ADAPTIVE REMOTE SENSING SOFTWARE TOOLS FOR IMPROVING REGIONAL WATER STEWARDSHIP

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ABSTRACT

Remotely sensed imagery has an important role to play in regional-scale analysis and management of water resources. Historically, the types of imagery collected have been aerial surveys of high resolution (~1m) panchromatic or color photography, and medium resolution (~30m) visible/near infrared multi-spectral digital satellite imagery (e.g., Landsat and Spot). There are many features of interest to be extracted from these datasets, ranging from direct mapping of water bodies and streams, to classification of land-cover and categorization of land-use throughout a watershed, to detection and monitoring of pollution and the presence of invasive species. Traditionally, this analysis has been manual, relying on a few experienced photo-interpretation and geographical information system experts in each relevant government agency, and hence expensive and time consuming. Automated software tools for assisting the analysis of remotely sensed imagery offer a way to boost analyst productivity significantly and make accessible new classes of remotely sensed imagery (e.g., hyper-spectral imagery). LANL has been developing adaptive tool-making software that can rapidly generate new remote sensing image processing algorithms for a wide range of imagery types and a wide range of features of interest. We describe one of these tool-making software packages, called 'Genie,' and discuss its uses for improving regional water stewardship.

Genie is an evolutionary computation (EC) software system, using a genetic algorithm (GA) to assemble image-processing tools from a collection of low-level image operators (e.g., edge detectors, texture measures, spectral operations, various morphological filters). Rather than optimize a single algorithm, Genie uses a population of competing candidate tools. Each candidate tool is an independent image-processing algorithm that generates a number of signature planes from the raw imagery. These signature planes are combined using a supervised classifier (Fisher linear discriminant) to generate a final Boolean feature mask. The population of candidate tools is ranked according to a fitness metric measuring their performance on some user-provided training data, and the most fit members of the population are permitted to reproduce. The population evolves until it converges to a solution, or the user decides to accept the current best solution. To help refine the search, the user is also able to modify the training data as Genie reports its initial results. The burden of low-level programming is thus shifted to the genetic algorithm, leaving the analyst free to concentrate on the critical task of making judgments. A comparison of Genie to standard supervised classifier algorithms of remote sensing has appeared in [1]. Genie is written in a mixture of Perl and C code, and runs on standard Linux workstations. A Windows NT/XP version is under development. The prototype Linux code has been released under an Open Source (LGPL) license, and can be obtained online from Los Alamos National Laboratory's Genie website: http://genie.lanl.gov.

Genie is being applied to a number of real world applications relevant to the challenges facing water resource authorities. Following the Los Alamos/Cerro Grande wild fire of 2000, Genie was used to remap the vegetation of the Jemez Mountains to map locations of high severity burn, and to determine habitat loss for elk and other fauna [2]. This wildfire was large, ~43,000 acres, and impacted lands managed by many different organizations, including federal and state governments, Native American communities, and private land owners. No single consistent land-cover or land-use map was available for this regional scale disaster. Using a relatively small area mapped in detail by ecologists at LANL, Genie was able to accurately and consistently remap the entire Jemez Mountains region in a dozen vegetative land-cover classes (Figure 1) using Landsat 7 ETM+ imagery. The mapping algorithms found by Genie produce qualitatively good results throughout an entire Landsat tile, and the results are good quantitatively in the region for which ground truth was available.

Interest in this result has led to an ongoing collaboration with the USDA Forest Service aimed at providing automated tools for rapidly mapping and monitoring national forests throughout the US. The pilot study will focus on New Mexican national forests, and is designed to tie in with advanced wildfire modeling techniques used for planning forest treatments as well as dynamic planning of firefighting resource allocation. Additionally, the collaboration with the US Environmental Protection Agency is demonstrating the effectiveness of Genie for mapping river and stream pollution associated with industrial and intensive agricultural processes. Early results from these studies suggest that the Genie approach to remote sensing science could be very useful for analysts faced with understanding and monitoring regional-scale ecosystems.

