Volume 1 - Technical

A **Proposal** in Response to **BAA 04-12, Addendum 2** Technical Area: **DSO GEO***

Meshless wavelets and their application to terrain modeling

PIs: Jack Snoeyink (leader), Leonard McMillan, Marc Pollefeys, Wei Wang (UNC-CH)
Charles Chui, Wenjie He (UMSL)

Department of Computer Science
University of North Carolina at Chapel Hill
Sitterson Hall, CB #3175
Chapel Hill, NC 27599-3175

Type of Business: **OTHER EDUCATIONAL**

Technical	Administrative
Professor Jack Snoeyink Voice: 919-962-1969 Fax: 919-962-1799 snoeyink@cs.unc.edu	Ms. Victoria Moore Voice: 919-962-3397 victoria_moore@unc.edu

Award Instrument Requested: **GRANT**

Performance period	Primary focus	Cost
Phase 1 **18 months**	**Mathematical devel & feasibility**	**764,945**
Phase 2 **18 months**	**Application and prototype devel**	**841,900**
Phase 3 **12 months**	**Intensive devel of key applications**	**393,427**
Phase 4 **12 months**	**Transition to industry**	**354,417**

Offeror’s DCMA and DCAA Office:
Department of Health and Human Services
Mid-Atlantic Office, Cohen Building
3330 Independence Avenue SW, Room 1067
Washington, D.C. 20201
202-260-7896

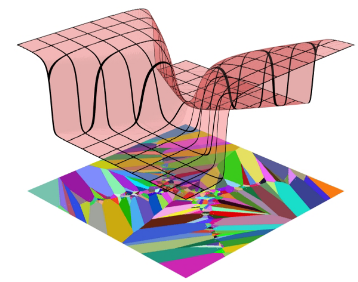
DUNS: 608195277, TIN: 56-6001393A1, CAGE CODE: 4B856

June 25, 2004

1 Executive Summary

We propose a new representation for geospatial data that is optimized for specific geometric and image queries in addition to being compact. Our representation employs "meshless" bivariate wavelets defined over scattered point sets. These scattered point sets act as the knots of multi-level bivariate B-splines. This allows for a far more flexible description than previous representations since the point set can be specified without connectivity and each point's influence is local, while still supporting the multiscale analysis afforded by wavelets.

The research objectives of this proposal are threefold. First, we will complete the theory of bivariate meshless wavelets. Second, we will develop point/knot selection algorithms which are optimized for specific geometric tasks and data queries. And third we will realize a practical implementation that demonstrates the advantages of our modeling approach.



Meshless wavelets have many theoretical advantages over previous wavelet representations defined over either regular grids or triangular meshes. General image compression methods on geospatial data are oblivious to later analysis operations that will be applied to the data. Their goal is merely to reconstruct an approximation of the original input with good visual fidelity. Our approach allows for locally adapted sampling within a multi-level representation, thus providing greater compression. Meshless wavelets will be better suited for describing both slow-varying and oscillatory data than mesh wavelets as a result of their higher degree and vanishing moments. Our representation need not pay the storage overhead of a mesh description, because that is implicit in the local geometry. They also have distinct advantages over second generation wavelets and radial-basis function representations.

A key advantage of our modeling approach for geospatial applications is that the point set (knot) selection can be optimized to maintain desired geometric properties of the data, such as the fidelity of isolines or the maintenance of critical geometric features. This is an essential property for accurate path-planning and image registration. It allows us to provide compact representations for several applications that are optimized for both efficiency and accuracy.

A crucial aspect of our approach is the flexibility to select key point-set features. We propose algorithms for selecting optimal point sets for specific geometric and registration tasks. In particular, we are interested in supporting point-to-point visibility calculations, route planning, image-to-geometry registration, geometry-to-geometry registration, image-based geometric queries, accurate isoline generation, and the computation of point-to-point geodesic paths. Identifying these point sets will require significant analysis including the identification of projective invariants, critical points, and singularities. Furthermore, we will consider agglomerative merging strategies as well as dispersive reduction/simplification approaches.

Domain specificity is central to effective compression. It is unrealistic to expect that compression methods designed to represent images would be equally efficient for representing geographic height-field information. Moreover, the fidelity measurements used in accessing image quality (Minimal mean-squared error) are not necessarily the most significant metrics for height-fields. We propose to develop new compressed representations specifically for geospatial data. Moreover, our approach supports irregular sampling (reducing errors introduced by resampling), a hierarchical structure (supporting multiscale processing and progressive transmission), and it can be tailored to support specific applications.

We have organized our proposed efforts into four phases, which may be summarized as

Phase 1. (18mo) the mathematics of meshless wavelets and finding key points for applications to include compression, registration, route planning, and visibility.

Phase 2. (18mo) developing prototypes for these applications on top of the meshless wavelets and key points representations,

Phase 3. (12mo) Option to develop one or more applications in detail, and

Phase 4. (12mo) Option for additional focused efforts by the PIs to transition technology to an industrial or military partner.

The core efforts of phases 1&2 – the development of meshless wavelets and selection of key points for applications – make the transition from theory to practice during this project. Optional activities within phase one (three-d reconstruction, and feasibility demonstration) give resources to explore other impacts of the meshless wavelet representation or produce demonstrations of feasibility in code in addition to technical white papers. Options in phase two give an idea of the costs of integrating the new modeling approach within the application areas suggested in the GEO* addendum.

2 Proposed Work

> The key to the computer modeling of landscape dynamics is a large map of a region, represented in the computer's memory as rows and columns of squares, each one corresponding to an actual square parcel of land.
> Kenneth E.F. Watt, Yearbook of Science, Encyclopedia Britannica, 1993, p. 352.

2.1 Motivation and Outline

Terrain data is irregular, no matter how often users of DTED (digital terrain elevation data) try to tell you otherwise. It is irregular because geographic phenomena are irregular, and occur at a wide range of spatial and temporal scales. It is irregular because the applications of terrain data have different needs: breaklines and extrema for visibility (observer placement or avoidance), low-slope regions for mobility and trafficability, illumination-invariant feature points for registration. It is irregular because it is conflated from many sources (through data fusion from several sensor modalities at several resolutions.) For time-critical and mission-critical applications of terrain, it is imperative to adapt the representation to its use.

Nevertheless, the most common terrain representation is as a raster grid of heights. Arbitrarily creating for each pixel its "actual square parcel of land" does have some advantages: raster grids storing coordinates and connectivity implicitly, are amenable to processing in hardware, and support multiscale analysis by subsampling. The limitations of force-fitting to square parcels becomes increasingly apparent as we add new sensor capabilities. We can now gather vast amounts of detailed spatial data with less cost and less risk to equipment and personnel. The benefits of this data can only be realized, however, if its information can be quickly extracted, succinctly represented, and correctly communicated at the appropriate level of abstraction to the men or machines that can use it effectively.

It can be difficult to extract information from data, and to integrate it with prior knowledge that may have different accuracy and level of detail. Because current representations often aim for the lowest common denominator, they do not easily combine, say, the irregular post spacing of LIDAR with imagery, or a coarse base map with very detailed refinements in selected strips. Current tools focus on batch processing by sequential steps, and do not attempt to maintain local consistency. The net result is that the flood of data from new sensors can delay processing, obscure the essentials, and hinder the tasks that it is intended to support.

Our meshless wavelets will have the advantages of multiscale analysis and implicit coordinates but in a much richer spline/wavelet format. Section 2.2 describes their development. In parallel, we will develop ways to extract hierarchies of key points for particular applications; as Section 2.3 describes, these are needed for the meshless wavelets, and will be useful for any domain-specific compression or multiscale analysis.

2.2 Meshless spline wavelet representation from irregular samples

Mathematical ideas: Simplex splines, tight-frame wavelets, small support, moment recovery approximate duals, vanishing moment recovery matrices.

Approach: meshless wavelet approach to multi-level modeling and analysis of scattered data, particularly of complex terrain data sets.

We will develop a novel hierarchical representation that does not depend on any mesh structure (such as rectangular or triangular meshes) but provides multiscale wavelet analysis for splines defined by irregular sampled data and imagery. This representation will enable applications that require transmission and analysis of large, complex terrain and image data.

The common mathematical abstraction of a terrain is as a height field over a 2-d domain, which is then represented by either a raster (regularly sampled on a grid) or a TIN (Triangulated Irregular Network; a triangulation that uses piecewise linear interpolation between irregular sample points) [23]. Rasters are ideal for base-level maps, and are extensively used for analysis tasks, especially those that can be cast as batch processing by applying filter kernels. TINs are better able to represent irregularly sampled data, but they do not integrate well with imagery that is more uniform (although not necessarily isotropic). The choice of linear interpolation is also limiting: TINs require extra points to represent even slowly varying data. Oscillating data must be represented in great detail, since linear wavelets have only one vanishing moment.

All of the traditional wavelet approaches [1, 5, 6, 7, 15, 17, 41, 44] have deficiencies for terrain applications: A regular mesh format is rigid, forcing a choice of scale that cannot accommodate the fastest varying features in a scene [1, 41, 44]. Other wavelet representations, such as second-generation wavelets constructed by the lifting scheme [36], achieve only one vanishing moment, which means that oscillating data cannot be compressed well. Radial-basis wavelets [11] are not effective for local updates due to their more global structure. Several types of spline representations are used as smoother representations, but they commonly return to a gridded set of knots, or they do not integrate well with imagery.

