Evaluation of Java™ Advanced Imaging as a Basis for Image Processing Applications in the Earth Sciences

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Affiliated Research Center

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Final Report:

Evaluation of Java™ Advanced Imaging as a Basis for Image Processing Applications in the Earth Sciences

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Preface

This project was the twelfth completed under the auspices of the NASA John C. Stennis Space Center Affiliated Research Center (ARC) as established on the campus of the Utah State University of Agriculture and Applied Science by the Commercial Remote Sensing Program (CRSP) under Cooperative Agreement No. NCC13-18. The ARC is administered through the Office of the College of Natural Resources and the Space Dynamics Laboratory of Utah State University Research Foundation. Their support is acknowledged and appreciated. The contributions of many persons have made possible the successful accomplishments listed in the report that follows, including those in private industry, government, and education. Of particular mention are Brian Burkhalter (JAI Product Engineer and ARC project PI) of Sun Microsystems, Inc.; Dr. Nathan Sovik, Dr. Bruce Davis, Dr. Molly Macauley, Dr. Paul Maughan, Stan Woolley, and Doc Smoot at SSC; and Laurie Littledike, Dr. David Norton, Dr. Allan Steed, and Richard Spencer of Utah State University. The guidance and support of the National Aeronautics and Space Administration is appreciated.

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Executive Summary

Sun Microsystems, Inc., developed the Java™ Advanced Imaging (JAI) Application Programmer's Interface (API) as a general purpose package to serve as the basis for Java™ image processing applications in a variety of domains. These domains included but were not limited to geospatial data processing, medical imaging, document imaging, defense and intelligence, and electronic commerce. Although a variety of expertise was available during the course of the design and development of the product, this does not guarantee the usability or completeness of the product in a given application domain. To assess the value of JAI in the application domain of the Earth Sciences, which is a subset of the geospatial data processing market segment, Sun decided to participate in the ARC project with Utah State University (USU).

The primary objective of the study was to determine whether JAI provided an adequate basis upon which image-processing applications for Earth Sciences usage could be developed. To this end, the USU/Sun Microsystems team formulated a matrix of requirements (Table 1), and JAI was inspected and utilized to evaluate whether these various requirements were satisfied either directly or by virtue of enabling technology. Some demonstration software using JAI was also developed to illustrate its image format handling and display capabilities as well as its usage in a typical Earth Sciences algorithm. A secondary objective was to establish contacts with potential users of JAI in areas related to the Earth Sciences.

The results of the evaluation were that JAI satisfied the majority of requirements directly; i.e., by furnishing the desired behavior without additional programming effort. In the majority of cases where required functionality was not provided directly, functionality was found to be implementable by means of the extensibility interface. The cases in which use of the extensibility interface was called for were all outside what the JAI designers considered to be the scope of general purpose imaging functionality. The remaining requirements that were not satisfied by JAI were instead considered to be outside the scope of the project and were in all cases available via other Java™ packages. The demonstration software showed JAI's ability to load data file formats typical in the Earth Sciences, to generate a classification map from those data, and to display and store the imagery and the class map.

Participation in the ARC project enabled Sun to enhance its knowledge of how well JAI satisfied the requirements of applications in the Earth Sciences and in remote sensing. This information will be utilized eventually to ascertain whether new functionality needs to be added to JAI to improve usability in this application domain and, if so, what functionality is lacking. In the course of this study, USU introduced Sun Microsystems to various elements of the U.S. Bureau of Land Management’s mapping division. It is expected that a sustained partnership by Sun Microsystems and USU may continue to provide additional contacts in the future.

1.0 Introduction

1.1 Company Profile

Sun Microsystems, Inc., was incorporated in 1982; its CEO and Chairman is Scott McNealy. The firm employs approximately 27,000 people, and 20 employees are working on the Java™ Advanced Imaging (JAI) project. Brian Burkhalter is the lead software engineer working on the project. Sun Microsystems markets a wide variety of computer products, including computer systems and peripherals, software, and networking. The JAI group is committed to having global acceptance for JAI in its key target markets: astronomy, medical imaging, geospatial data processing, defense and intelligence, document imaging, photography, e-commerce, and retail. The group wants JAI to have the functions and features that users will need. The long-term goal for JAI is to make it easy to use so that imaging companies can reduce the time required to produce a marketable product. The objective is to make JAI the imaging application programmer's interface (API) with the best available price-to-performance ratio. The goal is to meet or exceed the requirements and expectations of all users of JAI.