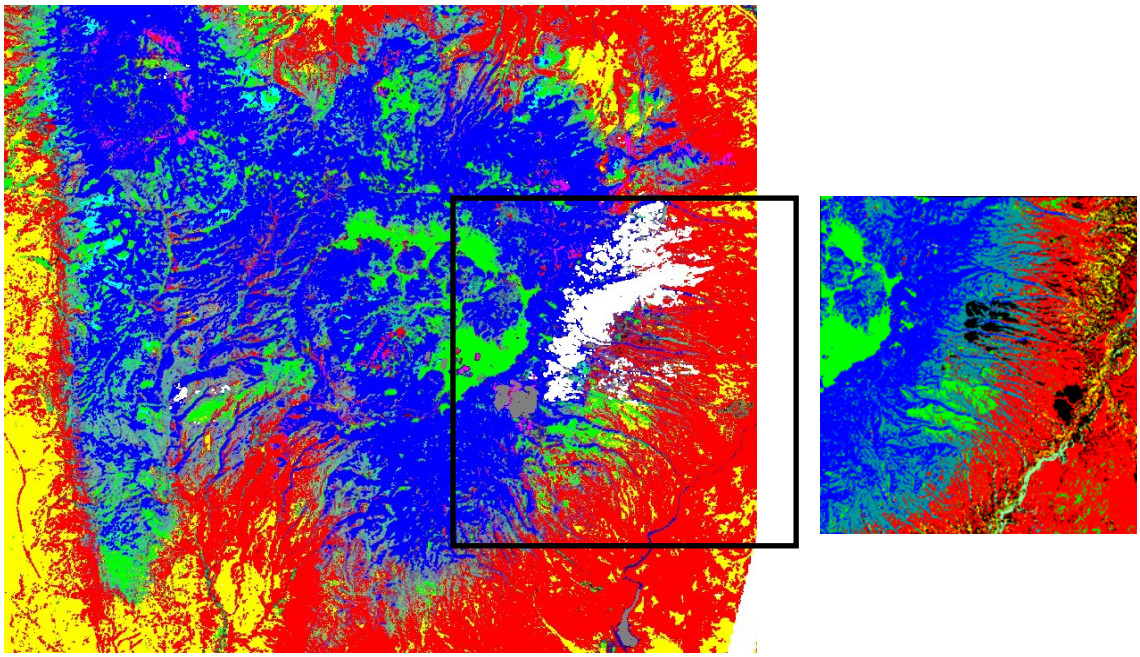

Figure 1. Right– manual land-cover map of Los Alamos town and forest, based on 1995 Landsat TM satellite image. Forest classes are in blue, open grasslands in green, scrubland/bare soil classes in red. Left– Genie map of region based on post-wildfire Landsat ETM+ satellite image. Los Alamos/Cerro Grande wildfire scar is shown in white.

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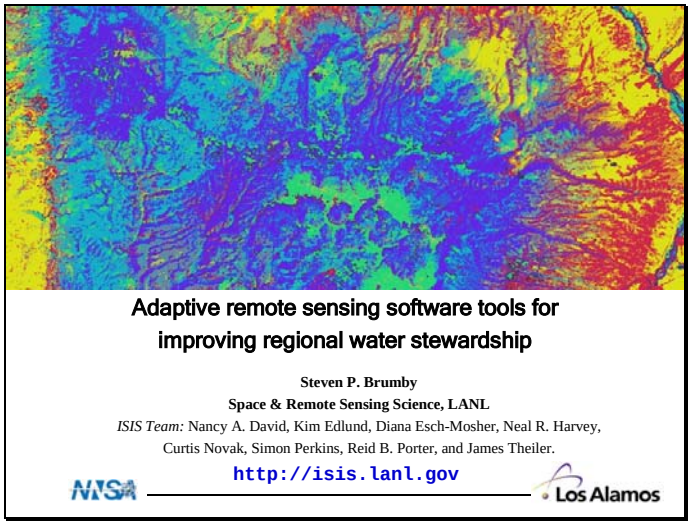
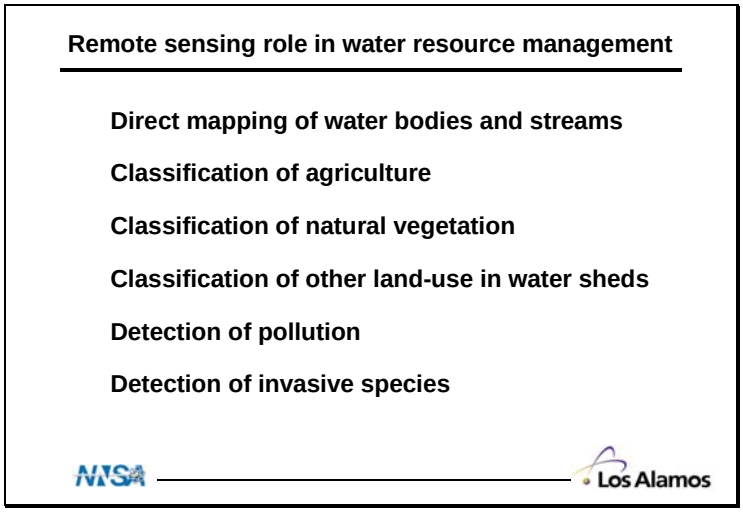
REFERENCES

