2014 47th Hawaii International Conference on System Science

Early Assessment of an Approach to Determining the Predictive Coverage of Case-Based Reasoning with Adaptation through CARMA

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Abstract

CARMA is a decision-support system for managing grasshopper infestations which uses an approach called approximate-model-based adaptation *whereby case-based reasoning (CBR) provides an approximate solution and model-based reasoning adapts this approximation into a precise solution. CARMA's predictive accuracy on a set of known cases confirmed the ability of the technique. The evaluation was not expanded beyond the initial set of known cases due to the human effort involved in constructing such cases. We provide an overview of CARMA, and detail initial attempts to establish a process for the automatic evaluation of such systems in order to identify potential gaps in predictive coverage using Monte Carlo methods. We propose that any generated situation which produces large adjustments in prediction during adaptation suggests a potential gap in the predictive ability of a CBR system. This represents an extension of prior CBR work which considers only the matching stage when evaluating predictive coverage.*

1. Introduction

CARMA, short for *CA*se-based *R*angeland grasshopper *M*anagement *A*dvisor, is a decision-support system for managing grasshopper infestations that has been successfully used since 1996 ([4, 8]). CARMA employs a variety of artificially-intelligent (AI) techniques to provide advice about the most environmentally and economically effective responses to grasshopper infestations. In the process, CARMA illustrates an approach to providing advice concerning the behavior of a complex biological system by leveraging multiple, individually incomplete, knowledge sources ([7]) including the introduction of a technique known as *approximate-model-based adaptation*[1] which integrates case-based reasoning (CBR) ([1, 14]) with model-based reasoning (MBR) for the purpose of prediction within complex physical systems.

CARMA was designed with usability as a primary goal with the intention being to present an interface so intuitive that it completely eliminates the need for a user manual. Recent "non-biased" survey results ([12]) using a modified online form of the desirability toolkit ([3]) suggest that the approach employed in CARMA's interface is a success. In 2003 CARMA was expanded to include a prototype cropland grasshopper advising module ([9]) in order to handle situations when grasshopper populations build up at the rangeland-cropland interface and spread into cropland such as small grains. Furthermore, the graphical user interface (GUI) has been converted to Java in a manner which illustrates a technique for integrating an artificially-intelligent Lisp reasoner with a Java GUI ([10]). The implementation follows a philosophy called *platform freedom* which emphasizes freedom from both platform dependence and software costs, and in the process demonstrates an approach to creating a web-capable Lisp application with an appealing GUI.

Initially focused on rangeland grasshoppers within the state of Wyoming, CARMA's capabilities were extended to support the development and implementation of more environmentally friendly and sustainable strategies, and to support advising in nine additional western U.S. states: Colorado, Idaho, Montana, Nebraska, New Mexico, North Dakota, Oregon, South Dakota, and Utah. In addition, CARMA has been presented to pest managers in all 17 western states in which grasshoppers present economic problems. The most recent version of CARMA, 5.051 is available free of charge for noncommercial purposes and can be downloaded and installed

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[1] Approximate-model-based adaptation is defined and contrasted with perfect-model-based adaptation by [5].

978-1-4799-2504-9/14 $31.00 © 2014 IEEE
DOI 10.1109/HICSS.2014.114

from http://carma.unk.edu or run as a Java Web Start application.

Given CARMA's longevity and role within the grasshopper infestation advising domain, we are always on the lookout for ways to move CARMA forward (e.g., by bringing it to new platforms or making enhancements). Recently, we began to look at CARMA's coverage of problem space through the combination of cases and the model (for adaptation). The cases themselves had been manually gathered over the course of several months based on responses to questionnaires sent to 20 entomologists recognized for their work in the area of grasshopper management and ecology. The cases are meant to be representative of the most common infestation scenarios [6], but not an exhaustive coverage of all potential scenarios (especially given the effort required to manual acquire such cases).