1.2 Purpose of ARC Partnership

Sun Microsystems, Inc., and Utah State University (USU) investigated the utility to Earth Sciences application developers of a Java™-based image processing application programmer's interface called Java™ Advanced Imaging. JAI is a standard extension to the Java™ platform intended for developing image processing applications and applets in Java™. The API streamlines the process of creating powerful imaging software solutions and facilitates image processing to be accomplished on any class of computer for which a Java™ 2 compatible virtual machine is available.

The JAI API has been developed by Sun Microsystems, Inc., in collaboration with academic, governmental, and corporate partners per the Java™ Community Process. The JAI 1.0 product specifications were jointly developed with Autometric, Inc.; Eastman Kodak, Inc.; and Siemens Corporate Research, Inc. The current version of JAI is JAI 1.0.2, which was released in December 1999.

This software is designed to run on operating systems that support the Java™ 2 Platform. An important capability of the package is its support for distributed image processing. This makes possible the processing of images using disparate computational resources that may be in entirely different physical locations.

Sun Microsystems is interested in making the JAI software more attractive to developers of image processing software used in the Earth Sciences domain by incorporating more of the functionality required by this market segment. The primary focus of this project is to add value to JAI and to enable it to better function in real-world, Earth Science-based remote sensing activities. The NASA USU Affiliated Research Center (ARC) team assisted through software evaluation and prototyping of proof of concept products that Sun can use to further the development of the JAI product. Sun Microsystems can use this research to evaluate JAI

applications in the Earth Sciences (including remote sensing and geographic information systems (GIS)) and potentially to add new functionality to future versions of the JAI software.

Potential customers of applications in this functional domain include the following:

- Government agencies that utilize remote sensing and GIS technologies
- Private companies with remote sensing laboratories
- Land users and managers
- Natural resource managers
- Universities with remote sensing laboratories

2.0 Project Description

2.1 Project Technical Approach

Sun Microsystems has developed a Java™ image processing application programmer's interface. It was desirable that a remote sensing laboratory assist Sun Microsystems in identifying applications for this software and test its functionality in real-world conditions. The steps undertaken to achieve these objectives were as follows:

1. Sun Microsystems Computer Systems representatives made a site visit to USU during the project to train USU staff on JAI software. In the course of this visit, USU staff demonstrated current image processing software being utilized in the Earth Sciences and remote sensing. The emphasis was on the demonstration of current state-of-the-practice functionality available in commercial-off-the-shelf packages used in earth-science-based remote sensing laboratories.
2. The project team used Sun Microsystems Java™ Advanced Imaging software to evaluate its capabilities in a specific application area (natural resource management and mapping). An evaluation of hardware and software requirements needed to perform a typical image-processing job using both currently available software and the enhanced JAI product was performed.
3. The project team evaluated the output and functionality of the software on remotely sensed imagery contained in USU's RS/GIS Lab data archives.
4. Throughout the project, the team explored new functionality for JAI aimed at natural resource management and mapping applications.
5. The team tested the viability of JAI using imagery of various sizes and types.
6. The final meeting was held between Sun Microsystems and the USU ARC project staff in Logan, Utah, on January 21, 2000. The USU staff presented the results of its investigative and prototypical investigations in terms of a functionality evaluation matrix and demonstration software, respectively. The results were discussed and consensus was achieved on all items that had been unclear.

7. The requirements with respect to JAI that were investigated included the following:
    - Preprocessing: radiometric correction, topographic slope and aspect effects, geometric correction.
    - Display and enhancement: includes file I/O, sub-banding, zoom/subsampling, spatial filtering, Fourier analysis, vegetation indexes.
    - Information extraction: classification, ancillary data handling.
    - Cartographic composition: printing, raster/vector data handling and merging.

2.2 Resources Provided

Sun Microsystems Computer Systems provided the following resources:

- Five hours per week until the proof of concept was achieved.
- Travel for Sun employees to Logan, Utah, for project meetings and training.
- Java™ Advanced Imaging software.
- Image processing and JAI software coding expertise.

Utah State University provided the following resources:

- 40 - 50 hours per week by staff and students through the proof-of-concept phase.
- Expertise with available remote sensing applications and software.
- Experience with mapping and interpreting environmental areas.
- Knowledge of application techniques of remote sensing.
- 30-meter resolution Thematic Mapper (TM) imagery and other image products as needed (owned by USU RS/GIS Lab).

