CARMA+: A General Architecture for Pest Management

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Abstract: CARMA is a decision-support system for rangeland pest infestations that has been used successfully in Wyoming counties since 1996. CARMA is limited to the specific task for which it was designed: providing advice to ranchers concerning insect infestations on rangeland. This paper describes CARMA+, an architecture that permits CARMA's design to be applied to other pest-management tasks. A task analysis is described for a crop protection module for CARMA+ that is currently under development.

Keywords: decision support systems, case-based reasoning, architecture, pest management

1 Introduction

CARMA is a decision-support system for rangeland grasshopper infestations that has been used successfully in Wyoming counties since 1996 [Hastings et al., 2002, Branting et al., 2001, Branting et al., 1997, Hastings et al., 1996]. CARMA's effectiveness depends on three factors:

- Integration of multiple knowledge sources, permitting expert advice despite the incompleteness of each individual knowledge source.
- An intuitive user interface, including a flexible elicitation strategy and clear graphics.
- Adaptability to different:
  1. economic conditions, such as changes in forage and pesticide prices, and pest treatment practices, and
  2. tasks, including pest management, research, development of industry strategies, and policy development.

CARMA is limited, however, to advice concerning rangeland grasshopper infestations. Grasshoppers also cause significant economic harm to cultivated cropland. In western North America, for example, cultivated cropland is frequently adjacent to or near rangeland and therefore affected by the same insect pests as infest rangelands. However, the advisory task for cropland is very different than that for rangeland.

This paper describes the design of a new module designed to apply CARMA's distinctive design features—integration of multiple knowledge sources, intuitive user interface, and adaptability—to the task of advising farmers on the best responses to cropland grasshopper infestations. Section 2 describes the motivation for developing the new module. The decision-support task addressed by the new module is set forth in Section 3. Section 4 describes the architecture of the new module and its integration with the current CARMA system.

2 The Need for a Cropland Grasshopper Infestation Advisor

Cropland grasshopper infestations cause significant economic harm worldwide. Advice concerning infestations of crops is of particular importance in regions such as western North American where much cropland is adjacent to rangeland and other non-cultivated habitats. Grasshoppers often move between such habitats and nearby cropland.

Only a minority of grasshopper species pose a threat to any given crop (e.g., a high density of A. elliotti, a strict grass-feeder, represents no risk to sugar beets). However, farmers generally perceive all grasshoppers as threats. As a result, farmers often use pesticides unnecessarily on their own land and exert political pressure for unnecessary pesticide use on adjacent rangeland. Such unneeded pesticide use can damage beneficial species and represents a needless economic burden on both farmers and government agencies.

Unfortunately, few resources exist for farmers to answer even basic questions concerning the threat posed to crops by grasshoppers, such as whether a given grasshopper species is capable of damaging a given crop, how wide an area around the cropland should be treated, or the residual properties of insecticides. In particular, no decision support systems exist for this task.

A cropland grasshopper advising module could be a valuable tool for both farmers and pest managers throughout western North American and in other areas where grasshoppers threaten cropland.

3 Task Analysis of Crop Infestation Advising

3.1 Potential Users

The CARMA+ Crop Protection Module is targeted at two distinct sets of users:

1. **APHIS.** The Animal and Plant Health Inspection Service (APHIS) within the USDA (United States Department of Agriculture) has been traditionally responsible for pest and disease management in the United States. An adaptable cropland module could be used by APHIS internally to illustrate an evolving set of knowledge and best practices within the field of cropland grasshopper management.
2. **Farmers.** Farmers could use the cropland advising module to learn about the immediate responses to cropland grasshopper infestations. The module would also point to likely sources of infesting grasshoppers and suggest long term farming practices that will minimize the threat of migrating grasshoppers. Politically, the educational role of this module will help APHIS if the farmers understand that the grasshoppers normally migrate from border areas rather than from adjacent federal rangeland.

The goal of the advising task is to determine the economically most advantageous response to a grasshopper infestation seen in cropland adjacent to a rangeland.

3.2 Task Decomposition

To determine the best approach to automating this task, we performed a detailed task analysis of human experts in this task. The analysis revealed that the advising task consists of the following subtasks:

1. Infer the relevant characteristics of the grasshopper infestation from observations. Important characteristic in croplands that are near rangelands include:
   (a) Grasshopper species, density and development in three locations near the border between between cropland and adjacent rangelands (see Figure 1):
      - 50 feet into the cropland (parallel to the border area)
      - Down the center of the border area (i.e., any non-tilled border or weedy areas, often referred to as a fencerow, road ditch, or conservation-reserve program)
      - 100 feet into the rangeland

   (b) Crop type, phenology (i.e., stage of growth), size, topology (i.e., range in crop or crop in range), tillage (i.e., tilled, minimal or no-till).

