Sentinel: Intelligent Information Sharing for Controlling the Emerald Ash Borer Threat

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Abstract. The Emerald Ash Borer (EAB) has killed or infested millions of ash trees in Michigan and is fast spreading to neighboring states. The US Department of Agriculture (USDA) estimates that if EAB went unchecked in the rest of the country, the loss to the nation could range from $20 billion to $60 billion. One key requirement for the success of EAB containment programs is the underlying information sharing infrastructure. EAB partners are maintaining Web sites to publish information about the borer. However, this approach for sharing information is ad hoc and requires intensive human intervention. In this paper, we propose a service-oriented infrastructure, called Sentinel, for the intelligent and timely sharing of EAB-related information

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1 Introduction

The Emerald Ash Borer (EAB) is a shiny and invasive green beetle known for killing Ash trees in the United States (US) [8,9]. The borer is native to Asia and is widely believed to have arrived from China through wooden crates used for packing auto parts. It has the potential to decimate Ash as a component of North American forests, which will have dramatic ecological and economic effects. Ash wood is used for all traditional applications of hardwood from flooring and cabinets to baseball bats. In addition, ash trees are beautiful shade giving trees and one of the commonly used landscaping trees in most cities of North America. EAB has already killed or infested ten million ash trees in Michigan alone and fast spreading to adjoining states. The USDA (US Department of Agriculture) estimates that at the national level, if the EAB went unchecked, the loss to the nation could range from 20-60 billion dollars [8,9].

Realizing the importance, the US Congress approved for the year 2006, about two and half times higher support funding for eradication of EAB. The USDA Animal and Plant Health Inspection Service (APHIS), the USDA Forest Service and the Canadian

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Food Inspection Agency, in cooperation with State Departments of Agriculture and Natural Resources, have joined forces to implement a long-term program to contain and eventually eradicate EAB from North America. The plan, which is in the early stages of implementation, combines efforts at different levels: *research*, *prevention*, *detection*, and *legal*. At the research level, scientists are working round the clock to understand the beetle's life cycle, find ways to detect new infestations, control EAB adults and larvae, and produce new insecticides. At the prevention level, mass awareness campaigns (e.g., via multimedia publicity on television, radio, and newspaper ads, fliers, press releases, and posters) are regularly launched to spread the word about EAB and the dangers posed by transporting firewood. At the detection level, federal, state, and local agencies promptly locate and eradicate outlier infestations (e.g., by cutting ash trees in infected areas). At the legal level, aggressive enforcement of state and federal quarantines is implemented. For instance, inspection and enforcement programs are targeting rest areas, highways and campgrounds at critical times of year such as major holidays and hunting season.

One key requirement for the success of the aforementioned EAB containment programs is the underlying information sharing infrastructure. EAB-interested partners (e.g., governments, universities, and news outlets), are continuously publishing information (e.g., quarantine procedures and areas, need for cutting Ash trees, research results) on their Web sites about the borer. Multi-state efforts are being made to bring the latest information about the insect (e.g., http://www.emeraldashborer.info). However, the current process for sharing EAB information is *ad hoc* and requires intensive human intervention which may hinder EAB containment plans. For example, Web sites include lists of phones numbers that can be used to report infestations. The called agencies generally process such information in a manual fashion; for instance, they need to figure out w*h*ich other EAB partners need to be notified, *how* (fax, letter, etc.), and *when*. In this paper, we propose a novel infrastructure, called *Sentinel,* for the *intelligent* and *timely* sharing of EAB-related information. *Sentinel* provides support for EAB partners in the following tasks:

1. *Dissemination*: Identify the partners that need to be notified about any given type of relevant EAB information; and
2. *Decision Making*: Determine the actions to be performed (e.g., launch an awareness campaign) at the reception of EAB.

The proposed approach seeks to achieve the following three objectives: (i) model information sharing patterns among EAB partners; (ii) enable the automatic and intelligent dissemination of EAB information; (iii) facilitate the decision making process for EAB containment. In the rest of this paper, we overview the techniques proposed in Sentinel to achieve the aforementioned objectives.

2 Ontology for Modeling EAB Interaction Patterns

An ontology is a formal and explicit specification of a shared conceptualization [2,4]. This concept is increasingly seen as key to facilitate knowledge sharing and reuse. In *Sentinel*, we propose an ontology, called *EAB ontology*, to model the different

patterns through which EAB partners exchange EAB-related information. We defined two taxonomies, namely *EAB Info (Fig 1) and EAB Partners (Fig 2)* taxonomies, to enable the specification of the EAB ontology.

