interval of time</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#corn_earworm_on_peanut_photograph">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">corn
earworm on peanut photograph</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#peanut_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#hopper">
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tarnished plant
bug</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#sweet_potato_whitefly">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#whitefly"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">sweet
potato whitefly</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#boll">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
rounded seedpod or capsule, especially of cotton</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#ground">
    <rdfs:subClassOf rdf:resource="#environmental_object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
surface of the land (soil)</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A25">
    <rdf:first rdf:resource="#plant"/>
    <rdf:rest rdf:nodeID="A31"/>
  </rdf:Description>
  <rdf:Description rdf:about="#tarnished_plant_bug_on_cotton_photograph">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">tarnished plant bug on
cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#medium">
    <rdfs:subClassOf rdf:resource="#size"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">of
middling size or dimensions, neither large nor small</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#part_of_organic_object">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">iundicate part of orgranic
object which is not anatomic structure i.e. edge and base</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#organic_object"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#adult">
    <owl:disjointWith rdf:resource="#larva"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect_life_cycle"/>
    <owl:disjointWith rdf:resource="#pupa"/>
    <owl:disjointWith rdf:resource="#egg"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_damaged_by">
    <owl:inverseOf rdf:resource="#make_damage_to"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:range rdf:resource="#agent"/>
    <rdfs:domain rdf:nodeID="A49"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A53">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:complementOf rdf:resource="#organism"/>
  </rdf:Description>
  <rdf:Description rdf:about="#human">
    <rdfs:subClassOf rdf:resource="#vertebrate"/>
```

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    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
tropical or subtropical bush producing soft white downy fibers and oil-rich
</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bract">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
modified leaf that arises from the stem at the point where the flower or flower cluster
develops in cotton</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#DatatypeProperty_3">
    <rdfs:domain rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#organism">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a living
thing such as a plant, animal, or bacterium</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#organic_object"/>
    <rdfs:subClassOf rdf:resource="#pest"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#non-organism_pest"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bloom_6">
    <rdf:type rdf:resource="#bloom"/>
    <is_a_part_of rdf:resource="#soybean_20"/>
  </rdf:Description>
  <rdf:Description rdf:about="#has_elements_of_egg_mass">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#egg_mass"/>
    <rdfs:subPropertyOf rdf:resource="#has_elements"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A57">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#plant_body_part"/>
  </rdf:Description>
  <rdf:Description rdf:about="#stink_bug_nymph">
    <rdfs:subClassOf rdf:resource="#stink_bug"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">stink
bug nymph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
```

