User Friendly Desktop Internet GIS (*uDig*) for OpenGIS Spatial Data Infrastructures

Solicitation #: 23516-03GEOI/A
Client Reference #: 23516-3-GEOI

GeoInnovations Target Area: **1 (GML Tools / WFS Clients & Connectors)**

Submitted By: Paul Ramsey, Director
Refractions Research Inc.
Suite 400 – 1207 Douglas Street
Victoria, BC, V8W-2E7
pramsey@refractions.net
http://www.refractions.net
Phone: (250) 383-3022
Fax: (250) 383-2140

Procurement Business #: 878913029PG0001

Proposal Date: December 17, 2003
Valid Until: May 17, 2004

3 PROJECT PROPOSAL

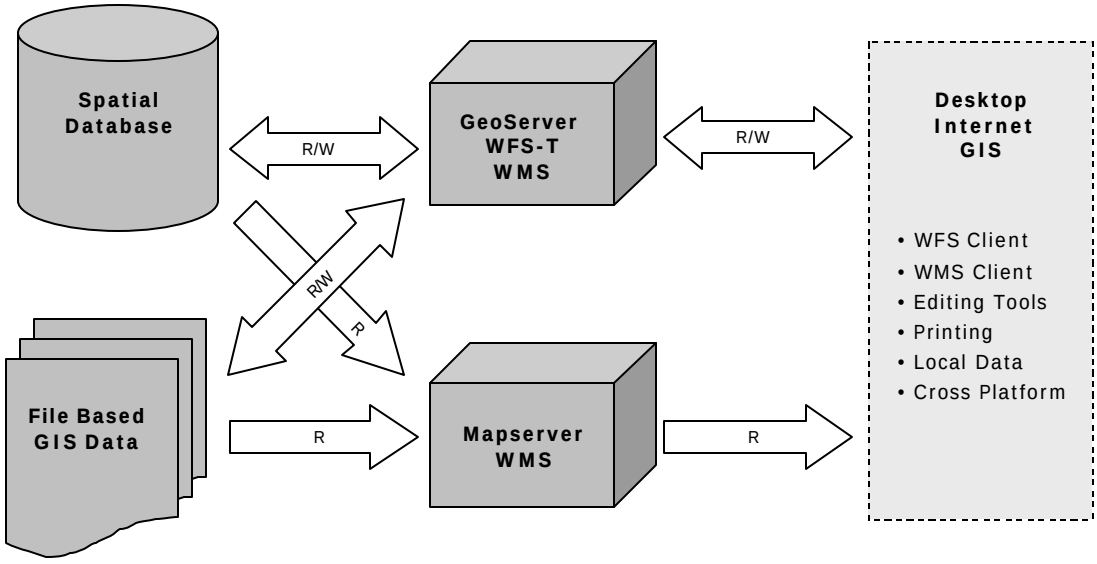
3.1 Innovation

3.1.1 Summary

The User-friendly Desktop Internet GIS for OpenGIS Spatial Data Infrastructures project (*uDig*) will create an open-source desktop GIS application, to make viewing, editing, and printing data from CGDI and local data sources simple for ordinary computer users.

Open-source components are a critical part of the CGDI vision, because they allow organizations to deploy infrastructure widely, in a distributed fashion, without incurring multiple licensing fees. Open-source components are also the most tractable for fast support of new OpenGIS interoperability standards.

There are already many different pieces of open-source software that implement OpenGIS server standards: Mapserver implements WMS, GeoServer implements WMS and WFS-T, PostGIS implements SFSQL, DeeGree implements WMS and WFS, and so on. However, there is not a single piece of desktop software capable of binding information from all these servers together into a unified desktop view. *uDig* is the open-source application which will bring CGDI data sources to the desktop, and integrate them with local data sources for standard business processes – data viewing, data editing, and data printing.