This mathematical development is a natural extension of our theory of tight-frame wavelets for univariate spline functions on a nested sequence of arbitrary knots to the bivariate case [8, 10, 9]. In preparing to request funding, we have already been able to lay the foundation for the bivariate case of tight-frame wavelets, with the construction of moment recovery approximate duals and vanishing moment recovery (VMR) matrices.

We are able to integrate meshless spline and wavelet representations by combining several technical ideas and new advances, which we can expand upon as desired. First, Neamtu's work [30, 31] gives a spline representation for irregular data: The scattered data set becomes the knot set for a bivariate B-spline, defined by summing up the appropriate simplex splines of specific degree k using k-th order Delaunay configurations.

Let k be a non-negative integer, $\mathcal{D}$ a bounded convex polygonal domain in $\mathbb{R}^2$, and T a knot set in $\mathcal{D}$. For any $X^J = \{\mathbf{x}^j : j \in J\} \subset T$ with $\#X^J = k+3$, one can define a simplex spline of degree k and knot set X^J by $M(\mathbf{x}|X^J) := \frac{\mathrm{vol}_k\{\mathbf{v}\in\sigma:\mathbf{v}|\mathbb{R}^2=\mathbf{x}\}}{\mathrm{vol}_{k+2}\sigma}$, such that the projection of the set of vertices of simplex σ to $\mathbb{R}^2$ is X^J. The space Π_k^2 of bivariate polynomials of (total) degree k is locally generated by simplex splines defined on the *Delaunay configuration* $\Delta_k = \{(X_B, X_I)\}$ of degree k introduced by Neamtu [30, 31]. Let $N(\cdot|X_B \cup X_I) := \binom{k+2}{2}^{-1} \mathrm{area}[X_B]\ M(\cdot|X_B \cup X_I)$.To reduce redundancy, simplex splines with the same interior knots X_I are combined:

$$B_I := \sum_{(X_B,X_I)\in\Delta_k, K=I} N(\cdot|X_B \cup X_K),\ I \in \mathcal{I}_k := \{I : (X_B, X_I) \in \Delta_k, \#X_B = 3\}.$$

Second, we choose a suitable nested sequence of knot subsets of the original knot set, to form a multi-level approximation by bivariate B-splines. Let $T^{(0)} \subset T^{(1)} \subset \cdots \subset T^{(j)} \subset \cdots$ be a nested sequence of knot sets, where $T^{(j)} = \{\mathbf{x}_\ell^{(j)}, \ell \in \mathbb{M}_j\},\ j \geq 0$, for some index set $\mathbb{M}_j$, with union dense in $\mathcal{D}$. Let $\Delta_k^{(j)}$ denote the Delaunay configuration associated with the knot set $T^{(j)}$, and $\Phi_j = [\phi_{j,\ell} :\ \ell \in \mathbb{N}_j]$ represent bivariate B-splines $[B_I : I \in \mathcal{I}_k]$ corresponding to $\Delta_k^{(j)}$. The refinement matrices P_j between the basis functions of level j and $j+1$, that is, $\Phi_j = \Phi_{j+1} P_j$, can be derived by the "knot insertion" identity

$$M(\cdot|X^J) = \sum_{i=0}^{r} c_i M(\cdot|X_i^J \cup \{\mathbf{y}\}), \tag{1}$$

where $X_i^J := X^J \backslash \{\mathbf{x}^i\}$, $\mathbf{x}^i \in X^J$ and $\mathbf{y} = \sum_{i=0}^r c_i \mathbf{x}^i$ with $\sum_{i=0}^r c_i = 1$.

Third, we introduce the notion of tight-frame wavelets with maximum order $m = k+1$ of vanishing moments corresponding to this multi-level approximation. Tight frames are a more redundant representation than orthonormal wavelets, but the additional freedom is necessary to have small support or, equivalently, short wavelet filters, for both analysis and synthesis phases.

Let $\{Q_j\}_{j \ge 0}$ be the two-scale matrices of the wavelets $\{\Psi_j\}_{j\ge 0}$, that is, $\Psi_j = \Phi_{j+1} Q_j$. By introducing the operators $T_j f := [\langle f, \phi_{j,\ell}\rangle]\, S_j\, [\langle f, \phi_{j,\ell}\rangle]^T$ that associate with some symmetric matrices S_j's, the notion of tight wavelet frames is modified to mean that

$$T_0 f + \sum_{j\ge 0} \sum_{\ell} |\langle f, \psi_{j,\ell}\rangle|^2 = \|f\|^2, \qquad f \in L_2(\mathcal{D}). \tag{2}$$

Then the tight frame condition imposed on the nonstationary wavelets is equivalent to

$$\lim_{j\to\infty} T_j f = \|f\|^2,\ f \in L_2(\mathcal{D}) \text{ and } S_{j+1} - P_j S_j P_j^T = Q_j Q_j^T. \tag{3}$$

The number of vanishing moments is then necessary for the wavelets to be orthogonal to all polynomials of degree up to k, so that the wavelets fit with the spline representation. Vanishing moments also ensure that the significant information is in the lower order terms, restoring the ability to perform compression that would otherwise be lost.

A major problem here is to study and construct VMR matrices S_j's that meet the following three requirements:

1. $\Phi_j^{S_j} := [\phi_{j,\ell}^{S_j}]_{1\le \ell \le r_j} = \Phi_j\ S_j$ is the row-vector of approximate duals for Φ_j, that is,

$$\langle p, \phi_{j,\ell}^{S_j}\rangle \ = \ P(X_{I_\ell}), \qquad \text{for } 1 \le \ell \le r_j, \quad \text{and } j \ge 0, \tag{4}$$

   where P is the polar form of $p \in \Pi_k^2$.
2. The matrices $S_{j+1} - P_j S_j P_j^T$ are semi-positive definite.
3. $\lim_{j\to\infty} [\langle f, \phi_{j,\ell}\rangle]\, S_j\, [\langle f, \phi_{j,\ell}\rangle]^T = \|f\|^2, \qquad f \in L_2(\mathcal{D})$.

Another major problem of the proposed research is to derive a scheme for computing block banded matrices Q_j with uniformly bounded bandwidths, such that $S_{j+1} - P_j S_j P_j^T = Q_j Q_j^T$. Define the operator $T_{j,j+1} f := [\langle f, \phi_{j+1}\rangle](S_{j+1} - P_j S_j P_j^T)[\langle f, \phi_{j+1}\rangle]^T$ on $L^2(\mathcal{D})$. Then the irregular wavelets $\{\psi_{j,\ell}\}$ have maximum vanishing moments, if and only if $T_{j,j+1} p = 0$ for all $p \in \Pi_k^2$.

For computational purposes, we next introduce the notion of moment vectors $M_j^{(\nu)} := [M_{j,\ell}^{(\nu)}, \ell \in \mathbb{M}_j]$ associated with Φ_j, by $M_{j,\ell}^{(\nu)} := \int_{\mathcal{D}} x^{\nu_1} y^{\nu_2} \phi_{j,\ell}(x,y)dxdy$. If Ψ_j has the maximum order of vanishing moments, then $M_j^{(\nu)} Q_j = 0$ for $\nu_1 + \nu_2 \le k$. Hence, there exists a full-rank matrix E_j, such that $M_j^{(\nu)} E_j = 0$ and $Q_j = E_j\, \widehat{Q}_j$ for some matrix $\widehat{Q}_j$. The structure of these matrices E_j should greatly facilitate computational efficiency. We believe the "difference matrices" analogous to the one-dimensional setting in [9] can be derived by applying the derivative formula $D_{\mathbf{x}^j - \mathbf{x}^i} M(\cdot|X^J) = (k+2)[M(\cdot|X_j^J) - M(\cdot|X_i^J)]$ for simplex splines [2, 28].

This development will support the creation of B-splines on irregular knot sets that support full wavelet analysis, so that we can consider the properties of terrain at different "scales." The definition of scale here depends on the local distribution of the knot set, and part of our work will be to characterize this dependence for use in applications. By using wavelets with the maximum order of vanishing moments, appropriate quantization and thresholding can be applied to significantly reduce the size of the representation without loss of quality for the applications. Furthermore, the tight frame structure of these wavelets ensures stability. The locality of the spline and wavelet basis functions provide the same functionality as the univariate spline/wavelets on arbitrary nested knot sequences, but now for complex terrain and image data. This meshless wavelet representation should thus support progressive refinement and coarsening, and we will explore the best way to do so.

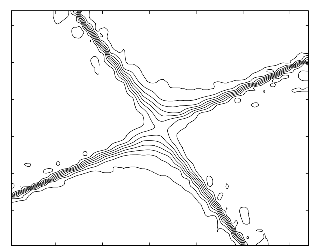
These representations may also be appropriate for gravimetric data, so we would be interested in interaction with other teams whose primary focus is gravimetric modeling.

2.3 Hierarchies of key points for specific applications

Mathematical ideas: Hierarchical sets of key points, invariant feature points,
Approach: Application-specific importance metrics for points

Meshless wavelets are built on top of a hierarchy of point sets. The construction of these hierarchies can be tuned to the intended application(s) of the representation. In this section, we briefly describe how selecting key points can result in highly compressed representations that remain effective for applications such as route planning, visibility, and image/terrain registration by feature points.

2.3.1 Route planning



The lossy image compression standard, JPEG2000, is being rapidly adopted as a representation for earth image data. JPEG2000 is a wavelet based encoder with significantly improved compression ratios relative to previous block-transform based JPEG compression. It is also inherently multiresolution and, thus, well suited for progressive transmission. Not only is JPEG2000 used for multispectal sensor data, it is also frequently applied to geometric data, in the form of uniformly sampled height-field data. However, JPEG2000 was designed primarily for compressing of continuous tone, photograph-like images, whose intended consumer is the human visual system. It was not optimized to maintain geometric fidelity or to support geometric operations or queries. Examples of the artifacts that result from processing geometry with JPEG2000 are shown at right. In this case the compression introduces high-frequency ringing artifacts, which are noticeable in the surface plot and it adds spurious structure to isovalue contour lines.