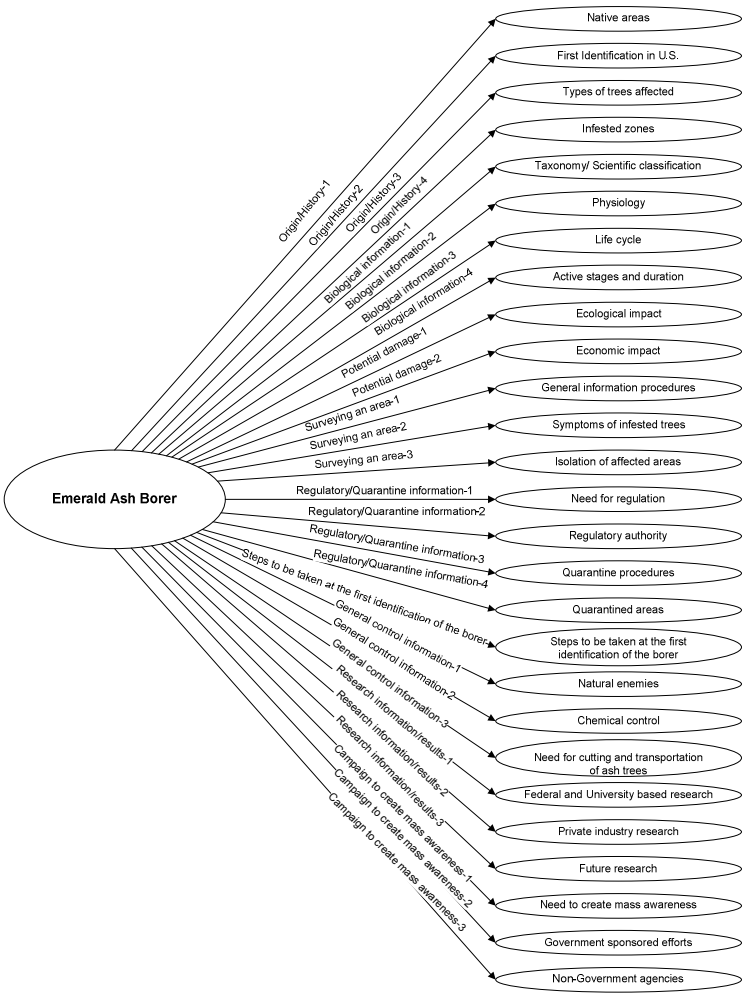

Fig. 1. RDF Graph for the EAB Info Taxonomy.

The EAB Info taxonomy gives the various types of information that may be exchanged among EAB partners. We model it using the RDF (Resource Description Framework) graph depicted in Fig 1. RDF is a model for representing ontologies on the Web [4]. RDF data model consists of statements about resources (i.e., all things that have an identifier on the Web), encoded as object-attribute-value characteristics.

The objects are resources, attributes are properties and values are resources or strings. The RDF graph includes EAB (the object), the various types of information (attributes) and the sub-categories of the types of information (values). The following are the various types of information on EAB (Fig 1): "Origin/History", "Biological Information", "Potential Damage", "Surveying an Area", "Regulatory/Quarantine Information", "Steps to be taken at the First, Identification of the Borer", "General Control Information", "Research Information/ Results", and "Campaign to Create Mass Awareness".

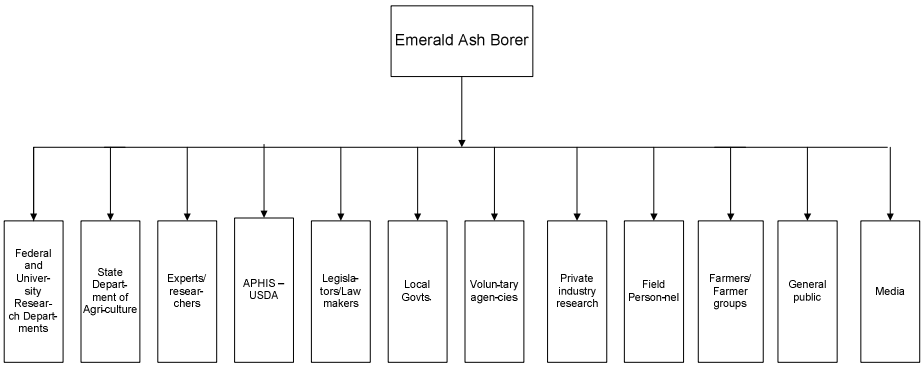

Fig. 2. EAB Partners Taxonomy.