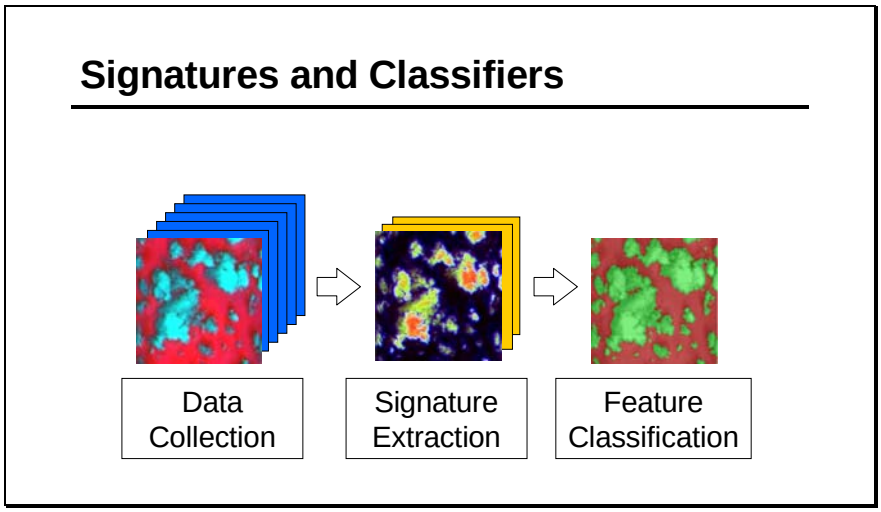
1. N. R. Harvey, J. Theiler, S. P. Brumby, S. Perkins, J. J. Szymanski, J. J. Bloch, R. B. Porter, M. Galassi, and A. C. Young, "Comparison of GENIE and Conventional Supervised Classifiers for Multispectral Image Feature Extraction," IEEE Transactions on Geoscience and Remote Sensing, Vol. 40, pp. 393-404, Feb. 2002.
2. Steven P. Brumby, Steven W. Koch, and Leslie A. Hansen, "Evolutionary Computation and Post-Wildfire Land-cover Mapping with Multispectral Imagery," Proc. SPIE 4545, 2001.



Automated software tools for assisting the analysis of remotely sensed imagery offer a way to significantly boost analyst productivity and make accessible new classes of remotely sensed imagery (e.g., hyper-spectral imagery). Los Alamos National Laboratory has been developing adaptive tool-making software that can rapidly generate new remote sensing image processing algorithms for a wide range of imagery types and a wide range of features of interest. We describe one of these tool-making software packages, called GENIE, and discuss its uses for improving regional water stewardship.



Remote sensing science and technology plays an important role in stewardship of water resources, and we describe several specific examples of feature detection tasks where automated systems can help human analysts.



Feature classification by, e.g., linear classifiers using multi-spectral imagery, can be helped by first transforming the raw image data into more physically useful and interesting quantities. For example, to look for clouds in infrared satellite imagery, the raw infrared radiances can be converted to effective brightness temperatures or ratios of band reflectivities, or can be examined for characteristic textures. We are interested in automated techniques that can build algorithms exploiting both spectral and textural information.

Machine Learning Techniques

- **Heuristic methods:**
  - Genetic algorithms
  - Simulated annealing
- **Traditional statistical methods:**
  - Discriminant analysis
  - Maximum Likelihood
- **Computational learning theory:**
  - Support vector machines
  - Boosting
  - Other "Large Margin" and kernel methods

Goal: Learn image processing to extract signatures *and* learn optimal parameters of classifier

Los Alamos National Laboratory is pursuing research into a wide range of automated image and signal processing techniques. The GENIE system is an example of a Genetic Algorithm method for image analysis.

ISIS: Intelligent Searching of Images and Signals

ISIS is a growing suite of Open Source image and signal analysis software tools for Linux workstations, each of which focuses on different tasks and/or solution methods:

GENIE - Genetic Programming

AFREET - Support Vector Machine

POOKA - Reconfigurable Computing

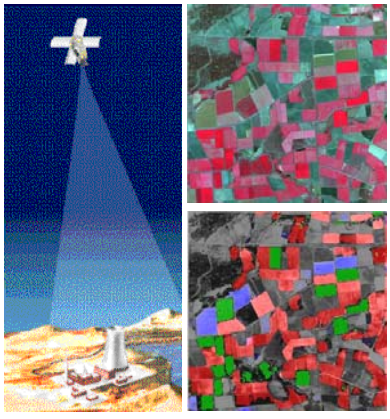
Download: http://isis.lanl.gov

Genie Pro – next generation learning engine, native to Windows XP, many image formats.

GENIE, along with several other of LANL's ISIS tools, have been released open source for Linux platforms. Please see http://isis.lanl.gov for details.