Conceptually this analytical surface is analogous to a ravine. A common military application for this data might route planning, and such a narrow passage might be a critical point on a large number of routes paths. However, ringing and smoothing artifacts such as those evident of the JPEG2000 representation could lead to significant errors when computing shortest paths. In the worst case such a ravine might even close in, or be blocked by a wave of non-existent ripples.

Ideally, one would like a representation that maintains high-fidelity models of critical features across a large range of scales. In addition to route-planning, similar arguments can be made for image-terrain registration and queries into the geo data.

2.3.2 Visibility

Computing visibility in a raster terrain is known as "viewshed analysis" in the GIS literature, e.g. [16], by analogy with the watershed analysis for drainage. Viewshed analysis is considered even more complex than watershed analysis because of the non-local nature of visibility. It benefits greatly from identifying the key points along ridges and silhouettes, to avoid spending the bulk of the computational effort on regions that are either entirely visible or entirely hidden. computation to this irregular set. Stewart's algorithms for visibility in terrain [35, 34] show this clearly, as they identify these key points and keep them in a data structure as the computation proceeds.

For watershed computation, the idea of a terrain representation that uses just the critical ridge and valley lines goes back twenty years to Douglas [13]. It never caught on because the collection of lines had no analysis framework, but that will now be able to be supplied by our meshless wavelets.

2.3.3 Feature points for matching across changes in perspective, illumination and imaging modality

Our goal is to extract feature points that allow to reliably register images to other images or to our terrain representation. This is challenging since multiple images can be acquired from viewpoints with different perspective projections or occlusions, with different sensor modalities (color, grayscale, infrared; even elevation) or under different illumination and appearance. Not only are there global changes in amount of light, but local changes due to cloud shadows, seasonal foliage, or even snow cover.

It is important to note that some of these changes can be predicted while others cannot. For example, if the orientation of the sensor is known, one could predict the perspective distortion. With know geometry, time and date, the location of shadows can be predicted. On the other hand, if we have no idea of the attitude of the sensor when it recorded an image, the perspective distortion is unknown.

This motivates two different mechanisms to enable matching over a wide range of possible variations. When the parameters guiding a change are known and a model is available to predict the change, we will use it to perform matching after having normalized for the change. However, when one or both of those are not available, we will attempt to match using feature points that are invariant to change. A simple example is with offsets in image intensities by subtracting the mean of image templates. The price paid for using invariance is that an entire equivalence class of different features map to the same invariant descriptor. In other words, using invariance to deal with changes diminishes the discriminatory power of feature descriptors. Thus we prefer to use models when possible and only rely on invariance when necessary.

In the scope of this project we will extract feature points suitable for matching across perspective, illumination and modality changes. The goal is to develop a feature selection mechanism that extracts the same feature points (i.e. points corresponding to the same world point) over a large range of perspective, illumination and modality variations. When constructing the terrain representation those points will be extracted at different scales and we intend to use them as nodes in our irregular multi-level point set underlying the spline wavelet representation.

For each feature point in our representation we will construct feature descriptors representative for the different observations that are available in the database. To match to previously unobserved variations, we will use transitivity. If feature 1 matches feature 2 under conditions A and 2 matches 3 under conditions B, then the likelihood that 1 matches 3 is also high. Note that the likelihood depends on the discriminatory power of a feature descriptor under certain circumstances, i.e. if white matches white when it has snowed, that does not mean that the underlying features really match. In other words, we intend to hallucinate the appearance of feature points under particular observation circumstances by looking at the appearance of similar features under similar circumstances. To perform those operations without preprocessing everything and building a hugely redundant representation, we will need to devise an efficient feature point look-up and matching.

After a redundant set of feature points has been extracted, feature points are analyzed and a subset of feature points is selected to be included in the terrain representation to support registration. The goal is to select a set of feature points that allow efficient unique and precise matching under the likely set of appearance changes. This representation will consist of features at multiple resolution levels. Some feature points might only be useful to deal with a subset of appearance changes. For reasons of efficiency we will develop heuristics to select the smallest possible set of feature points that allows registration over the full range of anticipated changes.

In the first phase we intend to develop the mathematical theory supporting both the invariant extraction of features as well as the transitive matching likelihood and implement a prototype. In the next phase we intend to perform a full scale implementation of this approach and integrate it with the developed terrain representation. In later phases we will work towards achieving the real-time requirements for registration applications.

3 Statement of Work

The core task of developing meshless wavelets has a number of steps. 1. Develop an efficient algorithm to generate the Delaunay configurations on given knot set in $\mathbb{R}^2$.
2. Find the formulation for the refinement matrix between two adjacent levels of bivariate B-spline bases functions in term of the corresponding two nested knot sequences based on the knot insertion formula of simplex splines.
3. Design a fast graphical displaying method for a bivariate simplex spline based on nonstationary subdivision scheme. This method will be extended to bivariate B-spline surfaces that approximate given height fields over 2-d domains. This step needs to use the result of Step 2.
4. Study the matrix factorization property corresponding to the vanishing moment condition. A formulation of the difference matrix will be derived from the derivative formula of simplex splines.
5. Find the formulation of the vanishing moment recovery matrices with the help of the polynomial reproduction property of the bivariate B-spline basis functions.

We intend to develop algorithms for dynamically generating Triangulated Irregular Networks (TINs) from meshless wavelets. TINs are useful representations for backward compatibility with existing GI and map information systems. TINs are also well suited for visualization and geometric queries. Moreover, TINs are useful support structures for meshless wavelets, particularly if they can be generated on demand at the required level of fidelity.

We will begin by triangulating the knots of the meshless wavelets. We will develop real-time algorithms for dynamically updating and refining these initial TINs. Our approach will combine simplification methods, based on progressive meshes [18], with data-dependent triangulations [14]. Our goal is to rely on local metrics for all mesh refinement and simplification, while maintaining a progressive multi-resolution representation. This will allow for accurate processing using only a subset of the full map database. We will also explore novel optimization criterions as objective functions for adapting the TIN construction. In particular, we are interested in minimizing errors along specified isocontours as well as satisfying other constraints.

Finally, we are interested in a new class of hierarchical simplification and retriangulation methods that can be modeled as higher-dimensional simplicial complexes, for which a given two dimensional slice would represent a particular TIN model. Moreover, smooth slices through a complex of tetrahedral would represent smooth transitions between TIN representations. We have already done preliminary experiments with a similar representation for computer vision applications with great success, and we are hopeful that it will be even more applicable to hierarchical map modeling.

We will also investigate algorithms for rapidly computing accurate geodesic approximations across the meshless wavelet. The computation of point-to-point geodesics is a central to path-planning. We first plan to adapt existing approximations methods developed for triangulated meshes. In particular, the methods of Kimmel and Sethian. We will also investigate the adaptation of exact geodesic methods such as Mitchell, Mount, and Papadimitriou. Our eventual goal, however, is to compute exact geodesics over the polynomial B-splines of the meshless wavelets. Ideally, we would also like to find upper and lower bounding constraints between successive levels of higher detail.

3.1 Registration of images

The key of our registration approach is use the novel feature points as described in this proposal. Those feature points combine a generative model of the feature appearance under different acquisition circumstances (including different sensors) for maximal discriminatory power with invariant descriptors to deal with unknown image acquisition parameters. Initial feature matches are obtained by searching for similar features in the database using appropriate indexes for efficiency. Those are filtered using principles of robust statistics and multiple view geometry so that the largest consistent set of features is obtained that could originate from a perspective view of the observed terrain. When initially multiple viable hypothesis are obtained those are each passed on to the next stage. Using those consistent match sets key acquisition parameters such as the camera pose and illumination can be computed. This allows to assume those parameters known and to shift some acquisition parameters in the descriptor from invariant mode to generative mode, yielding much better discrimination and much faster indexing and matching. This should allow to obtain many additional matches and to verify the existing matches. The next stage consists of refining the relative camera pose and other acquisition parameters using a maximum likelihood estimation approach over all the matches. This allows to achieve the highest possible accuracy and an estimate of the variances in pixels and in world coordinates. It also allows us to deals with uncertainties in the camera model. Given that we expect to localize each feature with an error of 0.5 pixels or less and that we will estimate a limited number of pose parameters from hundreds of feature matches which are each now within an estimated, we expect to achieve an overall registration accuracies far below a pixel (order of 0.1 pixels or below). For video streams advantage is taken of the small displacement between consecutive frames to achieve higher efficiency (note that this correspond to strong priors on the pose parameters allowing to mostly use generative instead of invariant descriptors and a highly restricted search).

The robust registration enables multiple application such as image stabilization, frame integration, super-resolution, passive moving target indication (robust filtering of local feature matches avoids the perturbation of the registration by moving objects), and three dimensional model building. Having particular experience with this last application (e.g. [32]), we propose to perform a specific effort to develop a real-time 3D terrain reconstruction, refinement and update approach that will build on our registration effort.

3.2 Efficient Database Retrieval

The vast quantity of data that we intend to process, forces us to consider how to best use databases to intelligently organize, index, and query our data. This data includes images, the geometric terrain model, and associated feature descriptors used to support efficient registration. The total number of feature points needed for a model of every land masses on earth would be on the order of hundreds of billions. Our goal is to support fast identification and retrieval of feature points from databases of this magnitude.