   (c) Rangeland condition, type (i.e., native or non-native), and size.
2. Determine the likelihood and level of damage:
   (a) Damage is likely if the observed grasshoppers favor the crop. For example, grass feeders will likely target only grass crops. Because most crops are technically tilled weeds, the forb/weed feeders are typically the grasshopper types most likely to pose a threat. CARMA's existing classification module (which only classifies grasshoppers as grass, mixed, or forb/weed feeders) will be fine-tuned to subclassify weed feeders to provide an accurate mapping to the various classes of crops.

   (b) The likelihood of crop damage is aggravated by:
      - Higher grasshopper densities and advanced development which will result in greater crop consumption,
      - A high probability of inward grasshopper migrations caused by poor habitat conditions in the surrounding nontilled lands (this is further aggravated by a small cropland to border area ratio),
      - The existence of grasshoppers within a crop entering a fragile period of growth (i.e., phenology),
      - The emergence of grasshoppers from within a minimal or no-till crop, and
      - The bordering of the cropland by non-native rangeland that will favor non-native grasshopper species that are more likely to target cropland.

   (c) If damage is unlikely, no action is required and the consultation ends.
3. If damage is likely, determine the appropriate response. Ideally, a cost/benefit analysis (similar to the analysis produced by CARMA) would determine whether treatment would be economically justifiable. However, the economics of cropland grasshopper treatment analysis are very complex due to the great number of possible crops and the highly variable and unpredictable values of each. In addition, crop values are generally so high that even minimal expected damage (especially at critical stages in the growth of a plant) can justify treatment. The goal, therefore, is not to predict the dollar amount of damage, but instead advise how to treat with insecticides to minimize the damage. The proper placement of treatment requires an accurate determination of the grasshoppers' point of origin:
   - **Border origin.** If sampling shows a large number of weed-feeding grasshoppers in the cropland, some in the border region, and none in the rangeland, then the grasshoppers seen in the cropland probably originated in the border area. This scenario requires treatment of the cropland (generally just the edge of the cropland if the infestation is noticed early) and the border region. The cost of treatment is the

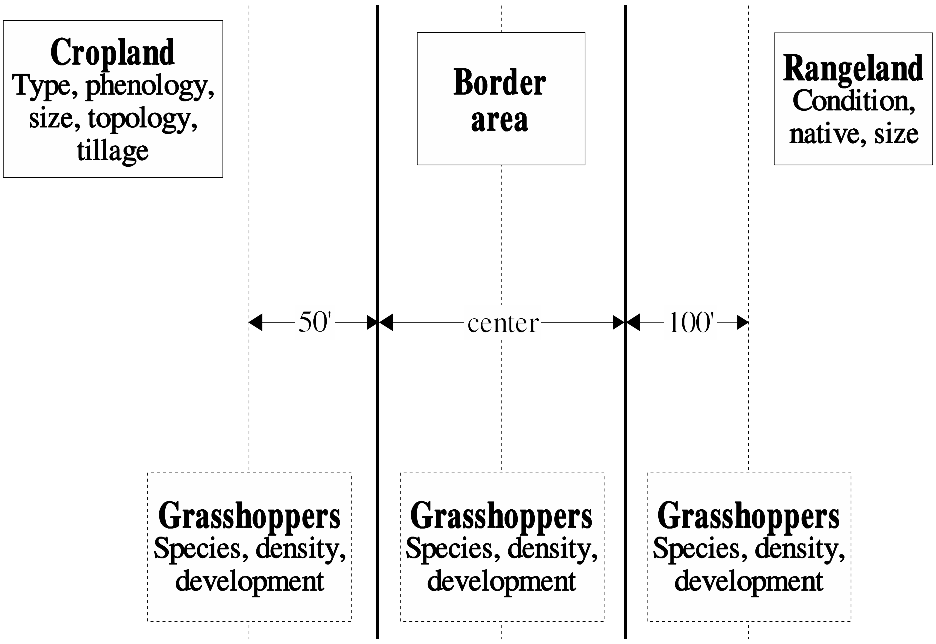

Figure 1: Information associated with possible points of origin for grasshoppers that can pose a threat to crops.

landowner's responsibility as the APHIS treatment program does not extend to private property. Due to the great variety of crops, for the time being, the landowner is responsible for reading the labels of available treatments to select one that can be applied on the landowner's specific crop.

- **Rangeland.** If sampling shows a large number of grasshoppers of the same type in the cropland, border area, and far out into the rangeland, then the grasshoppers seen in cropland probably originated in the surrounding rangeland. This is less common than origination in the border region because the grass feeders that exist on rangeland are unlikely to damage crops unless the crop is a grass type and poor rangeland conditions prompt a migration. This situation would require treatment of the cropland and border to immediately stop damage within the crop. The rangeland would be treated with a long lasting bait (such as carbaryl) that targets migrating grasshoppers and is less likely to affect non-target species.
- **Cropland.** Grasshoppers rarely emerge from within a crop except when the seldom-used practices of minimal or no-till farming are employed. Such a scenario would require treatment of the cropland only.