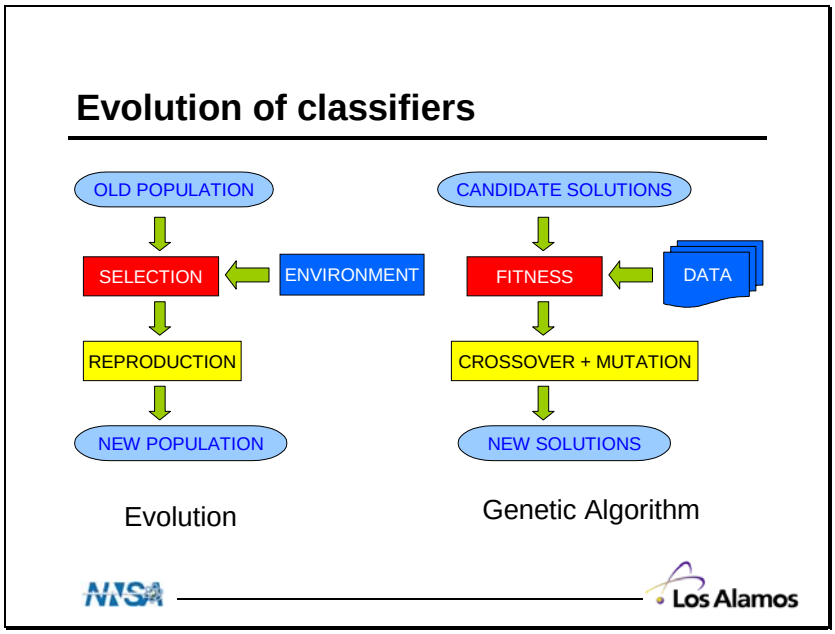
GENIE

GENetic Imagery Exploitation



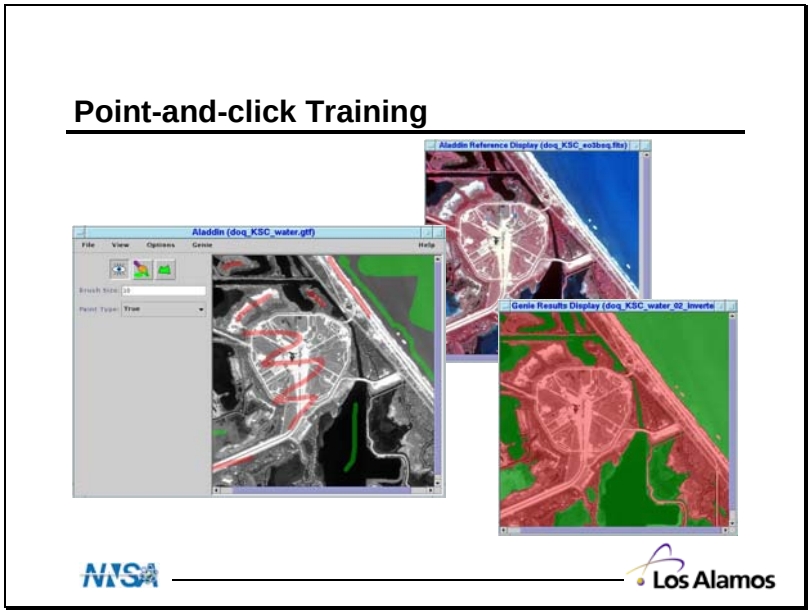
- Automated/Assisted Feature Extraction (AFE)
- Rapid Evolution of New Image Analysis Tools
- Panchromatic, Multi- and Hyper-spectral Imagery
- Land-cover Mapping
- Change Detection
- *Interactive User Interface*
- *Parallel/Scalable*
- *Reconfigurable Computing (RCC) Hardware Acceleration with POOKA system*

GENIE is a software system for rapidly evolving feature extraction algorithms for image analysis. With current sensor platforms collecting a flood of high-quality data, automatic feature extraction (AFE) has become a key to enabling human analysts to keep up with the flow. GENIE uses a genetic programming approach to produce AFE tools for broad-area features in multispectral, hyperspectral, panchromatic, and multi-instrument imagery. Both spectral and spatial signatures of features are discovered and exploited. The software features an interactive graphical user interface, and a parallel/scalable processing backend that runs on off-the-shelf computers (Linux workstations).

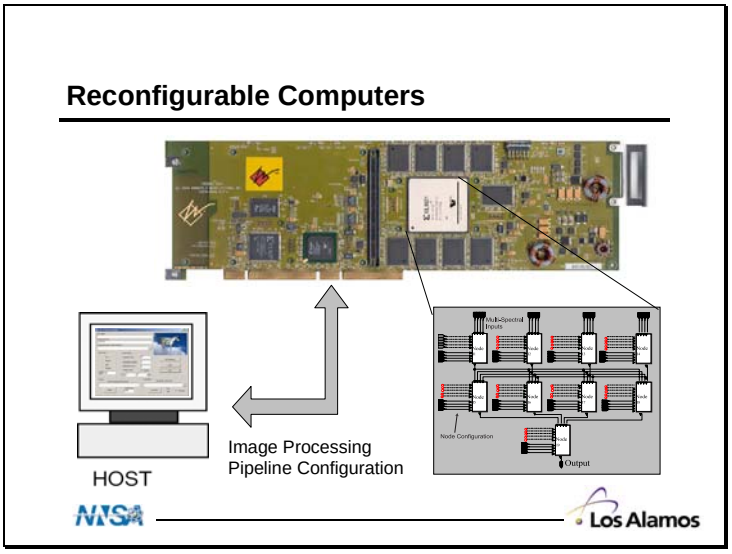


GENIE follows the standard paradigm of evolution with selection (left).