Interactive desktop access is the missing application in open-source OpenGIS standards-based spatial infrastructures

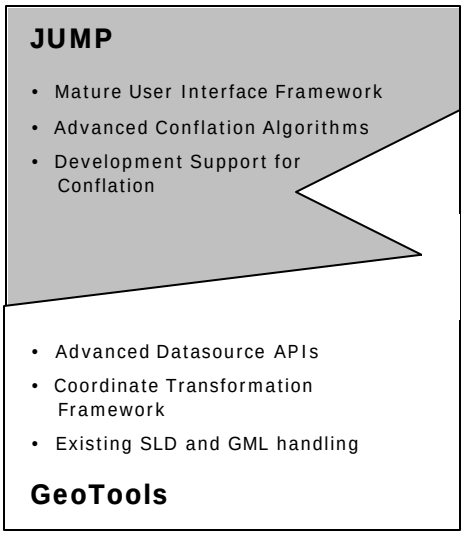
The *uDig* application will have the following capabilities:

- **WFS client read/write support**, to allow direct editing of data exposed via transactional Web Feature Servers (WFS-T).
- **WMS support**, to allow viewing of background data published via WMS.
- **Styled Layer Descriptor (SLD) support**, to allow the client-directed dynamic re-styling of WMS layers.
- **Web Catalog Server support**, for quick location of available CGDI layers.
- **Printing support**, to allow users to create standard and large format cartography from their desktops using CGDI data sources.
- **Standard GIS file format support**, to allow users to directly open, overlay, and edit local Shape and GeoTIFF files with CGDI online data.
- **Coordinate projection support**, to transparently integrate remote layers in the client application where necessary.
- **Database access support**, to allow users to directly open, overlay and edit data stored in PostGIS, OracleSpatial, ArcSDE, and MySQL.
- **Cross-platform support**, using Java as an implementation language, and providing one-click setup files for Windows, OS/X, Linux and Solaris.
- **Multi-lingual design**, allowing easy internationalization of the interface, with French and English translations of the interface completed initially.
- **Customizability and modularity**, to allow third party developers to add new capabilities, or strip out existing capabilities as necessary when integrating the application with existing enterprise infrastructures.

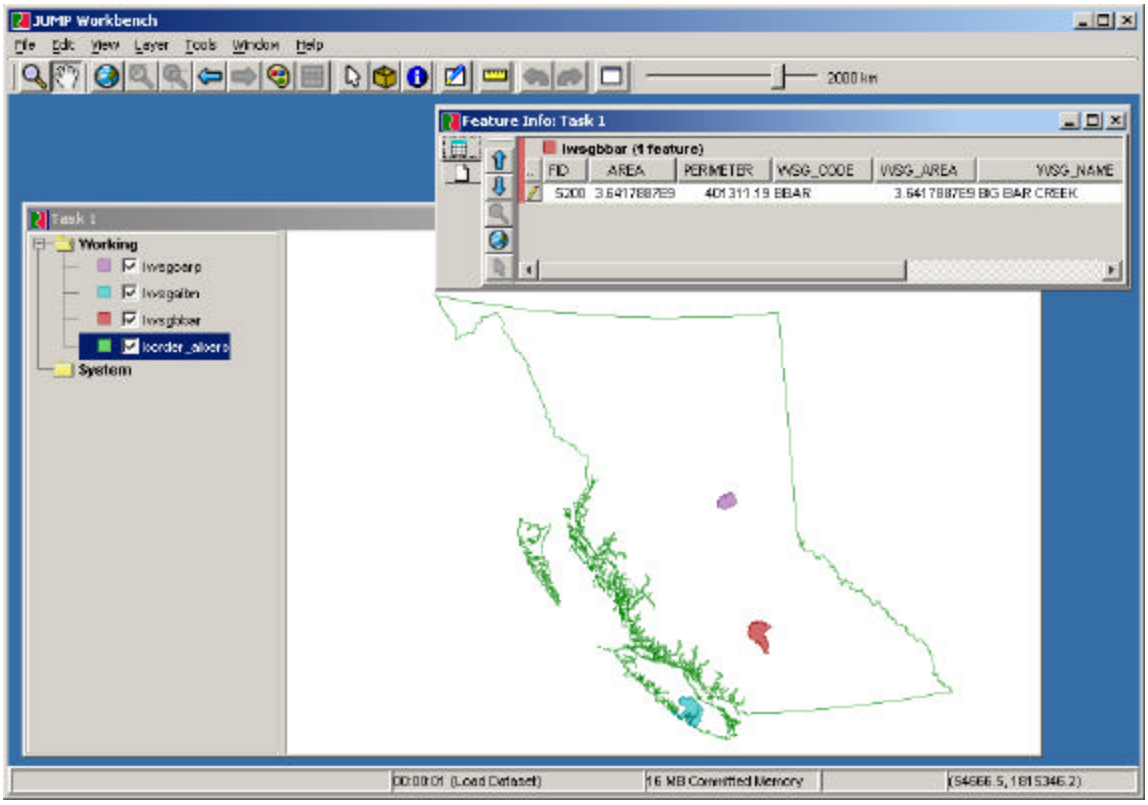
The capabilities list above is *extremely ambitious*, but is achievable by *leveraging existing functionality* available in open-source libraries.