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  </rdf:Description>
  <rdf:Description rdf:about="#word">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A term
of a Language that represents a concept</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#linguistic_expression"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_stainer_nymph">
    <rdfs:subClassOf rdf:resource="#cotton_stainer"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton
stainer nymph</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_pest_photograph">
    <rdfs:subClassOf rdf:resource="#agronomic_crop_pest_photograph"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">pest
photograph on cotton</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#artifact">
    <rdfs:subClassOf rdf:resource="#corpuscular_object"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
product of a Making by organism</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#appears_on_insect">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:about="#plant_body_part_etching">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">etching
on plant body part</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#etching"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#pupation">
    <rdfs:subClassOf rdf:resource="#developmental_process"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
process to develop from a larva into a pupa</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A30">
    <rdf:first rdf:resource="#adult"/>
    <rdf:rest rdf:nodeID="A35"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A50">
    <owl:unionOf rdf:nodeID="A40"/>
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    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#thrips">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">thrips</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_one_of_lifecycle">
    <rdfs:domain rdf:resource="#life_cycle"/>
    <rdfs:range rdf:resource="#organism"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A46">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DataRange"/>
    <owl:oneOf rdf:nodeID="A12"/>
  </rdf:Description>
  <rdf:Description rdf:about="#quantity">
    <rdfs:subClassOf rdf:resource="#abstract"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Any
specification of how many or how much of something there is. </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#soybean_stem_borer_adult">
    <rdfs:subClassOf rdf:resource="#soybean_stem_borer"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">soybean
stem borer adult</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bollworm">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">bollworm</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#southern_green_stink_bug">
    <rdfs:subClassOf rdf:resource="#stink_bug"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">southern
green stink bug</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#specimen">
    <rdfs:subClassOf rdf:resource="#artifact"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">something that is
```

representative because it is typical of its kind or of a whole, especially something that serves as an example </rdfs:comment>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
 </rdf:Description>
 <rdf:Description rdf:about="#boll_weevil_pupa">
  <rdfs:subClassOf rdf:resource="#boll_weevil"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">boll weevil pupa</rdfs:comment>
 </rdf:Description>
 <rdf:Description rdf:about="#cotton_stainer">
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  <rdfs:subClassOf rdf:resource="#stainer"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">cotton stainer</rdfs:comment>
 </rdf:Description>
 <rdf:Description rdf:about="#european_corn_borer_egg">
  <rdfs:subClassOf rdf:resource="#european_corn_borer"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">european corn borer egg</rdfs:comment>
 </rdf:Description>
 <rdf:Description rdf:about="#cotyledon">
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  <rdfs:subClassOf rdf:resource="#plant_body_part"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the first leaf, or one of the first pair of leaves, produced by the seed of a flowering plant. They may serve as food stores, remaining in the seed at germination, or produce food by photosynthesis. </rdfs:comment>
 </rdf:Description>
 <rdf:Description rdf:about="#is_a_next_stage_of_pupa">
  <rdfs:range rdf:resource="#larva"/>
  <owl:inverseOf rdf:resource="#is_a_previous_stage_of_pupa"/>
  <rdfs:domain rdf:nodeID="A42"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
 </rdf:Description>
 <rdf:Description rdf:about="#bean_leaf_beetle">
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  <rdfs:subClassOf rdf:resource="#beetle_adult"/>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">bean leaf beetle</rdfs:comment>
 </rdf:Description>
 <rdf:Description rdf:about="#crop">
  <rdfs:subClassOf rdf:resource="#collection"/>

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    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">any
group of plants grown by people for food or other use</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#white_fringed_beetle_grub">
    <rdfs:subClassOf rdf:resource="#beetle"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">white
fringed beetle grub</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#stubble">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">short
stalks left in the ground after a grain crop has been harvested</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#plant_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#soil">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#environmental_object"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the top
layer of most of the earth?s land surface, consisting of the unconsolidated products of
rock erosion and organic decay, along with bacteria and fungi ,: the place where plants
live </rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#whitefly_on_cotton_photograph">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">whitefly
on cotton photograph</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#cotton_pest_photograph"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A58">
    <rdf:rest rdf:nodeID="A57"/>
    <rdf:first rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_part_of_plant">
    <owl:inverseOf rdf:resource="#plant_has_parts"/>
    <rdfs:range rdf:resource="#plant"/>
    <rdfs:domain rdf:resource="#plant_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:subPropertyOf rdf:resource="#is_a_part_of"/>
  </rdf:Description>
  <rdf:Description rdf:about="#looper">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">looper</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
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  </rdf:Description>
  <rdf:Description rdf:about="#larva_17">
    <rdf:type rdf:resource="#larva"/>
    <locate_in_time
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</locate_in_time>
  </rdf:Description>
  <rdf:Description rdf:about="#day">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"> a period
of 24 hours, usually beginning and ending at midnight</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#time_interval"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bollworm_moth">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">adult
stage of bollworm</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#bollworm"/>
  </rdf:Description>
  <rdf:Description rdf:about="#bollworm_pupa">
    <rdfs:subClassOf rdf:resource="#bollworm"/>
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">bollworm
pupa</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_next_stage_of_egg">
    <rdfs:range rdf:resource="#egg"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
    <rdfs:domain rdf:resource="#larva"/>
  </rdf:Description>
  <rdf:Description rdf:about="#fungus">
    <owl:disjointWith rdf:resource="#protozoan"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#plant"/>
    <owl:disjointWith rdf:resource="#virus"/>
    <owl:disjointWith rdf:resource="#bacterium"/>
    <owl:disjointWith rdf:resource="#animal"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a single-
celled or multicellular organism without chlorophyll that reproduces by spores and lives
by absorbing nutrients from organic matter. Fungi include mildews, molds, mushrooms,
rusts, smuts, and yeasts</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#organism"/>
  </rdf:Description>
  <rdf:Description rdf:about="#is_a_next_stage_of_larva">
    <rdfs:range rdf:nodeID="A55"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
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    <owl:inverseOf rdf:resource="#is_a_previous_stage_of_larva"/>
    <rdfs:domain rdf:resource="#egg"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A4">
    <rdf:rest rdf:nodeID="A38"/>
    <rdf:first rdf:resource="#peanut"/>
  </rdf:Description>
  <rdf:Description rdf:about="#velvetbean_caterpillar">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">velvetbean
caterpillar</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
  </rdf:Description>
  <rdf:Description rdf:about="#constant_quantity">
    <rdfs:subClassOf rdf:resource="#physical_quantity"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">A
ConstantQuantity is a PhysicalQuantity which has a constant value, e.g. 3 meters and 5
hours. The magnitude (see MagnitudeFn) of every ConstantQuantity is a RealNumber.
The magnitude (see MagnitudeFn) of every ConstantQuantity is a RealNumber. The
magnitude (see MagnitudeFn) of every ConstantQuantity is a
RealNumber.</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#lint">
    <rdfs:subClassOf rdf:resource="#cotton_body_part"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
fibers that surround unprocessed cotton seeds</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#sweet_potato_whitefly_pupa">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">sweet
potato pupa</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#whitefly"/>
  </rdf:Description>
  <rdf:Description rdf:about="#digital_photograph">
    <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">photograph taken with
digital camera</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#photograph"/>
  </rdf:Description>
  <rdf:Description rdf:about="#edge">
    <rdfs:subClassOf rdf:resource="#part_of_organic_object"/>
```

```
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a line or
area that is the outermost part or the part farthest away from the center of organic object
</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#pupa">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:disjointWith rdf:resource="#larva"/>
    <owl:disjointWith rdf:resource="#adult"/>
    <rdfs:subClassOf rdf:resource="#insect_life_cycle"/>
    <owl:disjointWith rdf:resource="#egg"/>
  </rdf:Description>
  <rdf:Description rdf:about="#cotton_seedling">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"> young
developing cotton that is grown from a seed</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#cotton"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#pest">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">an
organism that cause any events such as damage to plant</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#agent"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#underside">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#part_of_organic_object"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
lower side or bottom of something</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#beetle_adult">
    <rdfs:subClassOf rdf:resource="#beetle"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#egg_mass">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">a
collection of egg</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#collection"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#general_view">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">overall
view</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#view"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
```

```
  <rdf:Description rdf:about="#plant_43">
    <rdf:type rdf:resource="#plant"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A59">
    <rdf:rest rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#nil"/>
    <rdf:first rdf:resource="#adult"/>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A37">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <owl:unionOf rdf:nodeID="A58"/>
  </rdf:Description>
  <rdf:Description rdf:about="#boll_weevil">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">boll
weevil</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:nodeID="A43">
    <rdf:rest rdf:nodeID="A59"/>
    <rdf:first rdf:resource="#pupa"/>
  </rdf:Description>
  <rdf:Description rdf:about="#thorax">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:subClassOf rdf:resource="#insect_body_part"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">the
middle division of the body of an insect</rdfs:comment>
  </rdf:Description>
  <rdf:Description rdf:about="#sooty_mold">
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">dark
fungi that grow on honeydew excreted by sucking insects or on exudates from leaves of
certain plants</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#fungus"/>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
  <rdf:Description rdf:about="#maturity_attribute">
    <rdfs:subClassOf rdf:resource="#biological_attribute"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">attribute
of organism's maturity</rdfs:comment>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
  </rdf:Description>
</rdf:RDF>
```