The accuracy of the predictive approach used within CARMA (i.e., approximate-model-based adaptation) had been previously confirmed through leave-one-out testing on a set of known cases [6]. In this testing, a known case is removed from the system, the system is trained on the remaining cases, and finally the system produces a prediction for the removed case. It is the presence of the model, in combination with the remaining cases, which allow CARMA to fill in the newly created gap in the case library caused by removing the case. Given a sufficient coverage of feature space by the case library, the system should be able to properly solve new cases. This evaluation of CARMA's predictive ability was not expanded beyond the set of known cases, other than ad hoc usage of the system by experts (which did not discover any gaps), due to the human effort involved in constructing and evaluating potential new test cases. Our current research seeks a way to broaden this prior evaluation to new cases to determine if there are any areas in problem space not properly handled by CARMA, and to eventually fine tune CARMA if any gaps are found.

This paper provides an overview of CARMA and its problem domain. It then details initial attempts to establish a process for the automatic evaluation of such a CBR system which uses adaptation (in this instance approximate-model-based adaptation) in order to identify potential gaps in predictive coverage. Monte Carlo methods are employed to quickly construct novel cases/situations which are then fed into the system. We propose that any new case which differs only minimally from a prior case in the case library, but which leads to a large difference in prediction through the adaptation process suggests a potential gap in the predictive ability of the system, and for which manual inspection may be necessary.

Sections 2 through 4 describe the problem domain and CARMA's evolving role as a decision support tool in the world of sustainable grasshopper pest management. Section 5 details CARMA's problem-solving approach as modeled after domain experts, as well as an overview of approximate-model-based adaptation in CARMA. Our proposed approach to evaluating approximate-model-based adaptation in CARMA is described in section 6 along with the results and a discussion. We include potential future work in section 7 followed by the conclusion.

Figure 1. Hopper band of early instar nymphs of the Clearwing grasshopper *Camnula pellucida*, **one of the most important agricultural grasshopper pests in the western U.S. Photo: A. Latchininsky.**

2. Grasshoppers as economic pests

Competing with humans, livestock and wildlife for forage and crops, grasshoppers (Orthoptera: Acrididae) are a serious economic problem in 17 U.S. states west of the Mississippi. They are estimated to destroy annually about 25% of the available rangeland forage in the U.S., at an inflation adjusted cost of US$1 billion ([13]). Currently, the only efficient strategy to deal with a grasshopper outbreak (Figure 1) consists in the use of insecticide applications. During the 1986-88 outbreaks, 20 million acres of western rangeland were treated with 1.3 million gallons of insecticides at a cost of US$75 million. Besides their high economic cost, large-scale insecticidal programs that "blanket" grasshopper infestations may be detrimental to the environment ([21]) and can even aggravate grasshopper outbreaks over the long-term ([17]).

3. CARMA: grasshopper decision support

CARMA provides the end-user with advice regarding grasshopper population management options in an economically and environmentally sound fashion. Historically, rangeland infestations were considered treatable when grasshoppers occurred at densities of eight or more grasshoppers per square yard. While this treatment threshold was thought to make sense from a protectionist point of view (i.e., protect the existing forage at all costs so as not to risk forage shortages), it did not always make economic sense ([18]). CARMA conducts detailed analysis of infestations looking at a number of factors including grasshopper densities as well as range productivity in order to provide an economic analysis of an infestation. In cases where treatment costs will outweigh the estimated value of forage saved by treatment, CARMA advises a "no treatment" option, which provides the greatest environmental savings of all.