We propose combining the functionality from two complementary open-source Java libraries:

- GeoTools (www.geotools.org), a strong OpenGIS infrastructure library that has advanced data access API, SLD, GML, and coordinate transformation support, but lacks a user interface.
- JUMP (www.jump-project.org), an existing spatial data interface framework, that has advanced data editing tools, data manipulation algorithms (such as warping, buffering, overlays, etc), a modular plug-in framework, but has relatively primitive data source support, no coordinate projection support, and no SLD support.



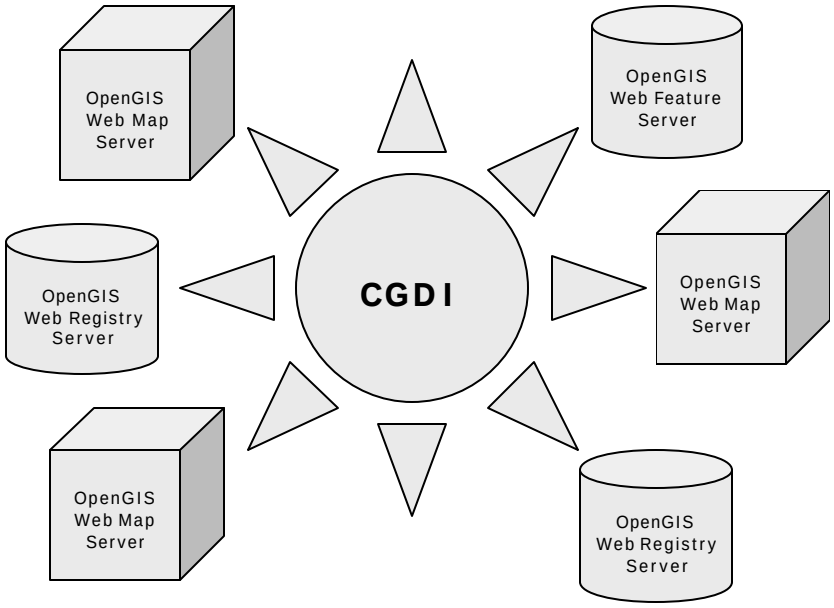
By combining the strongest aspects of the two projects, a uniquely capable application can be created, with less effort than building an application from scratch.



The JUMP framework has a simple desktop workbench, but lacks flexible data sources, coordinatey projection support, or SLD support.

3.1.2 Statement of Problem

The Canadian Geospatial Data Infrastructure (CGDI) has been successful in promoting the acceptance of OpenGIS internet standards, and encouraging Canadian organizations to publish data using those standards. As a result, there is a large amount of Canadian data available via standard open interfaces.



The Transactional Web Feature Server (WFS-T) standard is a popular OpenGIS standard for transactional editing of data over the internet. Several implementations, both open-source (GeoServer) and proprietary (CubeWerx) of the standard exist, and many organizations are studying WFS-T as a means of distributing maintenance of their data holdings.

However, the acceptance of WFS-T as a useful editing protocol is currently limited by the fact that there is no widely available, easy to use, interface to WFS data that can both read and edit the data transactionally. Current WFS client software is either

(a) entirely browser based, and necessarily of clunky design or

(b) bundled as an add-on to expensive desktop GIS software.

There is no WFS read/write client product available which can be widely deployed by organizations without incurring substantial financial overhead, or accepting a limiting browser-based interface.