The candidate solutions are initially randomly generated, and evolve to solve specific feature extraction tasks using a small quantity of training data provided by a human user.

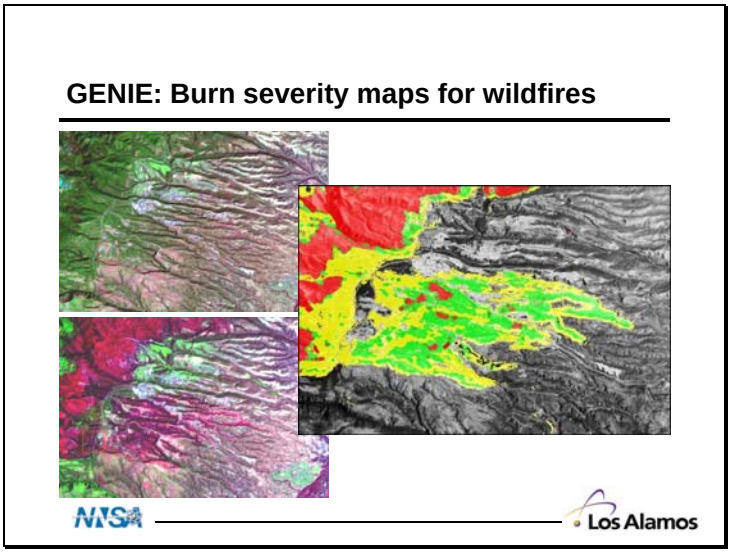


Training data for GENIE is provided via a simple graphical user interface. A mouse is used to indicate regions containing the feature of interest (marked in green) and regions containing 'background' (marked in red). The example above shows the system being trained (left) to detect water in high-resolution aerial photography (top right). GENIE's result is shown lower right.



In addition to the GENIE system for evolving software for automated feature extraction, LANL is developing evolvable hardware for fast feature extraction using video streams and/or very large imagery datasets.

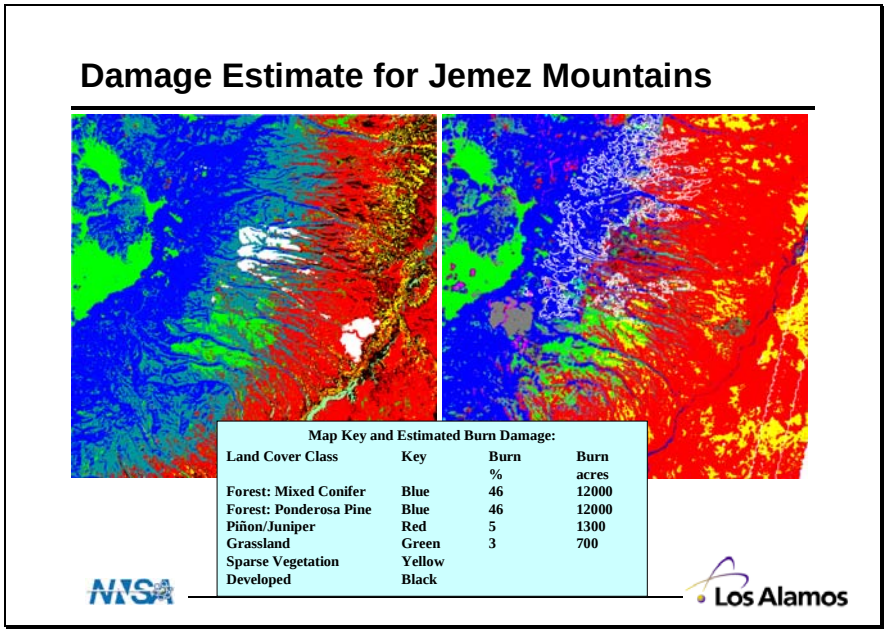
POOKA is a Reconfigurable Computer based system suitable for solving pixel-level classification problems in multi-spectral image data sets. The system is first optimized for a particular feature of interest and particular data set. It can then be applied to large image databases with two orders of magnitude greater throughput compared to software. The system is most suitable for solving large scale broad area search problems, to characterize land cover and terrain type.