4. CARMA and sustainable pest management

In addition to conventional, blanket applications of broad-spectrum insecticides like malathion and carbaryl, CARMA considers an option called Reduced Agent and Area Treatments (RAATs) ([19]). In fact, CARMA was instrumental in developing the RAATs strategy. RAATs is a method of integrated pest management (IPM) for rangeland grasshoppers in which the rate of insecticide is reduced from conventional levels as untreated swaths (refuges) are alternated with treated swaths. RAATs works both through chemical control, meaning grasshoppers are killed in treated swaths and as they move out of untreated swaths, and conservation biological control, which allows predators and parasites preserved in untreated swaths to suppress grasshoppers. Less insecticide in the environment lowers the risk to native species (including fish and wildlife), water quality, and humans. The untreated swaths provide a refuge for organisms with lower mobility than grasshoppers, and even those organisms that move into the treated swaths will be largely unaffected unless they feed on the foliage. The untreated swaths harbor species essential to rangeland ecosystems, including bio-control agents of grasshoppers and weeds. Low densities of surviving grasshoppers allow predators and parasites in the untreated refuges to re-colonize and thereby reestablish natural regulation of grasshopper populations. For these reasons, RAATs programs also may sustain higher densities of birds than blanket applications. This IPM approach (RAATs) can reduce the cost of control and the amount of insecticide applied to our rangelands from 50 to 75% ([16]). In 2003, the RAATs strategy was applied to 400,000 acres in Wyoming which saved half a million US dollars for local agriculturists. In 2010, during the worst grasshopper outbreak in 50 years, almost 6 million acres were protected in Wyoming with RAATs. The cost of the entire control program delivered by both, private and federal pest managers, was 7.4 million US dollars [20]. Had ranchers used the traditional, blanket application of insecticides at conventional high rates, the cost of control would have been over 20 million US dollars. The RAATs treatments effectively reduced pest densities below the economic level and allowed Wyoming agriculturists to save about 13 million US dollars in 2010, survive the unprecedented pest outbreak and maintain the viability of their operations.

The contribution that CARMA has played and continues to play in supporting the development and implementation of sustainable pest management strategies such as RAATs is detailed in [11]. RAATs became the preferred option in the USDA-APHIS Environmental Impact Statement when grasshopper control is required ([21]). CARMA is the only pest management software that includes RAATs as an option and an open-ended capacity for user-based treatment updates.

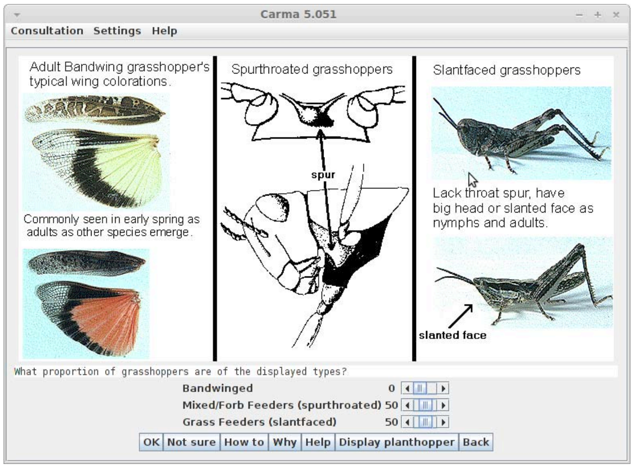
5. CARMA models the experts

CARMA is modeled after grasshopper pest management experts and interacts with users through the same sort of guided consultation employed by experts. The user is queried for information as needed in order to satisfy goals in an internal goal structure with the top-level goal being a completed consultation (or treatment recommendation). Much of the user input is used to construct an infestation case. Figure 2 shows an input window that asks the user to provide the grasshopper types present in their infestation.

5.1. Grasshopper infestation advising task

Briefly, the main steps in a consultation (as modeled after experts) are:

1. Determine the relevant facts of the infestation case from information provided by the user by means of heuristic rules.



Adult Bandwing grasshopper's typical wing colorations.

Commonly seen in early spring as adults as other species emerge.

Spurthroated grasshoppers

Slantfaced grasshoppers

Lack throat spur, have big head or slanted face as nymphs and adults.

What proportion of grasshoppers are of the displayed types?

Bandwinged 0
Mixed/Forb Feeders (spurthroated) 50
Grass Feeders (slantfaced) 50

Figure 2. CARMA's grasshopper type elicitation window.

2. Predict the proportion of available forage that will be consumed by each distinct grasshopper population using approximate-model-based adaptation.

3. Compare total grasshopper consumption with the proportion of available forage needed by livestock to determine if competition for forage will occur.

4. If the predicted forage consumption will lead to economic loss, determine which possible treatment options are excluded in the current situation.

5. Provide an economic analysis for each viable treatment option and recommend the treatment or treatments that are most economical.