Organizations that want to build WFS-T functionality into integrated business applications have a similar problem, in that WFS client component software is proprietary and multi-seat licensing can be prohibitive to under-funded organizations.

3.1.3 Objectives and Outcomes

The objective of this project is to build a user-friendly desktop internet GIS application — a "*uDig*"— as an open-source product, with source code freely licensed under the GNU General Public License (GPL).

The application must meet the needs of ordinary GIS users, as a viewer and basic data editor:

- Use a simple and consistent user interface paradigm
- View and edit data from different internet sources (WMS, WFS)
- View and edit data from different local data sources (files, databases)
- Integrate all data sources into a single view and projection on the fly
- Provide an interactive experience, even when using slower internet data sources
- Have a printing capability, to put internet and local data onto a paper map
- Work on all major desktop platforms (Windows, OS/X, Linux)

In addition, the application framework should be extensible by third party developers. It must be easy to add or remove functionality from the application or to embed components of the application in another system. The application must:

- Have a plug-in interface to allow open-source or proprietary third-party functionality to be added at runtime.
- Have a component model that allows portions of the system to be detached from the main interface and used in external applications.
- Have complete source code documentation and a programmers guide.

The completed product should have a positive outcome in the geospatial community of practice:

- The tool should be widely adopted for use by GIS generalists, in organizations at all levels of government and industry.
- The open-source project should attract third party developers and collaborative funders to continue to support development.
- The open-source project should work with the OpenGIS consortium to advance open-source as a means of promoting interoperability goals.

The completed product will provide a basis for sales and marketing of:

- Supported versions of open-source spatial infrastructure, WFS servers, WMS servers, spatial databases. With a capable desktop client, integrating internet publishing and operational data management becomes possible for organizations.

- Supported versions of the *uDig* desktop client. For organizations with larger deployments, supported versions, with a standard upgrade cycle and guaranteed testing methodology will be sold.
- Integration and customization services. For organizations wanting to add spatial data capability to their applications, or add special analytic or display functionality to *uDig*.

3.1.4 Building on Existing Open-source Technology

The proposed capabilities of the *uDig* desktop applications are extremely ambitious. These capabilities can be provided in a timely and cost effective fashion by leveraging existing open-source development into a new integrated product.

We are proposing to integrate two or more advanced open-source libraries to create the new *uDig* client. Rather than a group-up engineering exercise, the project will consist of targeted enhancements to the existing libraries, and application code to bind them together into a single program for end users.

Refractions Research is already working closely with the GeoTools development group to enhance the GeoServer web feature server, and with the JUMP development group to product visual interfaces for spatial data conflation problems. Eclipse is the standard Java development environment for Refractions Research.

The GeoTools spatial library (www.geotools.org) provides the following data handling capabilities:

- Connectivity to GIS data file sources.
- Connectivity to spatial databases.
- Coordinate transformation support.
- Styled layer descriptor support.
- Basic GML processing infrastructure.

The JUMP interface project (www.jump-project.org) provides the following interface capabilities:

- Interactive spatial feature editing.
- Interactive spatial feature styling, symbolism, transparency, fills.
- Simple user interface tools for spatial data.

The Eclipse platform project (www.eclipse.org) provides the following application design capabilities:

- High performance cross-platform Java user interface libraries.
- Advanced plug-in framework for integrating third party code.
- Very large user community and testing framework.

3.1.5 Meeting CGDI and GeoInnovations Goals

The *uDig* project meets the GeoInnovations Target area 2, goal 1, providing an interactive Web Feature Server (WFS) client, with viewing and editing capabilities, as well as the full capabilities of a general desktop GIS viewing application.

The *uDig* project will further provide additional benefits to the CGDI in several important ways.

- By enhancing the GeoTools and JUMP libraries and making them more widely usable by CGDI members.
- The open-source *uDig* application can be freely deployed by CGDI members,, without any proprietary licensing mechanisms.
- Supported versions of the *uDig* application and training / installation services will be available from Refractions, using materials developed in part by this project.
- Free access to OpenGIS compatible technologies like *uDig* will help promote the CGDI standards for Canada's spatial data infrastructure.
- By providing an innovative means of distributing data maintenance tasks (through WFS servers and clients) without relaxing the data quality control provided by a spatial database.