Existing work on image databases and spatial databases mainly focuses on managing simple imagery features [19, 22, 24, 29] (such as color histograms) and geometric features [21, 25, 33, 38, 39, 40, 42] (such as points and lines) and typically assumes databases of much smaller scales. The major challenge to be addressed is, given a query, how to quickly identify the potential targets to direct the query without an exhaustive search of the database. This is crucial in a realtime environment where queries need to be answered online. Ideally, many queries may be answered accurately without a full scan of the database.

To achieve this goal, a logical solution is to construct indexes on the feature points to facilitate the retrieval. We will exploit the multi-level representation of spline wavelets and the freedom of choosing feature points at each level of the hierarchy. For each feature point, we need to store the wavelet coefficients and various feature descriptors, upon which appropriate index structures need to be built to expedite the retrieval. By building an index structure on a set of feature points, those ones with similar feature descriptor values and/or wavelet coefficients will be naturally clustered together while ones with disparate descriptor values and/or wavelet coefficients will likely to be far apart in the index structure. We plan to build separate index structures for wavelet coefficients and feature descriptors. Since there may be unobserved variations at some feature points, the feature descriptors of different feature points may not be directly comparable to each other, which make it difficult to deploy a single index structure on the feature descriptors. Our approach consists of two steps. In the first step, we group observing conditions according to the probability that observations under these conditions are available at a given feature point. In the second step, an index structure is built for each condition group. Only the feature points that have observations under all conditions in the group are being indexed. This two-fold approach would allow us to take advantage of the fast retrieval supported by the indexes, and at the same time, minimize the number of times we need to apply transitivity to perform a match.

Additional considerations of such design include the adaptability to conflation and deflation of the terrain model, new features, and new query types, capability of supporting multiple users, and reliability of handling missing data and noisy environments.

3.3 3D terrain reconstruction, refinement and update from images

The feature points and associated descriptors that we extract from images and terrain are one of the key elements of our representation. This will mainly support registration between images and between images and terrain. As a specific application building on these capabilities we intend to develop algorithms for real-time 3D terrain reconstruction. Besides 3D reconstruction from an image sequence, we also intend to develop algorithms that refine an existing 3d model based on incoming video data. When the difference between the existing model and the observed scene is too large at a certain point, we would identify this as an area of change and update the model accordingly.

Our approach will consist of performing the registration of images using the feature points. From this the camera motion can be computed relative to the terrain and/or relative to the previous images. In case a 3D terrain model exists, images can be re-projected onto it. If the 3D terrain model is accurate images and terrain should correspond. For small discrepancies a refinement of the terrain representation can be performed that minimizes inconsistencies. In fact, when the resolution of the video allows to construct a higher-resolution representation than what the initial terrain model provided, we would increase the level of detail of our representation to take advantage of the additional information and incorporate it in our terrain model. For larger differences or when no 3D terrain model is available, a search must be performed over a much larger range. To perform this efficiently we intend to develop a hierarchical 3D reconstruction approach. The approach would be related to the plane-sweep algorithm [12]. We would generate a family of initial models and verify which model explains each part of the terrain best. From this an initial 3D terrain representation is constructed. This can then be refined using a similar approach but with new family of models now being generated in the neighborhood of the initial reconstruction. By adapting the terrain representation until the visual inconsistency disappears, an accurate terrain model can be constructed. Note that out goal is to perform this by taking advantage of the multi-scale nature of the spline-wavelet terrain representation. To locally update the model when change is detected a similar approach will be used, but only locally in the neighborhood of the detected change.

Our goal is to achieve the target of processing 512×512 images at 60Hz by the end of the program using COTS hardware, as opposed to specialized hardware such as provided by Sarnoff. We plan to take advantage of the tremendous processing power of todays GPU's (Graphics Processing Unit), i.e. more than 100Gflops for the most recent models and improving even faster than CPU's. We will use the CPU and GPU in tandem. The CPU will deal with the sparse feature tracking and ego-motion estimation while the GPU will estimate the multi-view correspondences and terrain geometry. At this point we have a two-view plane-sweep stereo algorithm running on 512×512 images at 30Hz for 32 disparity levels [43].

4 Milestones and Deliverables

In the first 18 months of this proposal (Phase 1.) we will concentrate on developing the mathematics of meshless wavelets, and developing algorithms for finding key points for specific applications to include compression, registration, route planning, and visibility. The specific milestones of this phase include:

1. Establishing a testbed data set for comparative analysis (within 6 mos)
2. Specifying a meshless wavelet representation of height field data (within 12 mos)
3. Algorithms for streaming k-th order Delaunay for simplex splines (within 12 mos)
4. Pilot tools for 3-D reconstruction using dynamically generated TINs (within 18 mos)

The primary deliverable from phase 1 will be in the form of a white paper describing all of the components and algorithms developed in Phase 1 of this grant. This will include the principles of operation, mathematical breakthroughs, functional descriptions, interfaces, and the current state of development. In addition, the white paper will include information about estimated performance characteristics and an integration strategy.

In phase 2 we will focus on developing application specific algorithms for selecting hierarchical point sets. The outcome of this phase will be various demonstration systems and various software and mathematical analysis tools. The specific milestones of this phase include:

1. A general optimization framework for selecting point sets (within 6 mos)
2. A focused effort of selecting point sets for Compression
3. Selection of critical points for image registration tasks
4. The development of indexing schemes and searching strategies for database query and retrival
5. Selection of critical points optimized for reconstructing iso-height contours

The deliverables of Phase 2 include a supplemental white paper describing all the new algorithms developed along with analysis of their computational efficiencies. We will also provide a series of demonstration systems for specific tasks. The source code of these implementations will be made available to those parties designated by the program officers. In phase 3 we will concentrate on the most promising of the key applications identified in phases 1 and 2. This phase will include evaluations and comparisons to alternative systems. We will also start to focus on the real-time aspects of image registration and database queries in this phase. The milestones of this phase will include:

1. Real-time progressive Mesh wavelet generation and display (perhaps using GPUs)
2. Real-time image-to-terrain registration
3. Real-time terrain searching and queries
4. Path-planning tools with adaptive refinements

In this later stage of the program, we hope to be teamed with providers or creators of geospatial data set, in order to evaluate the performance and quality of claims of our approach. In the final phase of this grant we will focus on transitioning our technology into strategic military applications. We will provide a white paper describing a summary of all the technologies developed. The PIs will give tutorials and talks describing our approach and its advantages to end-users and tool developers. We will provide source code newly developed components and algorithms including their principles of operation, mathematical background, functional descriptions, and the current state of development.

4.1 Risks

The proposed work has three important risks to its success.

First, it relies on new mathematical results to extend meshless wavelets to the bivariate case. We believe that tight frames and vanishing moment recovery functions will allow us to do this extension in phase 1, but because we need the mathematics to be implemented, we will need to explore the range of possible extensions throughout the project. The biggest challenges we anticipate are to determine the best way to do local refinement, to characterize the scale of irregular multiscale analysis, and decide on the right data to store to support fast computation. The phase structure of the project mitigates this risk, since we will have a clear idea as phase 1 ends of the capabilities of the developed mathematics to address the applications. The tasks for phase 2 can be selected based on these results. Furthermore, we identified the task of building hierarchies of irregular sets of key points as separate from the mathematics for meshless wavelets, so that even if meshless wavelets are not found to be an effective representation, the results on key points can help create more traditional mesh-based hierarchical TINs, B-splines, or wavelets.

Second, any representation runs the risk of being inundated by the flood of data that can be gathered. We need to remember that this is already true for DTED rasters; the shuttle radar topography mission (SRTM) is an example of the rapid rates at which data can be gathered and slow rate of processing. NIMA (now NGA) reported, "After 30 years of collection NIMA only had DTED for about 70 percent of the Earth's surface with measurements taken every 90 meters (DTED Level 1) and 5 percent with measurements taken every 30 meters (DTED Level 2). In only 9 days and 18 hours, SRTM collected elevation data for 80 percent of the world's landmass to enable the production of DTED Level 2. Areas the size of Alaska were mapped in 15 minutes and Florida in 90 seconds". Although the flight was in Feb 2000, JPL needed 18 months of preliminary data processing before passing the data to NGA, which contracted for final processing with delivery monthly from Dec 2003 through Sept 2004. The irregularity of our meshless wavelets is designed to make tasks like conflation easier, but any sophisticated representation runs the risk of becoming a processing bottleneck. In fact, we are almost certain that an innovation of this magnitude will be a bottleneck at the end of phase 2, which is why we suggest an optional phase 3 for improvement in key applications identified by DARPA. Where appropriate for these applications, we will consider streaming computation to handle large data sets and GPU (graphics processing unit) for hardware support.

Third, managing interaction for productive research is always a risk when a project brings together a team with diverse expertise ranging from wavelet analysis to computer vision to databases to geographic information systems. We will need expertise from other participants in the GEO* program – e.g., we would like to team up with an expert from industry in sensor technology who is able to provide characteristics and sample data from appropriate multispectral or hyperspectral sensors, should they play a role in key applications. We will need unclassified, yet military-specific data and information to develop effective proof-of-concept applications – e.g., for mobility and traversability, we will want information on different vehicle types such as their slope limits, clearance, weights, and the response of different soil types. For visibility computations with light or radar, we will want penetration models for different land cover. Because of previous successful experiences managing diverse academic and industry partnerships, our awareness and some small steps will be enough to mitigate the management risks. E.g., we have drawn the core team from only two institutions, we have structured the research so that delays or difficulties in obtaining data or guidance on key applications will not interrupt the progress of research (although data and guidance will maintain immediate relevance to the military), and we have included a small amount for bringing in outside experts to present colloquia.