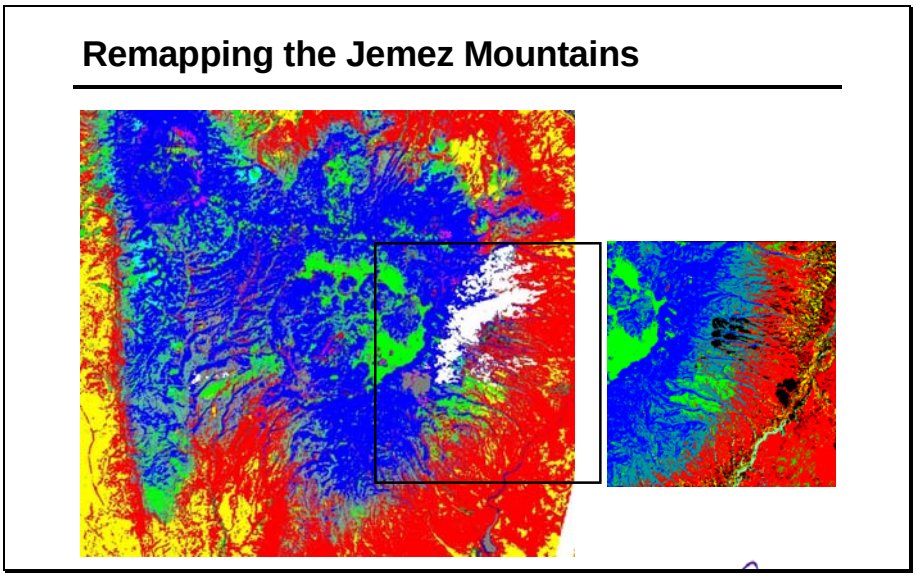
GENIE has been successfully applied to a number of real world remote sensing problems, including detection and analysis of wildfire burnscars.

The Cerro Grande/Los Alamos wildfire devastated over 43,000 acres (17,500 ha) of forested land, and destroyed over 200 structures in the town f Los Alamos. The need to monitor the continuing impact of the fire on the local environment led to the application of a number of advanced remote sensing technologies. During and after the fire, remote-sensing data was acquired from a variety of aircraft- and satellite-based sensors, including Landsat 7 Enhanced Thematic Mapper (ETM+) from before and after the wildfire. Using an existing land cover classification based on a Landsat 5 TM scene for our training data, we used GENIE to evolve algorithms that distinguished a range of wildfire and natural vegetation land cover categories, along with clouds and cloud shadows.

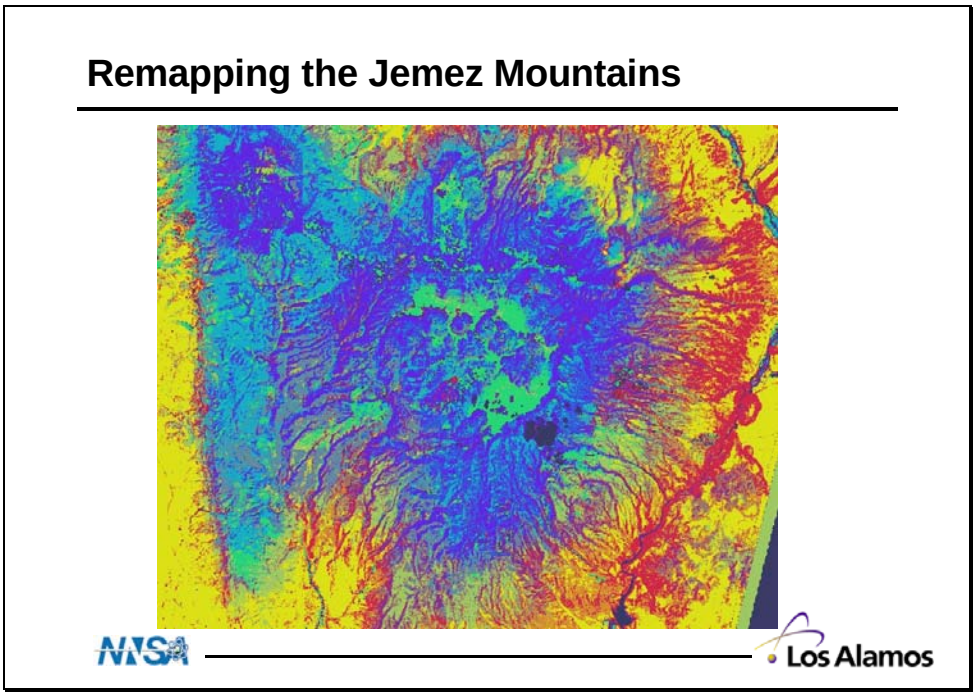
For the Cerro Grande/Los Alamos wildfire, GENIE evolved an algorithm for detecting high severity burn in Landsat ETM+ imagery that reproduced the details of hand-drawn map produced by US Forest Service experts.