3.0 Results

From the point of view of Sun Microsystems, the USU ARC investigation was valuable for two primary reasons. First, the study validated the initial content of the first version of the JAI specification and reference implementation. Second, the project provided an indication of some areas in which improvement could be made to enhance the value of JAI for use in the Earth Sciences, natural resource management, mapping, and remote sensing.

The content of JAI may be considered to be composed of two principal components: 1) the core, which provides generic image data handling features, such as tiling, deferred execution, multithreading, memory management, and network-awareness; and 2) the specific operations, which are based upon the core and made available directly to the user, such as image file input/output and image operators (filtering, geometric operations, etc.).

The study validated that the set of image processing operators and file format support provided a reasonable if not comprehensive basis for image processing applications in the Earth Sciences and related areas. The project also verified that the core architecture was sufficiently robust, especially in terms of its extensibility to support user implementation of operators that were not provided directly by JAI. Essentially all investigated capabilities were available directly from JAI, from straightforward user implementation using JAI's extensibility mechanism, or from other Java™ packages provided by the Java™ 2 virtual machine itself.

The study also provided guidance as to what new capabilities would be of most interest in the Earth Sciences and related areas. Principal among these were the various forms of supervised, unsupervised, and hybrid (spatial-spectral and contextual) classification. This was valuable information that is closely related if not integral to an area of capability that can be added to JAI in the future; i.e., image analysis.

Table 1. JAI functionality matrix.

Sun Microsystems, Inc./Utah State University
Affiliated Research Center Project

Evaluation of Java Advanced Imaging API for Utility
in Natural Resource Management Image Processing

Image Processing Requirements	Class Available in JAI 1.02	Considered for JAI 1.1	Responsibility of Application Developer	Available via Extensibility	Not Available	Additional Comments
Preprocessing						
Radiometric correction						
System corrections				X		e.g., LandSat fails on a scan line, how to "repair" it **MedianFilter ( )**
Atmospheric corrections (Deconvolution)				X		Removal of atmospheric attenuation, including scattering and absorption. This is a Must if you want to work with the hyperspectral imagery community or to normalize multi-date imagery for change detection apps
Topographic slope & aspect effects						Removal of all topographically induced illumination variation so that 2 objects having the same reflectance properties show the same brightness value in the image despite their different orientation to the sun's position
Simple cosine correction method				X		$L_H = \cos \theta_0 / \cos i$
Semiemperical methods				X		Minnaert Method and C Correction (includes Lambertian surface coefficient)
Statistical-Empirical Correction				X		Correlates predicted illumination from a digital elevation model with actual remote sensor data thereby allowing the rotation of the regression line such that a specific object (e.g., a particular type of deciduous forest) independent of **cos *i*** and produces the same Brightness Value (BV) throughout the image for this object.
Geometric correction						Takes into account errors due to platform altitude and attitude changes

Image Processing Requirements	Class Available in JAI 1.02	Considered for JAI 1.1	Responsibility of Application Developer	Available via Extensibility	Not Available	Additional Comments
Image-to-image registration	X					Translation and rotation alignment (coregistration of imagery). Should allow user to choose how or if data is manipulated spectrally during the geometric translation (zero-order or "nearest neighbor", first-order or "bilinear interp.", and cubic convolution) **"Warp"** or **"Affine"**
Image-to-map rectification	X					Process to make image geometry planimetric. Involves spatial interpolation as well as intensity interpolation (BV's). May not remove all topo effects.
Orthorectification of aerial photos				X		
Display and Enhancement						
File I/O	X			X		New I/O module in development to complement JAI 1.1 GEOTIFF and other industry standards are covered via the extensibility of the JAI package. **JAI.create ( ) "Fileload"**
Black & white, color-composite display	X					**BandSelect** – Allows for 3-color representation of >3 channel data. **ScrollingImagePanel ( ) swing component**
Density slice (color table manipulation)	X					**IndexColorModel**
Zoom (+, -)	X					**Scale** works for Zoom
Pan and Roam			X			No function in place for pan and roam
Image resampling						
Decimation	X					**JAI.create("scale")**
Pyramid layering	X					**ImagePyramid ( ), ImageMIPMap ( )**
Interpolation	X					**JAI.create("scale")** Nearest, Bicubic, BicubicZ, Bilinear
Transects				X		Important for evaluation of profiles within imagery
Contrast manipulation	X					**Rescale, Piecewise, Matchcdf (Histogram)** **JAI.create ("convolve")**