5 Previous work

This proposal gathers a team with extensive experience in the development of mathematics and algorithms for wavelets and splines, computer vision, databases, geographic information systems, and computational geometry.

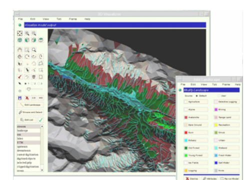
Chaired Prof Charles K. Chui, UMSL Math & CS since 1999. Courtesy appointment in Statistics, Stanford University since 1997. (PhD Math '67, U Wisc; SUNY Buffalo '67-'70; Texas A&M '70-'99). Author of $>$ 15 books on wavelets, splines, and approximation theory. Co-founder and co-editor-in-chief (with R. Coifman and I. Daubechies) of *Appl. and Comp. Harmonic Anal.* since 1993. Prior work with W. He is below.

Asst Prof Wenjie He, UMSL Math & CS since 1999. (PhD Math '98, U of Georgia; Postdoc Texas A&M). Together with Chui, He introduced the notion of vanishing-moment recovery (VMR) functions in [8]. for the construction of compactly supported wavelets under the tight frame mathematical structure that have the maximum order of vanishing moments. Without the VMR function, the spline wavelets with finite filters under the tight frame structure only have vanishing moments of the first order, for all orders m. Both further studied the construction of tight frames generated by two wavelets with minimum support [10].

In [9] they develop a general theory of locally supported wavelets on a bounded interval under the tight frame structure is developed. The generality of this theory applies to the non-stationary setting, such as splines with arbitrary nested knot sequences. We remark that wavelets on an unbounded interval, such as those discussed above, cannot be used as the "interior" wavelets for the bounded interval to maintain the tight frame structure. This surprising observation provides a clear evidence that the classical theory of orthonormal wavelets cannot be easily adopted for the study of tight frames. The VMR function is extended to matrix formulation, namely by considering symmetric positive definite matrices S_j for the j^{th} levels.

For the above theoretical development, a new concept, called "approximate duals", for replacing the dual basis so as to achieve the local support (i.e. finite filters) is introduced to obtain nonstationary wavelets with uniformly bounded filter lengths, even with the increasing density of the nested knot sequences of the B-splines, and having the arbitrarily desirable order L of vanishing moments, all under the tight frame structure. The above brief summary provides the foundation of our proposed research project.

Prof Jack Snoeyink, UNC CS since 2000 . (PhD CS '90, Stanford; Postdoc Utrecht; faculty UBC '91-'99) $>$ 100 papers in computational geometry and its applications



At UBC, Snoeyink had a longstanding collaboration with Facet Decision Systems which produced six MSc theses and one PhD thesis on algorithms for terrain models and algorithms in GIS. Prizes while at UBC include the BC ASI Inaugural Faculty award, Killam Research Prize, Charles A. McDowell Award for Excellence in Research, IBM Research Professorship in Computer Science. Some recent references can be found in the brief CV.

Since moving to UNC, he has been primarily funded to work on protein models, including a recent DARPA seed project on Enzyme Design (PI: Hellinga, Duke Biochem). (Snoeyink and the Hellinga team will submit their white paper for addendum 5 to this same BAA by July 16.) He also has funding from LLNL to apply computational topology to visualization, which is work that began with a CARGO seed project.

Assoc Prof Leonard McMillan, UNC CS since 2002 (PhD CS '97, UNC; faculty MIT '97-'02). McMillan is a pioneer in the area of data-driven computer graphics modeling. This includes his ground-breaking work on image-based modeling and rendering, a method for synthesizing new views from acquired imagery, and data-driven reflectance modeling. McMillan is also an active computer graphics, image processing, computer vision, and microelectronics researcher with $>$ 35 refereed publications.

McMillan was also PI of DARPA ITO project Computational Video (Grant F30602-97-1-0283). As part of this grant, he and his students developed a wide range of new technologies for filtering, processing, and interpreting streaming media types. These technology components composed Computational Video systems. The key applications of these systems were to support collaboration and situational awareness. The research outcomes of this program included significant new approaches to video compression and decompression [37, 3], remote telepresence [26], multiple-sensor fusion [20, 4], and the real-time geometric processing of streaming data types [27, 26].

Asst Prof Marc Pollefeys, UNC CS since 2002. (PhD '99 Leuven; Postdoc '99-'02); > 70 technical papers in computer vision, especially in geometry from images. Prizes include the prestigious Marr prize at ICCV '98. Has organized workshops and courses at major vision and graphics conferences and served on many conference program committees. Marc Pollefeys and coworkers were the first to develop a fully automated pipeline to reconstruct detailed 3D models automatically from video sequences. He has made contributions in computer vision, photogrammetry and computer graphics, specifically on structure from motion, self-calibration, stereo and image pair rectification, 3D modeling, image-based modeling and rendering, and applications.

Figure 1: 3D-from-video: reconstructed 3D model including camera poses (shown as pyramids)

Dr. Pollefeys has received seed funding for the DARPA IXO UrbanScape program to demonstrate 3D-from-video capability which will most likely be pursued in the program. He is also the PI of two NSF projects that work on different aspects of 3D modeling from images and image registration.

Asst Prof Wei Wang, UNC CS since 2002 (PhD CS 99, UCLA; research staff IBM 99 02). Wangs expertise is in the areas of database and data mining. Her PhD dissertation research has been widely regarded as ground-breaking work in using compact multi-resolution structures to efficiently support complex queries, data mining tasks, and evolution monitoring in spatial databases. Wang has also made remarkable contribution on searching and mining in high dimension feature space, and analyzing temporal data. She is also an active researcher in designing fast GPU implementation of database operations, feature selection, and mining graph databases. Wang has > 70 referred publications in databases, data mining, and related areas.

Wang developed a statistical grid-based approach, STING [38], to support many commonly asked region-oriented queries and data mining tasks on spatial databases. A pyramid-like structure is employed, in which the spatial area is divided recursively into rectangular cells down to certain granularity determined by the data distribution and resolution required by applications. Statistical information for each cell is calculated in a bottom-up manner and is used to answer queries. When processing a query, the hierarchical structure is examined in a top-down manner. In its successor, STING+ [40], users are provided with the capability to continuously monitor evolving patterns through user-specified triggers. STING+ employs a set of dynamic sub-triggers to monitor the change of the data and evaluates these sub-triggers in a certain order to yield least cost. To obtain further performance gain, a much compact spatial index structure PK-tree [39], which has a provable bounded worst case performance, can be used to replace the regular pyramid hierarchy.

5.1 Management

Snoeyink will lead this project and be the point of contact for interaction with DARPA, and the team at the University of Missouri, St. Louis (UMSL). He will coordinate preparation of reports and demonstrations. Each faculty member has money allocated for travel to DARPA PI meetings to present progress.

On the technical side, Chui and He will focus on the mathematical development of meshless wavelets. There will be some implementation work performed at UMSL, but most will occur at UNC Chapel Hill because of the suitability of the graduate students. The group at UNC Chapel Hill is quite tight-knit, and lab space is shared, so there is ample opportunity to meet and exchange ideas both formally and informally.

We have budgeted for one small workshop in phase two to promulgate the advantages of meshless wavelets, with a second in the phase 4 option.

References

[1] M. J. Abásolo and F. J. Perales. Wavelet analysis for a new multiresolution model for large-scale textured terrains. *J. of WSCG*, 11(1), 2003.

[2] B. D. Bojanov, H. A. Hakopian, and A. A. Sahakian. *Spline functions and multivariate interpolations*. Kluwer Academic Publ., 1993.

[3] Hector M. Briceño, Steven Gortler, and Leonard McMillan. NAIVE–network aware internet video encoding. In *Proceedings of the seventh ACM international conference on Multimedia (ACM MULTIMEDIA 99)*, pages 251–260. ACM Press, 1999.

[4] Chris Buehler, Michael Bosse, Leonard McMillan, Steven Gortler, and Michael Cohen. Unstructured lumigraph rendering. In *Proceedings of the 28th annual conference on Computer graphics and interactive techniques (SIGGRAPH 2001)*, pages 425–432. ACM Press, 2001.

[5] A. Certain, J. Popovic, T. DeRose, T. Duchamp, D. Salesin, and W. Stuetzle. Interactive multiresolution surface viewing. In *Proceedings of SIGGRAPH '96*, August 1996.

[6] C. K. Chui. *An Introduction to Wavelets*. Academic Press, Boston, 1992.

[7] C. K. Chui. *Wavelets: A Mathematical Tool for Signal Analysis*. SIAM, Philadelphia, 1997.

[8] C. K. Chui, W. He, and J. Stöckler. Compactly supported tight and sibling frames with maximum vanishing moments. *Appl. Comp. Harmonic Anal.*, 13:224–262, 2002.

[9] C. K. Chui, W. He, and J. Stöckler. Nonstationary tight wavelet frames. *Appl. Comp. Harmonic Anal.*, pages 187–206, 2002. accepted (82 pages).

[10] C. K. Chui, W. He, and J. Stöckler. Tight frames with maximum vanishing moments and minimum support. *Approximation Theory*, pages 187–206, 2002.

[11] C. K. Chui, J. Stöckler, and J. D. Ward. Analytic wavelets generated by radial functions. *Adv. in Comp. Math.*, 5:95–123, 1996.