For a detailed description of the rangeland grasshopper infestation advising task and the implementation of the consultation process within CARMA, the reader is referred to [8]. Approximate-model-based adaptation from step 2 is most relevant to the later experiment and is thus described in greater detail in the following subsection.

5.2. Approximate-model-based adaptation

Our protocol analysis indicated that entomologists estimate forage consumption by comparing new cases to prototypical infestation scenarios. These prototypical cases differ from conventional cases in two important respects. First, the prototypical cases are not expressed in terms of observable features (e.g., "Whenever I take a step, I see six grasshoppers with brightly colored wings fly"), but rather in terms of abstract derived features (e.g., "Approximately nine nymphal overwintering grasshoppers in the adult phase per square yard"). Second, the prototypical cases are extended in time, representing the history of a particular grasshopper population over its lifespan. Each prototypical case is therefore represented by a "snapshot" at a particular, representative point in time selected by the entomologist. In general, this representative point is one at which the grasshoppers are at a developmental phase in which treatment is feasible.

CARMA begins a consultation by eliciting information to determine the relevant features of a new case. CARMA can then employ approximate-model-based adaptation whereby the causal model assists case-based reasoning in four different ways: case factoring; temporal projection; featural adaptation; and critical-period adjustment. The assumption underlying approximate-model-based adaptation is that the causal models associated with a biological or other partially understood systems may be accurate in the neighborhood of a case, even if the models are insufficient for accurate prediction throughout the entire feature space.

1. Factoring Cases into Subcases. CARMA's consumption prediction module first splits the overall population into subcases of grasshoppers with distinct overwintering types (i.e., overwintering as nymphs or eggs), since forage consumption by those that overwinter as nymphs is much different from consumption by those that overwinter as eggs.

2. Temporal Projection. Before performing case matching and adaptation in order to predict the forage loss of a subcase, CARMA retrieves all prototypical cases whose life history (i.e., overwintering type) matches that of the subcase, and projects the prototypical cases forwards or backwards to align their average developmental phases with that of the new subcase.

3. Featural Adaptation. The consumption predicted by the best matching prototypical case is modified to account for any featural differences between it and the subcase. This adaptation is based on the influence of each feature on consumption as represented by featural adaptation weights.

4. Critical-Period Adjustment. Consumption is only damaging if it occurs during the critical forage growing period of a rangeland habitat. The forage loss predicted by a prototypical case must be modified if the proportion of the lifespan of the grasshoppers overlapping the critical period differs

significantly in the new case from the proportion in the prototypical case.

For a more complete description of approximate-model-based adaptation in CARMA, see [6].

6. Evaluating approximate-model-based adaptation within CARMA

Prior case-based reasoning research suggests that the predictive coverage of a CBR system can be evaluated based on how well new cases match existing cases in the case library [15]. Their experiments involved using a Monte Carlo approach to randomly create new cases, and then calculating how closely they match. New cases which are sufficiently distant from existing cases are candidates for addition to the case library in order to improve coverage of problem space. Given a close match, they consider the problem solved. However, for CBR systems which use adaptation to generate a final solution, the adaptation stage must also be considered when evaluating the system. Because CARMA uses adaptation (through approximate-model-based adaptation), it represents an initial test bed for trying out potential evaluation ideas.

6.1. Generating random cases

Table 1 illustrates the relevant features present in cases within CARMA, and the range of values possible in the random cases generated in our experiment. Some of the features are qualitative (e.g., precipitation), while others are numeric (e.g., grasshopper density). Two of the features (location and overwintering type) were fixed at one potential value in order to reduce complexity for this experiment. For example, location was set at "La Grange, Wyoming" because the CARMA's cases themselves are centered at "La Grange" – CARMA's model would otherwise adjust for any differences in location between a new case and a prototypical case. In addition, the overwintering type was set to "egg" because that is the type of most interest (the "nymphal" overwintering type is somewhat of a special case).

Because the timing of average developmental phase of the grasshoppers is related to the climate for the location (which is generally related to the date for the location) – a linear regression between date and phase was developed from the prototypical cases, and the random date for the new case is fed into the formula to produce the phase.