The EAB Partners taxonomy gives the categories of partners that may need to exchange EAB-related information (Fig 2). We identify twelve (12) categories of partners: "Federal and university research departments", "State department of agriculture", "experts/researchers", "APHIS–USDA", "legislators/law makers", "local Government", "voluntary agencies", "private industry", "field personnel", "farmers/ farmer groups", "general public", and "media".

The EAB ontology can be depicted as a labeled directed graph; nodes represent concepts and labeled edges represent relationships between concepts. Concepts refer to different categories of EAB partners as defined in the EAB Partners taxonomy. An edge from E_1 to E_2 labeled with T_I means that partners that belong to category E_1 shares information of type T_I (as defined in the EAB Info taxonomy) with partners that belong to category E_2.

3 The Sentinel Framework: an Overview

Sentinel uses the EAB ontology as a basis for disseminating EAB-related information and providing assistance during decision making. In the rest of this section we overview the major techniques proposed in *Sentinel*.

3.1 Modeling EAB Partners as Web Services

One important feature of *Sentinel* is the automatic interaction among EAB partners (i.e., sending/receiving information). EAB partners belong to heterogeneous, autonomous, and geographically distant organizations (e.g., the USDA APHIS, nursery operator). To enable such interactions, we represent each EAB partner by a *Web service* (called EAB Web service). A Web service is an application accessible on the Web via programmatic means [1]. Web services adopt standard technologies such as XML and HTTP for the exchange of messages. We use *software design patterns* to define a toolbox that can be used by EAB partners to easily create EAB Web services [5]. In a nutshell, a *software design pattern* is a general solution to a recurrent design problem. EAB partners simply need to use the toolbox (via a friendly user interface) to instantiate their Web services. All Web services related to EAB are registered in the service directory (UDDI in our case) under the category "Emerald Ash Borer". The Web service will further be categorized based on the type of partner to which the Web service belongs (as defined in the EAB Partners taxonomy).

3.2 Dissemination Techniques for EAB Web Services

Information dissemination involves two types of EAB Web services: *producers* (send messages) and *consumers* (receive messages). The same EAB Web service may act as a producer and consumer. We design two classes of dissemination techniques: *pull* and *push*. In the *pull* class, information is delivered by producers as a reply to specific requests submitted by consumers. We identify two pull techniques: *explicit* and *implicit*. The *pull explicit* mechanism is the most common Web service exchange pattern; a consumer submits a request for information to a producer which sends back a reply to the consumer. The *pull implicit* technique corresponds to the well-known publish/subscribe interaction scheme [3]. Consumers explicitly register their interest (via subscription) in receiving messages that belong to certain information types (as defined in the EAB Info Taxonomy) with potential producers. The *push* technique uses the EAB to enable the sharing of information with EAB partners that did not request or subscribe to it, but would benefit from receiving it. Issues such as double notifications and notification loops are addressed.

3.3 EAB Ontology Evolution

The EAB ontology is initially created based on domain expertise. However, this ontology is dynamic and can evolve over time; relationships and EAB partner types may be added or removed. We identify two ways for updating the EAB ontology: manual and automatic. In the manual technique, domain experts add/remove relationships and/or EAB partner types. In the automatic technique, we develop data mining algorithms to discover new association rules among EAB partners [6]. The data mining algorithms monitor pull disseminations to identify frequent interaction

patterns and update the EAB ontology accordingly. Updates are propagated to all relevant EAB Web services.

3.4 The EAB Decision Making Process

Sharing information among EAB partners generally triggers a number of internal decisions and actions (besides forwarding information to other partners) within each partner. For example, a government agency may notice that, during the past two major holidays, a substantial number of people have been fined for moving firewood outside a certain quarantine area. It may decide to improve its publicity campaign in that area in the coming holiday. We develop *machine learning* techniques to generate decision rules. Machine learning is concerned with the development of algorithms and techniques that allow computers and programs to "learn" [7]. We use several learning approaches such as supervised, unsupervised, semi-supervised, and reinforcement.

4 Conclusion

We presented in this paper our ongoing research in the *Sentinel* project. As of today, we developed the EAB ontology and the proposed techniques for dissemination among EAB services. We also implemented these techniques in *Sentinel* prototype. As a proof of concept, we deployed representative EAB Web services in the university's local network. We are currently investigating techniques for EAB ontology evolution and facilitating the EAB decision making process.

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