APPENDIX E
QUESTIONAIRE ON EVALUATION

General questions

1. What is your name?

2. what is your occupation?

Please choose: --choose--

3. How often do you search information online?

Please choose: --choose--

4. How often do you search images online?

Please choose: --choose--

5. Do you know crops, insects, and relationships between them?

Please choose:

- strongly agree
- agree
- disagree
- strongly disagree
- n/a

Submit

questions on subject

1. What is your name?

2. What type of interface did you test?

Please choose:

- A. Keyword-based interface such as Google
- B. graphical interface

3. How many empty results were found when using this interface?

Please choose:

- none
- 1-3
- 4-6
- 5-9
- more than 9
- n/a

4. When you get an empty result, did this interface help you find another way to retrieve?

Please choose:

- strongly agree
- agree
- disagree
- strongly disagree
- n/a

5. Did this interface help you learn more about crops, pests, and relationships between them?

Please choose:

- strongly agree
- agree
- disagree
- strongly disagree
- n/a

6. Did this interface help you find accurate images?

Please choose:

- strong agree

7. Did this interfacce help you retrieve images easily?

Please choose:

- strongly agree
- agree
- disagree
- strongly disagree
- n/a

8. This interface showed terms related with images. Did the terms help you to understand relationships between crops and pests?

Please choose:

- strong agree
- agree
- disagree
- strongly disagree
- n/a
- I did not see terms related with images.

9. Comments on this interface:

Submit

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BIOGRAPHICAL SKETCH

I was born in a small town near Seoul, South Korea in 1973. I got bachelor degree of agriculture from the Department of Agricultural Biology in Korea University, South Korea. I got my master of science from the Department of Microbiology in Seoul National University, South Korea. I will get the Ph.D. degree in the Department of Agricultural and Biological Engineering in University of Florida on December, 2005. I have one daughter, Bonny Koo.