	Number	Range of values	
		Low end	High end
Date	92	May 1	July 31
Location	1	La Grange, WY	
Overwinter type	1	egg	
Feeding types	101	mixed 100% grass 0%	mixed 0% grass 100%
Average phase	6	2.0	7.0
Density (gh/yd^2)	40	1	40
Precipitation	3	wet	dry
Temperatures	3	cool	hot
Infest. history	5	low	high
Range value	5	low	high

Table 1. Random case production.

The range of possible feeding type values is as follows: (mixed 100%, grass 0%), (mixed 99%, grass 1%), ..., (mixed 0%, grass 100%) where the percentage of mixed feeders is equal to 100 minus the number of grass feeders. Note that the average development phase of the grasshoppers is actually a real value, but for this table we will assume integer values 2 through 7. With this assumption, for this experiment there are $501,768,000$ different points (i.e., random cases) possible in feature space. Even with the simplifying assumptions (including the fixed location), the problem space is too complex to explore exhaustively in any reasonable amount of time.

6.2. Experiment & results

Random cases were generated and fed into CARMA bypassing the user interface. Cases can be randomly generated and fed through the system at an approximate rate of 700 cases per minute on a standard laptop. Figure 3 shows the results of this testing with 50 randomly generated cases. The chart includes the similarity ratio (in yellow) between the random case and the closest matching case in the case library. The similarity ratio is the matching difference divided by the maximum possible case difference – we won't describe the specifics of the matching difference as they could vary from one CBR system to the next, but each CBR system should have measure of match similarity. The chart also includes the predictive difference (in red) between the closest matching case and the prediction generated by CARMA for the random case up to a possible maximum of 100. The results are sorted by this predictive difference. Because grasshopper forage consumption is strongly related to the number of surviving grasshoppers (survival can be reduced/increased by other factors including disease and weather conditions), the difference in grasshopper density (in blue) between the closest case and the random case is also shown.