As organizations maintain large and changing data sets (such as roads, parcels, even social information like community mapping) there is going to be a need for distributed access and editing. Tools for data editing and viewing need to be made available to the larger community in order to promote the goals of a nationwide spatial system like CGDI.

3.1.6 Marketable Products

The *uDig* project will create important marketable products and services:

- Refractions will offer for sale a supported version of *uDig*, with one-click installation on Windows, Linux, and OS/X. The supported version will include user documentation, annual versioned updates, and quality assurance guarantees.
- Refractions will offer consulting services in customizing *uDig*, either integrating it into business applications, or in adding spatial processing capabilities for tasks such as data conflation, automatic data processing.
- Refractions will offer consulting services in creating vertically integrated spatial data infrastructures, using the *uDig* and related open-source components, such as GeoServer, Mapserver and PostGIS/PostgreSQL.

3.2 Technical Feasibility and Risk Assessment

Refractions believes the *uDig* project is technically feasible and of low risk.

- We will be making extensive use of existing open-source background intellectual property to lower development effort.
- We will be working in well-contained development stages, and doing background research where implementation directions are not immediately clear.
- We will be ensuring that source code control and versioning are maintained throughout the project.
- We will be managing risk at all phases.

3.2.1 Methodology

Our technical methodology for the *uDig* project involves:

- Use of standards to maintain interoperability and act as **guides of well-considered design solutions**.
- Use of open-source software to **maximize leverage of existing background intellectual property**.
- Project management principles to ensure that schedules and targets are **updated and realistic** at all phases of the project.
- Source code control to ensure that all project members can work **simultaneously and without code synchronization problems**.
- Iterative design to ensure that working implementations are available at early phases of the project, and that **early implementation lessons can be applied to later designs**.

3.2.1.1 Use of Standards

Refractions develops products using standards as a guide to required system functionality and rational system architecture. Our PostGIS/PostgreSQL spatial extension uses the OpenGIS Simple Features for SQL standard, because it promotes the interoperability of the product, provides a design pattern to inform the direction of development, and makes the product relevant to the wide range of clients who are invested in the standards process.

Where applicable standards exist, the *uDig* project will make use of them. We anticipate that the following standards will be heavily used during the project:

- OpenGIS Web Feature Server standard, the basic client/server protocol of GeoServer and the basis for the project.
- Geographic Markup Language (GML), the basic format for WFS spatial data transfer.
- OpenGIS Web Map Server standard, for multiple version compatibility with WMS servers.

- W3C Consortium XML, for external file formats, and as a constituent of GML.
- W3C Consortium XML Schema, for data schema restrictions as part of validation.
- OpenGIS "Simple Features for SQL" standard, the design standard behind the Java Topology Suite, and PostGIS/PostgreSQL.
- Java Database Connectivity (JDBC) for connections to backend spatial databases.

In addition, the recently published OpenGIS discussion paper, "Integrated Client for Multiple OGC-compliant Services" (OGC 03-021) will provide an initial guide to implementation as well as a source of useful "lessons learned".

3.2.1.2 Use of Open-source Software

Refractions has committed to both use and improve on open-source software as a part of our business operations. One practical effect of this commitment is the PostGIS/PostgreSQL spatial database extension, and our involvement in the GeoServer WFS project. Another is this proposal, which will improve on the existing GeoTools and JUMP code bases in order to provide an innovative new application.

The *uDig* project will use open-source software in order to maximize our technical productivity. The project will be in Java, and will therefore make extensive use of the Apache/Jakarta family of open-source Java libraries. Open-source Java XML processing libraries will also be used.

The following open-source products will support the *uDig* project:

- Apache/Tomcat (jakarta.apache.org/tomcat) as the development test bed for J2EE applications.
- GeoTools (www.geotools.org) as the base library for spatial data access and filters.
- Java Topology Suite (www.vividsolutions.com/jts/jtshome.htm) as the base library for spatial data representation and topological tests.
- JUMP (www.jump-project.org) as an interface framework and editing toolkit.
- GeoServer (geoserver.sourceforge.org) as a WFS reference implementation.
- Mapserver (mapserver.gis.umn.edu) as a WMS and WFS reference implementation.
- PostGIS/PostgreSQL as a data source to GeoServer for testing.
- Jakarta (jakarta.apache.org) Java development libraries (Log4J, Ant, Struts, etc).
- Eclipse (www.eclipse.org) as an application and plug-in framework.