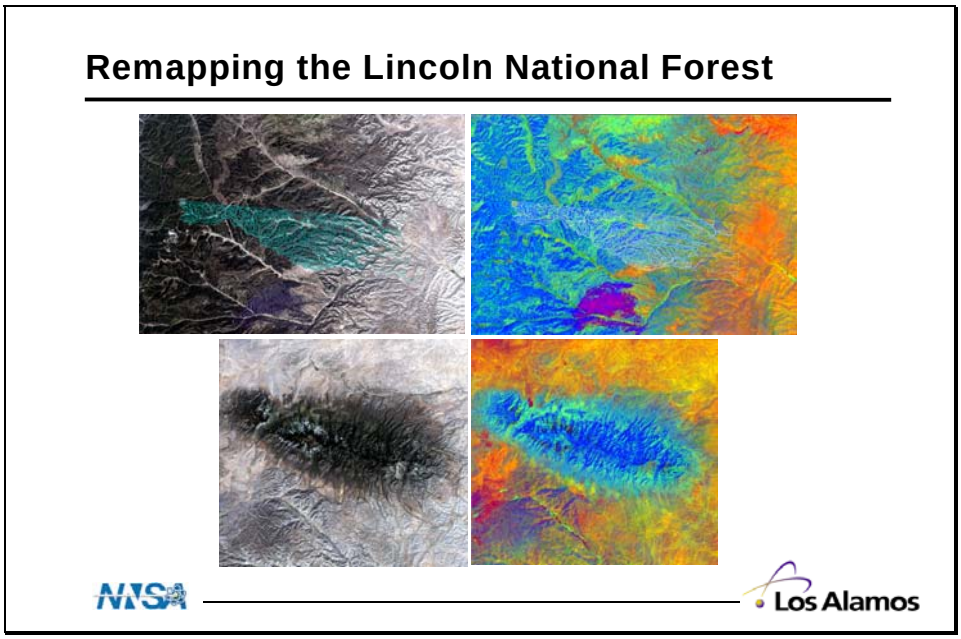
GENIE produced results that enabled fast and accurate analysis of the damage and loss of habitat caused by the Cerro Grande/Los Alamos wildfire.



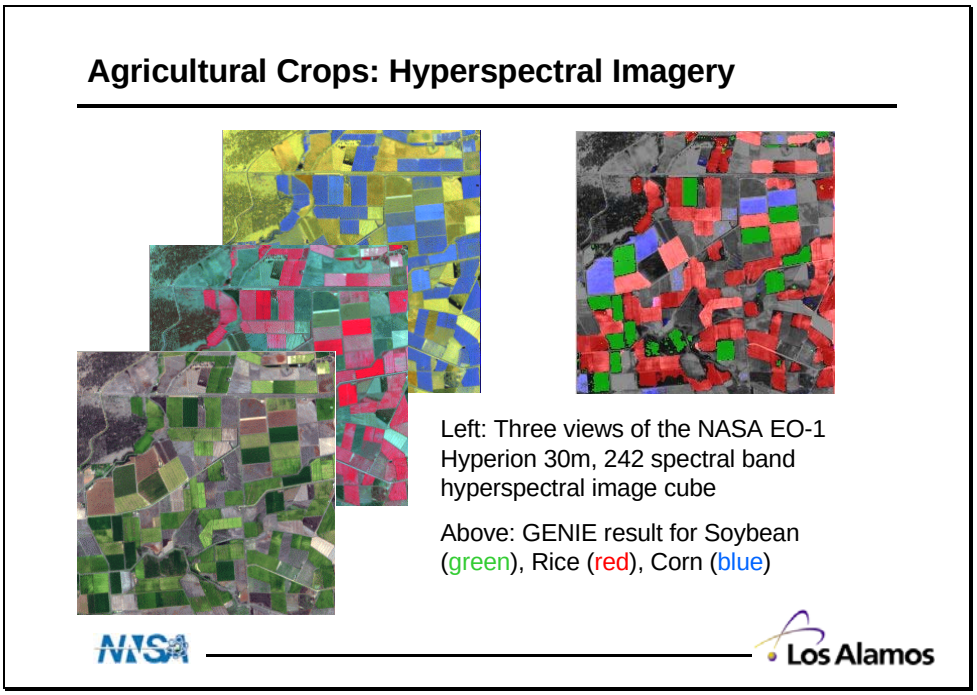
Another advantage of the GENIE system is that its algorithms show robust performance outside of the training region. In this example, we show how a series of land-cover classifiers evolved by GENIE using training data from a human-made land-cover map focused on the town of Los Alamos (right) can be applied to a much larger region covering the entire Jemez Mountains (left). The land-cover classifiers appear to continue to work well through-out the Landsat tile. Such robust behavior can be very helpful to regional planning authorities managing lands with diverse ownership possessing inconsistent or incomplete land-cover/land-use maps.