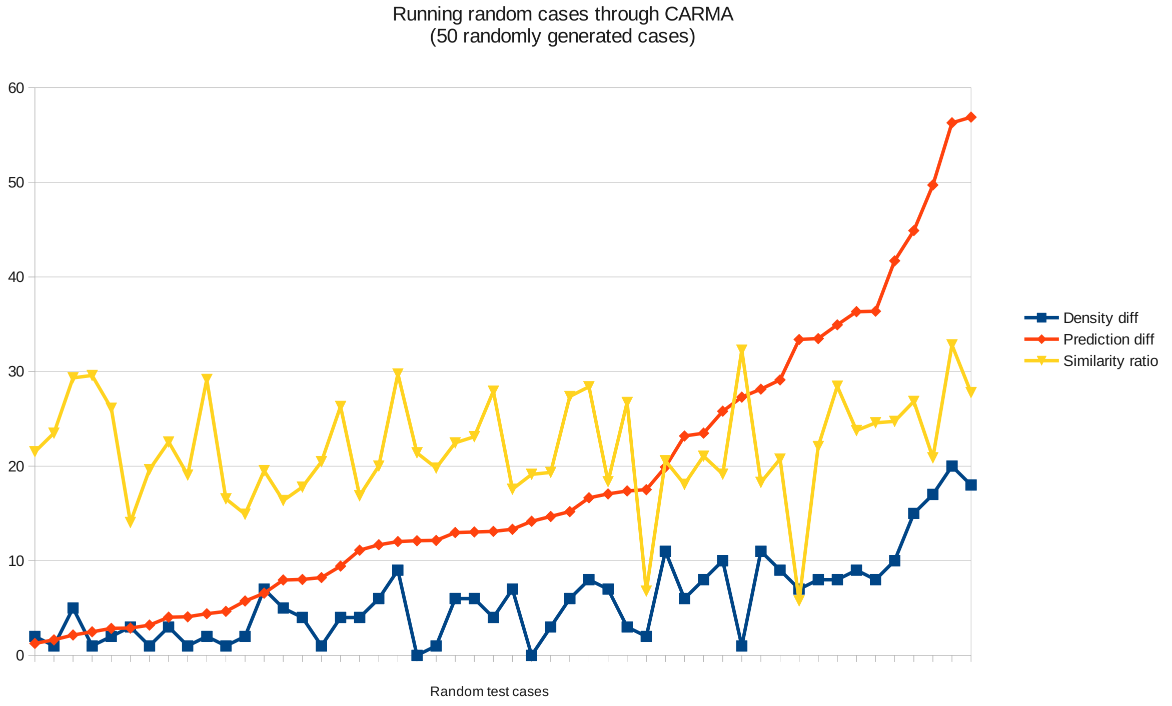


Figure 3. Test results on 50 randomly generated cases.

6.3. Discussion

We consider that the predictive difference between a new random case and the closest matching case for a CBR system which uses adaptation might be a better indicator of potential gaps in the predictive coverage of the system. If the difference is high, that indicates a case where a great deal of adaptation has taken place. There is nothing wrong with that given a perfect adaptation module. However, it stands to reason that the further the system has to adapt to account for feature differences, the more likelihood of error. Given that CARMA's case library is quite small, not all new cases will be a close match and thus adaptation will have greater impact.

Notice that there seems to be little if any relationship between the similarity/matching ratio and the final predictive difference. In CARMA, those two components were trained in isolation (match weights were set using mutual information gain, and adaptation weights were tuned using hill climbing), so there is not a strong direct link between them. In the chart, there appears to be a stronger link between the density and predictive differences. Exploring this link further, we found that in CARMA, although density is ranked relatively high in terms of importance for matching, its impact is sometimes overridden in matching by the combination of a stronger overall match of other features (which individually are not as important as density but when combined are collectively more important). This leads to a match with a greater difference in density. Such occurences don't indicate that CARMA is necessarily faulty in its predictions because a new random case with a high density matched with an existing case with a lower density will obviously result in a greater amount of adaptation and thus a greater predictive difference. But, these instances with a higher predictive difference represent a natural starting point if further (manual) examination were to take place.

We feel that this approach could have broad applicability to case-based reasoning systems in general where case matching and solution differences can be measured, particularly for systems where case library size is limited.

7. Future work

This work represents a preliminary test of our idea using CARMA as a test bed. At this point, further inspection of the specific results would require human intervention by domain experts. Rather than consume their time with cases that may not be problematic, we hope to further refine our ideas in order to be able to pinpoint with better certainty candidates for manual inspection. Given the speed of this testing approach, an automated analysis approach which can more clearly flag potential problems is necessary, but that has not been formulated yet. We are currently turning our attention to data sets in the UCI Machine Learning repository [2]. The data sets are much larger than CARMA's case library and we feel that we can gain a better understanding of our approach, after which we can return our attention to CARMA. We are also looking at porting CARMA to mobile devices.

8. Conclusion

CARMA is a decision support system for managing grasshopper infestations that has been successfully used since 1996. CARMA's primary reason approach, called *approximate-model-based adaptation*, utilizes case-based reasoning to provide an approximate solution and model-based reasoning to adapt this approximation into a precise solution. CARMA's predictive accuracy using this approach had been previously confirmed. The evaluation was not expanded beyond the initial set of known cases due to the human effort involved in constructing such cases. This paper detailed initial attempts to establish a process for the automatic evaluation of such a system (which uses approximate-model-based adaptation) in order to identify potential gaps in predictive coverage by using Monte Carlo methods to quickly construct novel situations and feed them into the system. Our work suggests that any new situation which differs only minimally from a prior case (in the case library), but which leads to a large difference in prediction (through the adaptation process) suggests a potential gap in the predictive ability of the system, and for which manual inspection may be necessary. Our work in this area will continue in order to gain a better understanding of our approach.

9. Acknowledgments

CARMA's development since 2003 was supported through funds from Cooperative Agreements between USDA-APHIS-PPQ (Western Region) and the University of Wyoming (grants USDAAPHIS5112, USDAAPH44906, USDAAPH44909GHS and USDAAPH44913GHM). This latest research was supported through an Undergraduate Research Fellowship from the University of Nebraska-Kearney.

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