3.2.1.3 Project Management

The Refractions *uDig* team includes a dedicated Project Management resource. This team member will be responsible for ensuring that all project activities are monitored, and that the status of each activity is regularly updated in the project plan.

Refractions Research will apply its standard Project Management methodologies to the *uDig* project, to ensure a successful outcome. The various components or Project Management can be grouped into five categories:

- Project Planning;
- Risk Management;
- Issue Management;
- Change Management; and
- Quality Management.

Project Planning

As part of this GeoInnovations submission, Refractions has developed a detailed project plan, including a breakdown of tasks, personnel assigned, effort required, and start and completion dates. Also, the project scope and objectives have been clearly defined. The Project Manager will use information contained in this submission as a baseline project plan, and will develop more detailed work plans which ensure that deliverables are clear and that workload is optimally distributed among the resources.

The project plan and work plans will be updated on a daily or weekly basis as progress is made and tasks are completed. Furthermore, project plans and work plans on a project of non-trivial size must be flexible, and allow for unexpected delays, additional tangential tasks, and even to accommodate early task completion. Refractions' Project Manager will work to anticipate such developments through daily correspondence with project staff, and will update the project plan and work plans when necessary.

Risk Management

Refractions believes that the exhaustive work we have performed to develop this GeoInnovations proposal has resulted in a document which mitigates much of the risk associated with the *uDig* project. We have a clear vision, attainable objectives, a highly skilled project team, and a sound project plan. Furthermore, Refractions is highly experienced in the technological fields which dominate this project.

Refractions Research is a stable company with strong relationships with public and private sector organizations. We feel strongly that we have assembled a team that can achieve the goals of the *uDig* project. In the event that a resource becomes unavailable for a certain project role, we have identified potential replacement team members with similar skills who could take on that role.

Refractions has performed sufficient research, and has specific experience, knowledge and skills, to be confident of a successful outcome for the *uDig* project

Issue Management

Through experience, Refractions Research knows that issues will arise during the course of a project, which require some sort of decision or resolution. The more ambitious the project, the greater the number of issues to be handled. Efficient, issue management is therefore critical. Refractions Issue Management methodology consists of a number of logical steps:

- Identification of an issue
- Description of the issue and its implications
- Research, test and report on proposed solutions
- Selection of optimal solution in a meeting of key stakeholders

Furthermore, issue management documentation is maintained by the Project Manager, ensuring that project participants can view information about a current issue, and review issues which have been closed.

Change Management

Parameters of a project typically change, at least to a small degree, during the course of a project. These changes can be motivated by the client, or by information gained by the project staff as they complete project tasks. Often a change will be initiated based on the Issue Management process. Refractions Change Management methodology consists of a number of logical steps:

- Identification of each requested change
- Analysis of dependencies and what the effects will be to other tasks/modules
- Decision on approval of the change
- Update to project plan and work plan reflecting the change
- Notification of all project team members
- Follow-up review of the change and its effect on other tasks/modules

Change management documentation is maintained by the Project Manager, ensuring that project participants can view information about a current issue, and review issues which have been closed.

Quality Management

Refractions believes that a project is not successful unless all of our client's requirements are met. To ensure this is always the case, Refractions utilizes a comprehensive Quality Management plan:

- Quality Planning is the process of identifying project objectives and using these objectives to define quality standards and measures of success. The Project Manager is chiefly responsible for Quality Planning.
- As modules or tasks are completed, Quality Control Testing will ensure that work completed meets Refractions' code, application, document and product standards.

- Quality Assurance: Throughout the project, the quality standards defined during Quality Planning will be used to test project deliverables, and to ensure a successful outcome.

Project Management Summary

Refractions Research has successfully completed dozens of medium and large scale projects. Our comprehensive Project Management approach includes several distinct management methodologies which ensure successful outcomes while acknowledging the complex nature of many projects. The implementation of Project Planning, Risk Management, Issue Management, Change Management and Quality Management are important responsibilities for our Project Managers.