Image Processing Requirements	Class Available in JAI 1.02	Considered for JAI 1.1	Responsibility of Application Developer	Available via Extensibility	Not Available	Additional Comments
Image algebra	X					**BandSelect**, **no layer stacking operator though** (See Chapter 6 of *Programming in Java Advanced Imaging*, http://java.sun.com/products/java-media/jai/forDevelopers/jai1_0_1guide-unc/JAITOC.fm.html
Band ratioing	X					Can be applied to reduce the effects of environmental conditions
Image differencing	X					
Layer stacking		X				
Spatial filtering						
Convolution filtering						Convolution **(JAI.create("convolve", ???, null))**
Low/high pass filters	X					
Edge enhancement	X					GradientMagnitude function; Pixel by pixel w/ Threshold.value; sharp
Fourier Analysis						
Fast Fourier Transform	X					DFT **(JAI.create("DFT"))** Discrete Fourier Transform
Inverse Fast Fourier Transform	X					IDFT Inverse Discrete Fourier Transform
Special Transformations						
Principal Component Analysis			X			
Vegetation Indexes						
Normalized Difference Vegetation Index	X					JAI Image Algebra allows implementation
Tasseled Cap				X		JAI Image Algebra allows implementation
Frequency transformations (Fourier, cosine, etc.)	X					DFT, DCT **(JAI.create("DFT"))** Discrete Fourier Transform, Discrete Cosine Transform
Digital Elevation Models						Implemented with Java 3D?
For processing uses		X				
For 3-D visualization uses					X	
Animation	X					May require interoperability with Java Media File
Information Extraction						

Image Processing Requirements	Class Available in JAI 1.02	Considered for JAI 1.1	Responsibility of Application Developer	Available via Extensibility	Not Available	Additional Comments
Supervised classification						
Parallelepiped algorithm				X		Decision rule based on simple Boolean logic. Standard deviation thresholds create n-dimensional space parallelepiped based on training data. If a pixel falls into one of the created parallelepipeds, it is assigned to that class; otherwise it is assigned to an "unclassified" category. Math libraries compute StdDev for each band using training points selected by user. Compare pixels for < or = stdDev specified. If within stdDev for All Bands, Add to class, otherwise place into "unclassified" class.
Minimum distance				X		User defines mean vectors for each class with training data. Euclidean distance to vector determines minimum distance and therefore defines class assignment for each pixel.
Maximum likelihood				X		
Unsupervised classification						
Multi-pass ISODATA (clustering)				X		
Hybrid classification using ancillary information					X	
Incorporation of ancillary data during classification			X			
Cartographic Composition and Other						
Scaled postscript output of images and maps			X			Can print (postscript implementable)
Vector/Raster based GIS						Vector only but there are no attribute handlers

4.0 Metrics

Performance metrics are an integral component of the ARC project to realize increased sales and profit. Sun Microsystems expects this product eventually to be used by various government, private, and educational organizations. This product can provide the basis for further applications, making it possible for more people to use the technology over the Internet. Advances in the remote sensing science will be realized as new and faster techniques are designed.

During the course of this project, upper management within Sun Microsystems determined that they were stretched too thin with their many ongoing product development activities. The result is an extended development period for JAI 1.1. It is, therefore, not possible to directly address many of the originally proposed metrics for this project at this time. Dollar values are currently unknown; however, USU is dedicated to tracking this product over the next several years to provide metrics feedback as the product is marketed.

Sun Microsystems believes that the use of JAI could save developers a lot of money versus developing a product from "zero" but cannot, at this time, provide numbers on increased sales resulting from this project. While it is likely that the information learned from this project will support adding certain functionality in some future release of JAI, it is unlikely that this product will be the next release (again, partially due to the extension of the development schedule).

5.0 Conclusions

As outlined in greater detail in the "Results" section above, this ARC project was of benefit to Sun Microsystems primarily in two ways:

1. Verification of Existing Design and Implementation of JAI
    - Most operators required for Earth Science applications in terms of input/output, processing, and display of imagery are available directly from JAI or from other packages in the Java™ virtual machine.
    - More specialized operators not provided by JAI could be implemented by application developers in the Earth Sciences.
2. Indication of Potential Improvements to JAI
    - Principal areas of improvement that would make JAI more attractive to Earth Sciences developers were identified (see matrix above).
    - The areas of potential enhancement consist mostly of new operators that developers could presently add themselves using JAI's inherent extensibility.

The expertise of the investigators at USU was found to be particularly valuable in terms of providing verification of Sun Microsystems' efforts to date and in furnishing greater insight into the use of image processing for Earth Science applications.