4 A CARMA+ Module for Crop Protection

CARMA contains many of the problem-elicitation tools and much of the general domain knowledge needed for cropland infestation advising, including general grasshopper identification knowledge, and developmental and population dynamic models of grasshoppers. However, simply adding additional information to CARMA's existing architecture is not sufficient to permit CARMA to address new pest-management tasks, such as crop protection. Instead, CARMA's architecture must be modified.

CARMA+ represents a multilayer reconfiguration of CARMA (see Figure 2) that allows the addition of advising "plug-ins" (e.g., a Rangeland Module and a Cropland Module). The top layer, called the "Consultation Manager", coordinates the communication between the user and the core of the system during the consultation process. The "Consultation Manager" starts by passing the goal "Complete Consultation" to the inference engine in the "Core". The satisfaction of general domain identification goals leads a consultation into module-specific rules. The processing of these module-specific rules may in turn invoke the Case-based, Model-based or Probabilistic Reasoners to analyze the current situation using domain specific knowledge (e.g., when analyzing a rangeland grasshopper infestation, the inference engine will request the Case-based Reasoner to find the prototypical case in Rangeland Module's case base that is most similar to the new case).

A reconfigured CARMA+ will support the extension of CARMA from its current rangeland grasshopper capabilities to the cropland grasshopper advising task discussed in Section 3 through the addition of a cropland grasshopper module that reuses existing general domain knowledge. Initially, cropland knowledge in the form of rules and a model appear to offer the greatest initial po-

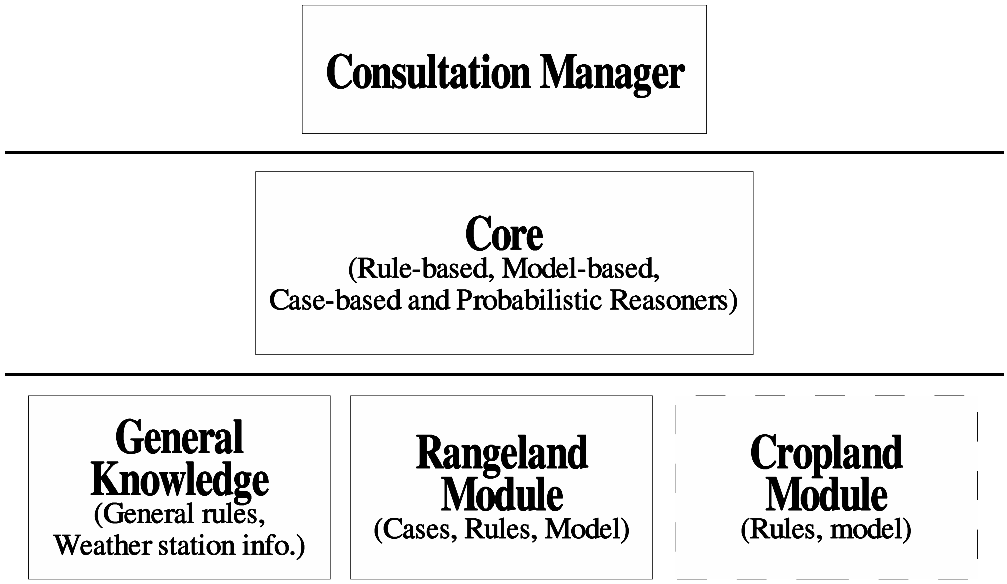

Figure 2: The top-level view of the architecture of CARMA+.

tential for building a foundation for the cropland module. The same questions—and supporting diagnostics—used for the rangeland grasshopper portion of CARMA (e.g., basic taxonomy, developmental stage, and habitat conditions) would be applicable, although greater taxonomic information and support may be necessary. Economic analyses will be severely limited by a lack of empirical data, so recommendations will be largely constrained to an analysis of the likelihood of damage, rather than the costs and benefits of treatment.

Note that the cropland module, as currently envisioned, does not include a case-based reasoning component, even though case-based reasoning plays a central role in damage estimates in CARMA's rangeland module. This difference is because in cropland, in contrast to rangeland, accurate pest consumption estimates can be modeled on the basis of well-understood relationships between grasshopper species and target crops. Cropland advising therefore does not seem to require case-based reasoning to compensate for an inadequate model, as in rangeland grasshopper advising.

CARMA+ differs from CARMA in separating reasoners (e.g., CBR, RBR, and MBR) from domain specific knowledge. This separation is intended to improve scalability with respect to future pest management extensions by providing a consistent interface residing centrally within the core.

5 Summary

This paper has described the need for an automated cropland grasshopper infestation advisor, set forth an analysis of expert performance in this task, and sketched an extension of CARMA to accommodate the requirements for this task.

CARMA+ is intended to extend the design features that were responsible for CARMA's effectiveness—integration of multiple knowledge sources, intuitive user interface, and adaptability to different economic conditions and tasks—to other pest-management tasks. A task analysis was set forth for a CARMA+ module for crop protection. This module is currently under development. The initial implementation of the Crop Protection module should be completed by the end of the summer of 2003.

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