3.2.1.4 Source Code Control and Version Management

All *uDig* source code and documentation will be managed in a Concurrent Versioning System (CVS) archive. The CVS will be linked to a project web site, which will allow daily snapshots of API documentation and project progress to be generated for use by the project team and GeoInnovations staff.

3.2.1.5 Iterative Design

The *uDig* project will work within an "iterative design" framework. "Iterative design" is a means of combining implementation cycles with design cycles. The iterative design process is as follows:

1. Define the minimum feature-set which can be fully implemented into a working system.
2. Implement the minimum feature-set and test the working system.
3. Document the design lessons learned during the implementation phase.
4. Use the lessons learned in the previous implementation to change the system design, and add a subset of additional features to the system, ending with a working testable system.
5. Repeat steps 3 and 4 for each new feature set.

The result of iterative design is a system which is informed by the implementation characteristics of the problem. The advantage of iterative design is that it mitigates the risks involved in integrated design-implement-test processes. Single-stage processes collapse all the design risk into a single implementation phase – if the design is incorrect, the level of effort necessary to recover is very high. Iterative processes spread implementation risk over numerous small phases, and a mistake at any one phase has a relatively low recovery cost.

3.2.2 Intellectual Property

The *uDig* will be making use of extensive **background intellectual property** via re-use of open-source code. Only background intellectual property licensed under non-discriminatory open-source licenses will be used.

The foreground intellectual property created during this project will be largely integrated into the GeoTools and JUMP projects. Some components of the foreground intellectual property will remain proprietary to Refractions Research. The following intellectual property will be included in the open-source GeoTools project:

- WFS DataStore code for reading from and writing to WFS servers.
- Enhancements for streaming (read / write directly to disk / database) data sources.
- Enhancements for streaming (read / write directly to disk) raster handling capabilities.
- Support for raster coordinate re-projection.
- Support for direct editing of features from re-projected data sources.

We anticipate the following foreground intellectual property will be owned by Refractions Research but licensed under an open-source license:

- The uDig application itself, with all specific application level enhancements that are not directly included in the JUMP or GeoTools libraries.
- The uDig users guides, developers guides and training materials.

3.2.3 Risks

3.2.3.1 Technical

The primary technical risks are associated with user interface issues in the new application:

- Defining a sufficiently flexible printing user interface without creating excessive development effort.
- Creating large format print outputs using the Java printing API, which has been primary tested with letter sized text-rich output.
- Creating a canvas that can edit dynamically reprojected inputs and pass the resultants back to the source databases without coordinate drift or transaction issues.

We will work to mitigate the technical risk by:

- Performing early research into the capabilities of key components and identifying replacement libraries or mitigating development in the case of an un-avoidable deficiency.

- Performing simple test cases early in the design process, to understand the abilities and limitations of the libraries we are using for development.
- Working with the GeoTools team to ensure that the underlying infrastructure can be cleanly used in an interactive applications.

3.2.3.2 Resources

Refractions has many other skilled designers, including Paul Ramsey and Jeff Lounsbury, either of whom can take on the lead design role. Java implementation responsibilities will be shared amongst the rest of the staff. Java implementation skills are also easily obtainable from graduates of the nearby University of Victoria, which uses Java as the core of the Computing Science curriculum.

3.2.3.3 Access to Data

There is no substantial risk associated with data access. Test data for the system is readily available from the BC Ministry of Sustainable Resource Management, who is a partner on this project. Additionally, synthetic data will be used to test system response to degenerate cases.

3.2.3.4 Commitments

There is no substantial risk associated with other corporate commitments. Adequate resources in staff time and physical resources are committed to complete the project as outlined in this proposal. Additional corporate commitments will be met with additional resources above and beyond the *uDig* resources.

3.2.3.5 Project Dependencies

The *uDig* project has no project dependencies, and can proceed with the GeoTools, JUMP, and Eclipse projects in their current state.