[12] R. Collins. A space-sweep approach to true multi-image matching. In *Proceedings of Conference on Computer Vision and Pattern Recognition*, pages 358–363, 1996.

[13] David H. Douglas. Experiments to locate ridges and channels to create a new type of digital elevation model. *The Canadian Surveyer*, 41(3):373–406, Autumn 1986.

[14] Nira Dyn and Shmuel Rippa. Data-dependent triangulations for scattered data interpolation and finite element approximation. *Applied Numer. Math.*, 12:89–105, 1993.

[15] M. Eck, T. DeRose, T. Duchamp, H. Hoppe, M. Lounsbery, and W. Stuetzle. Multiresolution analysis of arbitrary meshes. In *SIGGRAPH'95 Conference Proceedings*, pages 173–182, 1995.

[16] Peter F. Fisher. Algorithm and implementation uncertainty in viewshed analysis. *International Journal of Geographical Information Systems*, 7(4):331–347, 1993.

[17] M. Gross, O. Staadt, and R. Gatti. Efficient triangular surface approximation using wavelets and quadtree data structure. *IEEE Transactions on Visualization and Computer Graphics*, 2(2), June 1996.

[18] H. Hoppe. Progressive meshes. In *SIGGRAPH'96 Conference Proceedings*, pages 99–108, 1996.

[19] Wynne Hsu, Jing Dai, and Mong-Li Lee. Mining viewpoint patterns in image databases. In *KDD*, pages 553–558, 2003.

[20] Aaron Isaksen, Leonard McMillan, and Steven J. Gortler. Dynamically reparameterized light fields. In *Proceedings of the 27th annual conference on Computer graphics and interactive techniques (SIGGRAPH 2000)*, pages 297–306. ACM Press/Addison-Wesley Publishing Co., 2000.

[21] Daniel A. Keim. Efficient geometry-based similarity search of 3d spatial databases. In *SIGMOD*, pages 491–430, 1999.

[22] Daniel A. Keim, Martin Heczko, Alexander Hinneburg, and Markus Wawryniuk. Multi-resolution similarity search in image databases. In *Multimedia Information Systems*, pages 76–85, 2002.

[23] Mark P. Kumler. An intensive comparison of triangulated irregular network (TINs) and digital elevation models (DEMs). *Cartographica*, 31(2), 1994. monograph 45.

[24] Shu Lin, M. Tamer zsu, Vincent Oria, and Raymond T. Ng. An extendible hash for multi-precision similarity querying of image databases. In *VLDB*, pages 221–230, 2001.

[25] Xuemin Lin, Qing Liu, Yidong Yuan, and Xiaofang Zhou. Multiscale histograms: Summarizing topological relations in large spatial datasets. In *VLDB*, pages 814–825, 2003.

[26] Wojciech Matusik, Chris Buehler, and Leonard McMillan. Polyhedral visual hulls for real-time rendering. In *Proceedings of Twelfth Eurographics Workshop on Rendering (EGRW 2001)*, pages 115–126, London, Great Britain, 2001. Springer.

[27] Wojciech Matusik, Chris Buehler, Ramesh Raskar, Steven J. Gortler, and Leonard McMillan. Image-based visual hulls. In *Proceedings of the 27th annual conference on Computer graphics and interactive techniques (SIGGRAPH 2000)*, pages 369–374. ACM Press/Addison-Wesley Publishing Co., 2000.

[28] C. A. Micchelli. Mathematical aspects of geometric modeling. *CBMS-NSF Regional Conference Series in Applied Mathematics*, 65, 1995.

[29] Apostol Natsev, Rajeev Rastogi, and Kyuseok Shim. WALRUS: a similarity retrieval algorithm for image databases. In *SIGMOD*, pages 395–406, 1999.

[30] M. Neamtu. What is the natural generalization of univariate splines to higher dimensions? In T. Lyche and L. L. Schumaker, editors, *Mathematical Methods for Curves and Surfaces*, pages 355–392. Vanderbilt University Press, Nashville, 2001.

[31] M. Neamtu. Delaunay configurations and multivariate splines: A generalization of a result of B. N. Delaunay. *Trans. Amer. Math. Soc.*, 2004. To appear. `http://math.vanderbilt.edu/~neamtu/papers/papers.html`.

[32] M. Pollefeys, L. Van Gool, M. Vergauwen, F. Verbiest, K. Cornelis, J. Tops, and R. Koch. Visual modeling with a hand-held camera. *International Journal of Computer Vision*, 59(3):207–232, 2004.

[33] Sham Prasher and Xiaofang Zhou. Efficient update and retrieval of objects in a multiresolution geospatial database. In *SSDBM*, pages 193–201, 2003.

[34] A. James Stewart. Hierarchical visibility in terrains. In *Eurographics Rendering Workshop*, June 1997.

[35] A. James Stewart. Fast horizon computation at all points of a terrain with visibility and shading applications. *IEEE Transactions on Visualization and Computer Graphics*, 4(1):82–93, March 1998.

[36] W. Sweldens. The lifting scheme: A construction of second generation wavelets. *J. Math. Anal.*, 29:511–546, 1998.

[37] Osama Tolba, Hector M. Briceño, and Leonard McMillan. Pure java-based streaming mpeg player. In *SPIE Proceedings: Multimedia Systems and Applications*, volume 3528, pages 216–224. SPIE, 1999.

[38] Wei Wang, Jiong Yang, and Richard Muntz. Sting: a statistical information grid approach to spatial data mining. In *VLDB*, pages 186–195, 1997.

[39] Wei Wang, Jiong Yang, and Richard Muntz. Pk-tree: a spatial index structure for high dimensional point data. In *Foundations of Data Organization*, pages 27–36, 1998.

[40] Wei Wang, Jiong Yang, and Richard Muntz. Sting+: an approach to active spatial data mining. In *ICDE*, pages 116–125, 1999.

[41] J. Wu and K. Amaratunga. Wavelet triangulated irregular networks. *Int. J. Geographical Information Science*, 17:273–289, 2003.

[42] Kai Xu, Xiaofang Zhou, and Xuemin Lin. Direct mesh: a multiresolution approach to terrain visualization. In *ICDE*, pages 766–777, 2004.

[43] R. Yang and M. Pollefeys. Muli-resolution real-time stereo on commodity graphics hardware. In *Proc. IEEE Conf. on Computer Vision and Pattern Recognition*, pages 211–218, 2003.

[44] P. Zatelli and A. Antonello. New grass models for multiresolution analysis with wavelets. In *Proceedings of the Open GIS, GRASS users conference*, pages 11–13, September 2002.

Jack Scott Snoeyink

Department of Computer Science
University of North Carolina at Chapel Hill
CB# 3175, Sitterson Hall
Chapel Hill, NC 27599-3175 USA
http://www.cs.unc.edu/~snoeyink

ph: +1 (919) 962-1969
fax: +1 (919) 962-1799
snoeyink@cs.unc.edu
Citizenship: USA

Professional Preparation:

09/85-09/90	STANFORD UNIVERSITY, Stanford, CA USA Ph.D., Computer Science
09/81-06/85	CALVIN COLLEGE, Grand Rapids, MI, USA B.S., Mathematics & B.S., Computer Science
09/90-07/91	UTRECHT UNIVERSITY, Utrecht, the Netherlands Postdoctoral research in Computer Science

Appointments:

Since 01/00	Professor, UNIV. NORTH CAROLINA AT CHAPEL HILL, USA
07/99-12/99	Visiting professor, UNIV. NORTH CAROLINA AT CHAPEL HILL, USA
07/96-02/00	Associate professor with tenure, UNIV. BRITISH COLUMBIA, Vancouver Canada
10/97-06/98	Visiting researcher, INRIA SOPHIA-ANTIPOLIS, France
07/97-12/97	Visiting associate professor, THE JOHNS HOPKINS U., Baltimore, MD
08/91-06/96	Assistant professor, UNIVERSITY OF BRITISH COLUMBIA, Vancouver, Canada

Relevant publications

1. Liu, Y., and Snoeyink, J, Flooding Triangulated Terrain, to appear in Int'l Symp Spatial Data Handling, Aug 04.
2. Isenburg, Lindstrom, Snoeyink, Lossless compression of floating-point geometry, to appear, CAD 3D, (2004).
3. Carr, H. and Snoeyink, J. Flexible and local isosurfaces - Using topology for exploratory visualization. In *IEEE/EG VisSym'03*, pages 49-58, 285, 2003.
4. Isenburg, M., Lindstrom, P., Gumhold, S., and Snoeyink, J. Large mesh simplification using processing sequences. In *Proc. Vis'03*, pages 465-472, Oct. 2003.
5. Isenburg, M. and Snoeyink, J. Compressing texture coordinates with selective linear predictions. *Computer Graphics International,* pages 126-133, 2003.
6. Isenburg, M. and Snoeyink, J. Coding polygon meshes as compressable ASCII. In *Proceedings of Web3D Symposium'02*, pages 1-10, Feb. 2002. Best paper.
7. Speckmann, B. and Snoeyink, J. Easy triangle strips for TIN terrain models. International Journal of Geographical Information Systems 15(4): 379–386, 2001.