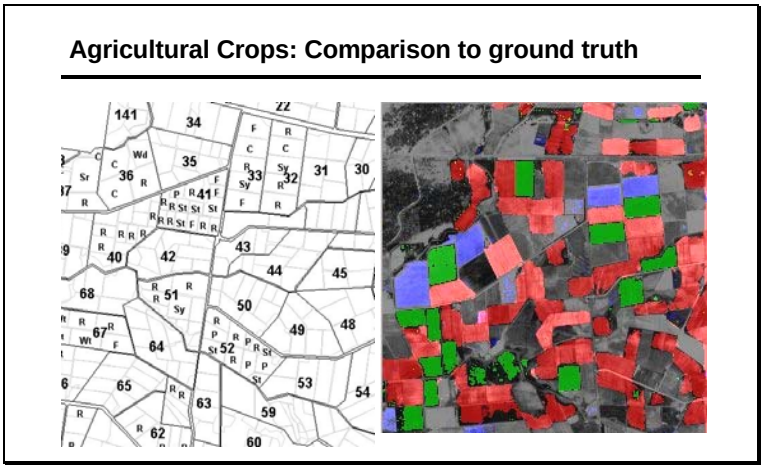
We are currently investigating machine-learning schemes for finer classification of vegetative land-cover, producing many more categories of land-cover, to support forest stewardship and wildfire prevention/ modeling.



GENIE's successful application to the Cerro Grande/Los Alamos wildfire has led to ongoing collaboration with US Forest Service. One test case will be the Lincoln National Forest in southern New Mexico.



GENIE has been used to identify commerical agricultural crops using NASA Hyperion 30m infrared hyper-spectral imagery.

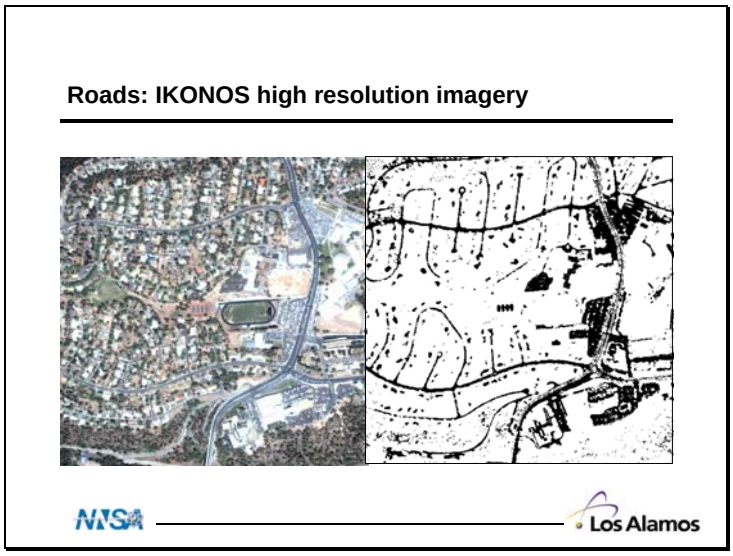


GENIE's map for several commercial agricultural crops (right), compared to a ground truth map provided by the farmers.

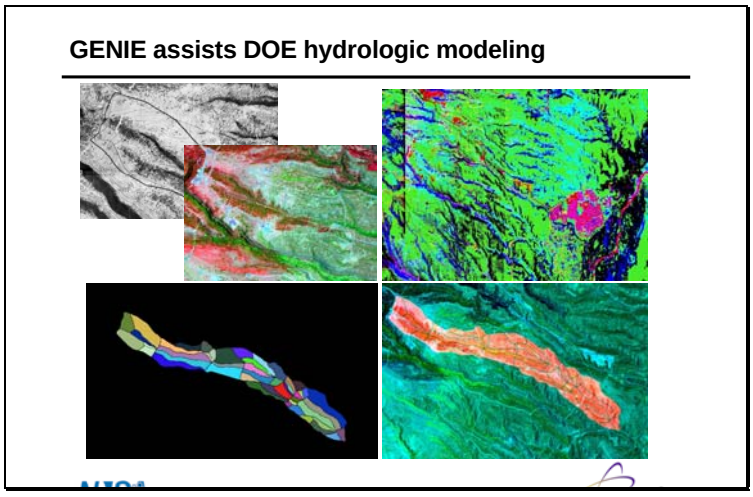
Quantitative Results

Feature	Training Scene		Test Scene	
	Detection Rate [%]	False Alarm Rate [%]	Detection Rate [%]	False Alarm Rate [%]
Rice	99.88	0.22	96.82	4.4
Soy	99.93	0.0	100.0	5.82
Corn	98.75	1.0	75.0	0.85

Results for the detection of crops in NASA Hyperion data.



Example of GENIE being used to estimate areal fraction of roads and other impermeable surfaces in IKONOS high-resolution commercial satellite imagery.



Example of GENIE being used to estimate land-cover classes for a hydrological modeling application, using an airborne multispectral imager. GENIE was used to update land-cover maps and estimate new surface properties for hydrologic model cells, and compare changing land-cover to archival aerial photos.

Conclusions

- ISIS tools have been successfully applied to many imagery datasets
- Software is available for download for Linux computers from isis.lanl.gov
- ISIS tools exploit textural and spectral signatures, new work aims to include geometric signature

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