3.3 Durability and Sustainability

3.3.1 Impact of Future Developments

The *uDig* project is tightly tied to the WFS standard, and the future sustainability of that standard. As an OpenGIS standard, endorsed by CGDI, we feel that WFS should have a reasonable life span. As a young standard, WFS is likely to increase in penetration in the near term.

The evolution of the WFS standard over time presents a potential future impact. Changes in the standard will require changes to the implementations. We feel that by integrating with the GeoTools spatial data-sources, we obtain maximum future-proofing – as an active open-source project, GeoTools will continue to track developments in the standard as they are publicly released by the OpenGIS Consortium. Because it is an open-source project, GeoTools can be updated by third parties to maintain relevance as WFS requirements change over time.

Other new internet GIS technologies are introduced by the OpenGIS consortium, the *uDig* application will have to be updated to take advantage of them. The most likely candidates for future integration at this time are the Web Coverage Server, which provides online access to raster data, and the Web Registry Server, which catalogues available internet services. The Web Registry Server may make *uDig* even more powerful, allowing dynamic configuration and data discovery based on current view area and available servers.

3.3.2 Sustainability

The *uDig* application is predicated on concepts of extensibility, which in turn promote sustainability:

- The GeoTools core libraries can serve as the basis for additional OpenGIS web services. Future possible projects include a GeoCoding Client, and Gazetteer Client to allow quick location finding. Because the core modules (data accessors, filters and topological tests, coordinate support, rendering infrastructure) are componentized and reusable, the overall libraries will be sustained in the long term by many parties.
- The *uDig* architecture will be explicitly based on plugable components. As a result, new interface tools and data manipulation components can be added to the system without substantial re-working of the core. This promotes the easy sustainability of the project.

3.3.3 Track Record

In general, open-source projects tend to be self-maintaining over time once they reach a certain critical mass of number of users and active code contributors. The Linux, Apache, Mapserver, and PostgreSQL products are all examples of projects will have been and will continue to be sustainable and durable over the long term, even though none have a single corporate entity backing them. We believe the GeoTools project – and by extension the *uDig* application based on GeoTools– will have the same self-sustaining life cycle.

In particular, Refractions has demonstrated a commitment to product sustainability in developing and maintaining the PostGIS/PostgreSQL open-source spatial database extension (postgis.refractions.net). Initially released in May 2001, the PostGIS extension has gone through 10 release cycles since then and continues in active development. The code is currently downloaded over 600 times per month, and the active participants in the PostGIS users mailing list number over 400. New releases of PostGIS are planned throughout 2004, with raster support and network support to be included.

As a part of our 2003 GeoInnovations project, Refractions is currently directly involved in the development of the GeoServer open-source Web Feature Server, which can provide WFS services to PostGIS, Oracle and SDE databases. We have added a new data locking API which has increased performance by 15 fold, and are providing ongoing development and support to the project as a whole.

Refractions has the same commitment to the *uDig* project as it has had to the PostGIS and GeoServer projects.

3.4 Standards and Interoperability

The *uDig* project will provide a client that is completely consistent with the CGDI architectures and makes use of CGDI standards:

- *uDig* will act as a Web Feature Server client
- *uDig* will provide access to GML data sources via WMS
- *uDig* will act as a Web Map Server client
- *uDig* will prototype a Web Registry Server search capability

In addition to being completely standards compliant as a client, the *uDig* project will be providing critical enhancements to open-source technology that promote standards:

- The *uDig* project will enhance the GeoServer WFS project by providing a WFS client data store.
- The *uDig* project will enhance the OpenGIS Web Registry Server standard by providing a test implementation of a WRS client and providing feedback to the standards body.

Finally, the *uDig* project will promote interoperability by binding together data from multiple sources – both OpenGIS standards based and proprietary based – into a single interface for ordinary users to consume. With a simple usable interface for common spatial data tasks available, using and maintaining data in OpenGIS / CGDI based infrastructures becomes more realistic for ordinary users.

The *uDig* architecture and underlying libraries are all based on the OpenGIS Simple Features module. In fact, both GeoTools and JUMP share the underlying JTS Topology Suite as a standard geometry and geometry processing model – JTS uses the Simple Features Model as the implementation guide. The JTS Topology Suite was originally funded by GeoConnections to provide a standard library for building data manipulation tools.