Other recent publications (from >125 reviewed articles and conference publications)

1. Bandyopadhyay, D. and Snoeyink, J. Almost-Delaunay simplices: Nearest neighbor relations for imprecise points. In ACM-SIAM Symp on Discrete Algorithms, pages 403-412, 2004
2. Cabello, S., Liu, Y., Mantler, A., and Snoeyink, J. Testing homotopy for paths in the plane. *Discrete & Computational Geometry*, 31:61-81, 2004.
3. Carr, H., Snoeyink, J., and Axen, U. Computing contour trees in all dimensions. *Computational Geometry: Theory and Applications*, 24:75-94, 2003.
4. Kettner, L., Rossignac, J., and Snoeyink, J. The Safari interface for visualizing time-dependent volume data using iso-surfaces and a control plane. *Computational Geometry: Theory and Applications*, 25:97-116, 2003.
5. Haas, J., Snoeyink, J., and Thurston, W. P. The size of spanning disks for PL knots. *Discrete & Computational Geometry*, 29(1):1-17, 2003.

Synergistic Activities

Awards
- Killam Research Prize at UBC, 1998.
- Charles A. McDowell Award for Excellence in Research at UBC, 1997.
- Inaugural ASI Faculty Award, BC Advanced Systems Institute, October 1996. ("For outstanding service…fostering University/Industry collaborations")

Confer.
- Co-chair, 20th ACM SCG, NY, June 2004.
- Special session co-org "Geometry of Protein Modeling", AMS mtg #997, Lawrenceville, NJ, Apr 2004.
- Workshop co-org., Comp. Cartography, Dagstuhl, Germany, October 2003.
- Co-organizer, Triangle Biophysics Symposium, Chapel Hill, NC, Nov 2002.
- Co-organizer and co-chair, 3rd ALENEX, Washington, DC, Jan 2001.
- Organizer and prog. Chair, 11th CCCG, Aug 1999.
- Program comm., ISAAC'04, WAFR'04, SMI'04, WADS'01, ICALP'01, WAE'00,

e(i) Collaborators

UBC Comp Science Dept,	Pankaj Agarwal (Duke),	D. Z. Chen (Notre Dame),
R. L. Drysdale (Dartm.)	H. Edelsbrunner (Duke),	M. Goodrich (UC Irvine),
Joel Haas (UC Davis),	H. Hellinga (Duke),	J-C Latombe (Stanford),
P. Lindstrom (LLNL),	J.S.B. Mitchell (SUNY SB),	V. Pascucci (LLNL),
D.&J. Richardson (Duke)	J. Rossignac (GA Tech),	G. Rote (Berlin),
Micha Sharir (Tel Aviv U),	Ileana Streinu (Smith),	Marc van Kreveld (Utrecht)

e(ii) Advisors

PhD: Leonidas Guibas (Stanford)
Postdoc: Mark Overmars (Utrecht)

e(iii) Advisees	PhD	MSc	postdoctoral	undergrad
current supervision	7	3	0	0
completed last 5 years	4	3	5	7
total completed	5	11	11	12

Current:
- PhD students: M. Isenburg (04), A. Mascarenhas (04), A. Mantler (05), D. Bandyopadhyay(05), D. O'Brien(05), Y. Liu (05) A Leaver-Fay (06)
- MSc students: C. Falls, X. Wang, Kimberley Noonan (04).

Completed:
- PhD: H. Carr (04), B. Speckmann (01), Gopi M. (01), M. McAllister(00), T. Chan (awarded a 1997 NSERC Doctoral Prize)
- MSc: L.W. Su(01), A. Mantler (00), H. Carr(00), M. Isenburg(99), D. Bullock(99), R. Beirouti (97), G. Litchfield(97), S. Yu (96), D.S. Andrews (96), C. Zhu (94), M. McAllister (93).
- Postdocs: : D. Hsu (02-03), R. P. Berretty (01), L. Kettner (99-01), S. Bespamyatnikh (98-00), M. Segal (99-00) (co-supervised with D. Kirkpatrick)
- Undergraduate research: 11 summer interns; 4 co-op workterms.
- Other: B. Jünger (Diplom, Darmstadt, 96), J. Adegeest (91; cosupervised Utrecht).

Leonard McMillan

University of North Carolina,
Department of Computer Science,
Sitterson Hall, CB #3175,
Chapel Hill, NC 27599
Phone: 919-962-1778
email: mcmillan@cs.unc.edu

Professional Preparation:

Institution	Major	Degree & Year
Georgia Institute of Technology	Electrical Engineering	BSEE 1983
Georgia Institute of Technology	Electrical Engineering	MSEE 1984
University of North Carolina	Computer Science	Ph.D. 1997

Appointments:

University of North Carolina	Associate Professor	August 2002
Massachusetts Institute of Technology	Associate Professor	June 2001
Massachusetts Institute of Technology	Assistant Professor	April 1997
Sun Microsystems	Sr. Staff Engineer	Nov 1988
Radiant Graphics	President	March 1988
AT&T Bell Laboratories	Member of Technical Staff	June 1984

Publications Related to this Proposal:

Sand, Peter, Leonard McMillan, and Jovan Popovic, *"Continuous Caputre of Skin Deformation,"* To appear in **Proceedings of ACM SIGGRAPH 2003**, (San Diego, CA, July 27-31).

Matusik, Wojciech, Hanspeter Pfister, Addy Ngan, Paul Beardsley, and Leonard McMillan, "*Image-Based 3D Photography Using Opacity Hulls,*" **Proceedings of ACM SIGGRAPH 2002**, (in Computer Graphics Proceedings, Annual Conference Series, July 2002), pp. 427-437.

Matusik, Wojciech, Chris Buehler, and Leonard McMillan, *"Polyhedral Visual Hulls for Real-Time Rendering,"* to appear in **Proceedings of the 12th Eurographics Workshop on Rendering**, (London, UK June 25-27, 2001).

Matusik, Wojciech, Chris Buehler, Ramesh Raskar, Steven Gortler, and Leonard McMillan *"Image-Based Visual Hulls,"* **Proceedings of ACM SIGGRAPH 2000**, (New Orleans, LA July 23-28, 2000), pp. 369-374.

Isaksen, Aaron, Leonard McMillan, and Steven Gortler, *"Dynamically Reparameterized Light Fields,"* **Proceedings of ACM SIGGRAPH 2000**, (New Orleans, LA July 23-28, 2000), pp. 297-306.

Additional Significant Publications:

Cutler, Barbara, Julie Dorsey, Leonard McMillan, Matthias Mueller, and Robert Jagnow, "*A Procedural Approach to Authoring Solid Models,*" **Proceedings of ACM SIGGRAPH 2002**, (in Computer Graphics Proceedings, Annual Conference Series, July 2002), pp. 302-311.

Yang, Jason C., Matthew Everett, Chris Buehler, Leonard McMillan, "*A Real-Time Distributed Light Field Camera*" To appear in Proceedings of **The 13th Eurographics Workshop on Rendering**, (Pisa, Italy, June 26-28, 2002).

Matusik, Wojciech, Hanspeter Pfister, Remo Ziegler, Addy Ngan, Leonard McMillan, "*Acquisition and Rendering of Transparent and Refractive Objects*" To appear in Proceedings of **The 13th Eurographics Workshop on Rendering**, (Pisa, Italy, June 26-28, 2002).

Buehler, Chris, Michael Bosse, Leonard McMillan, Steven Gortler, and Michael Cohen, *"Unstructured Lumigraph Rendering,"* **Proceedings of ACM SIGGRAPH 2001**, (Los Angeles, CA August 12-17, 2001), pp. 425-432.

Buehler, Chris, Steven Gortler, Michael Cohen, and Leonard McMillan, "*Min Surfaces for Stereo*" To appear in **Proceedings of ECCV 2002**. (Copenhagen, Denmark, May 27-June 2, 2002).

Synergistic Activities:

Technical Papers Committee: SIGGRAPH	2003, 2004
Technical Papers Committee: Computer Vision and Pattern Recognition Annual Conference (CVPR)	February 2003
Bose Jr. Faculty Teaching Award	May 2001
Program Committee: ACM 2001 Symposium on Interactive 3D Graphics (I3D)	Nov 2000
Ruth and Joel Spira Teaching Award	May 2000
Technical Papers Committee: SIGGRAPH '99	March 1999
Papers Committee: Eurographics'98 Rendering Workshop	March 1998
Co-organizer: 1st Annual Workshop on Image-Based Modeling and Rendering (Stanford University, Palo Alto, CA)	Oct. 1998

Biographical Sketch – Marc Pollefeys

Professional Preparation.

1994	K.U.Leuven, Belgium	M.S. EE
1999	K.U.Leuven, Belgium	Ph.D. EE (greatest dictinction with the congratulations of the board)
1999-2002	K.U.Leuven, Belgium	Post-doc in Computer Vision

Appointments.

2002-	Assistant Professor	University of North Carolina – Chapel Hill
1999-2002	Post-doctoral Researcher	K.U.Leuven (Belgium)
1994-1999	Research Assistant	K.U.Leuven (Belgium)

Refereed publications (10 selected out of 60)

1. M. Pollefeys, L. Van Gool, M. Vergauwen, F. Verbiest, K. Cornelis, J. Tops, R. Koch, Visual modeling with a hand-held camera, *International Journal of Computer Vision* 59(3), 207-232, 2004.

2. R. Yang, M. Pollefeys, H. Yang, G. Welch, A Unified Approach to Real-Time, Multi-Resolution, Multi-Baseline 2D View Synthesis and 3D Depth Estimation using Commodity Graphics Hardware, *International Journal of Image and Graphics* (to appear).

3. S. Sinha, M. Pollefeys. Camera Network Calibration from Dynamic Silhouettes, *Proc. of IEEE Conf. on Computer Vision and Pattern Recognition*, 2004, (to appear).

4. M. Pollefeys, S. Sinha. Iso-disparity surfaces for general stereo configurations, T. Pajdla and J. Matas (Eds.), *Computer Vision - ECCV 2004 (European Conference on Computer Vision)*, LNCS, Vol. 3023, pp. 509-520, Springer-Verlag, 2004.

5. R. Yang, M. Pollefeys, and G. Welch. Dealing with Textureless Regions and Specular Highlight: A Progressive Space Carving Scheme Using a Novel Photo-consistency Measure, *Proc. International Conference on Computer Vision*, 2003.

6. R. Yang and M. Pollefeys. Muli-Resolution Real-Time Stereo on Commodity Graphics Hardware, *Proc. IEEE Conf. on Computer Vision and Pattern Recognition*, 2003.

7. M. Pollefeys, L. Van Gool, M. Vergauwen, K. Cornelis, F. Verbiest, J. Tops, 3D Recording for Archaeological Fieldwork, *IEEE Computer Graphics and Applications (CGA)*, Vol. 23, No. 3, pp.20-27, May/June 2003.

8. G. Van Meerbergen, M. Vergauwen, M. Pollefeys, L. Van Gool. 2002. "A Hierarchical Symmetric Stereo Algorithm Using Dynamic Programming", *International Journal on Computer Vision* 47(1/2/3): 275-285.

9. M. Pollefeys, R. Koch and L. Van Gool. 1998. Self-Calibration and Metric Reconstruction in spite of Varying and Unknown Internal Camera Parameters, *Proc. International Conference on Computer Vision*, pp.90-95, Bombay (India). **Winner David Marr prize**. Extended version also in *International Journal of Computer Vision*, 32(1), 7-25, 1999.

10. M. Pollefeys and L. Van Gool, 1999. "Stratified Self-Calibration with the Modulus Constraint", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol 21, No.8, pp.707-724.

Awards

Marr Prize ICCV '98; NSF CAREER '03; BARCO prize '99; DAGM best paper '99; CIPA best poster '01.

Synergistic Activities.

- A complete **image/video to 3D software processing pipeline** has been developed over the last few years. It combines state-of-the-art algorithms developed in computer vision, computer graphics and photogrammetry. It is being used as a tool for research as well as for education.

- **Courses and turorials** were organized at major vision and graphics conferences on the topic of *3D modeling from images*: 3DPVT04, ISPRS04, Siggraph00/01/02/03, ECCV00, 3DIM01/03 and CVPR01/03 (these last courses were co-organized with Anders Heyden, resp. Andrew Zisserman). I have also participated as a lecturer in other courses at Siggraph01/02/03. More than thousand people have attended these courses and evaluation and feedback have been very positive. As a service to the community on-line tutorial notes have also been made available (http://www.cs.unc.edu/~marc/tutorial/).

- **Services to scientific community:** Organizer (with Andrew Fitzgibbon, Andrew Zisserman and Luc Van Gool) of the *Workshop on Structure from Multiple Images of Large-scale Environments*, Dublin (Ireland), July 1-2, 2000, and *Workshop on Vision and Modelling of Dynamic Scenes*, Copenhagen (Denmark), June 2, 2002. Program committee member for multiple conferences including CVPR04, ECCV04, ICCV03, CVPR03, 3DIM03, ECCV02, IEEE Workshop on Stereo and Multi-Baseline Vision 2001 and 3DIM01. Regular reviewer for most of the major vision, graphics and photogrammetry journals and conferences.

- Our research has been applied in different fields, ranging from archaeology and architectural heritage preservation to planetary rover exploration, to solve real problems. Results of the applications to the archaeological site of Sagalassos (Turkey) have systematically been integrated in public lectures on the site, which yearly reach thousands of people, and has also been used for a television documentary and a setup for rover-based planetary exploration integrating our research has also been shown at public exhibits.

Collaborators & Other Affiliations

Collaborators I. Akkermans (K.U.Leuven), T. Behnke (DLR), R. Bertrand (VH&S), B. Brunner (DLR), K. Cornelis (KUL), J. Cosmas (Brunel Univ.), D. De Becker (KUL), P. Debevec (USC), F. Defoort (Cirque Digital, CA), R. De Geest (KUL), P. Degezelle (OptiDrive), B. Deknuydt (IMEC), J. Denzler (Univ. of Erlangen-Nürnberg), R. Dequeker (OptiDrive), C. Fehn (Heinrich Hertz Institute), A. Fitzgibbon (University of Oxford), B. Fontaine (Space Application Services), M. Gervautz (Imagination), E. Grabczewsky (Brunel U.), M. Grabner (TUGraz), D. Green (Brunel U.), B. Heigl (Siemens), A. Heyden (Lund U.), J. Hug (ETH Zürich), S. Hynst (Imagination), T. Itagaki (Brunel U.), W. Ijsselsteijn (TUEindhoven), M. Kampel (TUVienna), S.B. Kang (Microsoft), G. Kalberer (ETHZ), K. Kartner (TUGraz), R. Koch (Univ. of Kiel), J.-P. Kruth (KULeuven), K. Landzettel (DLR), R. Lauwereins (IMEC), B. Lauwers (KULeuven), F. Leberl (TUGraz), M. Leeman (KUL), D. Martens (KUL), H. Michaelis (DLR), R. Moreas (KUL), K. Nuyts (KUL), H. Neuckermans (KUL), H. Niemann (Univ. of Erlangen-Nürnberg), J. Tops (KUL),E. Ofek (3DV), M. Op de Beeck (Philips), M. Proesmans (Eyetronics), L. Qionyang (KUL), A. Redert (Philips), R. Sablatnig (TUVienna), K. Schindler (TUGraz), J. Schouteden (Acunia), I. Sexton (De Monfort Univ.), S. Sinha (UNC), G. Slabaugh (Georgia Tech) P. Smars (Univ. of Bath), L. Steinicke (SAS), M. Steinmetz (DLR), P. Surman (De Montfort Univ.), D. Termont (SAS), T. Tuytelaars (KUL), K. Van Balen (KUL), H. Van Brussel (KUL), L. Van Gool (KUL/ETHZ), G. Van Meerbergen (KUL), D. Vanrintel (Eyetronics), F. Verbiest (KUL), M. Vergauwen (KUL), G. Visentin (ESA), M. Waelkens (KUL), G. Welch (UNC), F. Xu (KUL), H. Yang (UNC), R. Yang (UNC), A. Zalesny (ETHZ), A. Zisserman (University of Oxford).

Graduate and Postdoctoral Advisors Luc Van Gool (K.U.Leuven, ETHZürich).

Students advised/current Ph.D. students Priscilla Alexander, Seon Joo Kim, Jason Repko, Sudipta Sinha, Steve Titus, Sriram-Thirthala Venkata, Jingyu Yan (U.N.C.) Maarten Vergauwen, Frank Verbiest, Gelu Muresan, Cristian Forausberger, Ive Akkermans, Jan Tops, Joris Schouteden, Kurt Cornelis, Danny Martens (K.U.Leuven).

Wei Wang

University of North Carolina, Department of Computer Science, Sitterson Hall, CB #3175, Chapel Hill, NC 27599
Phone: 919-962-1744 Email: weiwang@cs.unc.edu URL: http://www.cs.unc.edu/~weiwang/

Professional Preparation:

Institution	Major	Degree	Year
State University of New York at Binghamton	System Science	MS	1995
University of California at Los Angeles	Computer Science	PH.D.	1999

Appointments:

University of North Carolina at Chapel Hill	Assistant Professor	August 2002
IBM T. J. Watson Research Center	Research Staff Member	July 1999

Publications Related to this Proposal:

Jun Huan, Wei Wang, Deepak Bandyopadhyay, Jack Snoeyink, Jan Prins, and Alexander Tropsha. Mining spatial motifs from protein structure graphs, ***Proceedings of the 8th Annual International Conference on Research in Computational Molecular Biology (RECOMB)***, 2004.

Jun Huan, Wei Wang, Anglina Washington, Jan Prins, Ruchir Shah, and Alexander Tropsha. Accurate classification of protein structural families using coherent subgraph analysis, ***Proceedings of the Pacific Symposium on Biocomputing (PSB)***, pp. 411-422, 2004.

Jun Huan, Wei Wang, and Jan Prins. Efficient mining of frequent subgraph in the presence of isomorphism, ***Proceedings of the 3rd IEEE International Conference on Data Mining (ICDM)***, pp. 549-552, 2003.

Jinze Liu and Wei Wang. OP-cluster: clustering by tendency in high dimensional space, ***Proceedings of the 3rd IEEE International Conference on Data Mining (ICDM)***, pp. 184-197, 2003.

Haixun Wang, Wei Wang, Jiong Yang, and Philip Yu. Clustering by pattern similarity in large data sets, ***Proceedings of the ACM SIGMOD International Conference on Management of Data (SIGMOD)***, pp. 394-405, 2002.

Additional Significant Publications:

Wei Wang, Jiong Yang, and Philip Yu. WAR: weighted association rules for item intensities, ***Knowledge and Information Systems Journal (KAIS)***, 2004.

Jiong Yang, Wei Wang, and Philip Yu. Discovering high order periodic patterns, ***Knowledge and Information Systems Journal (KAIS)***, 2004.

Jiong Yang, Wei Wang, and Philip Yu. Mining surprising periodic patterns, ***Data Mining and Knowledge Discovery (DMKD)***, 2004.

Jiong Yang, Wei Wang, and Philip Yu. Mining asynchronous periodic patterns in time series data, ***IEEE Transactions on Knowledge and Data Engineering (TKDE)***, vol. 15, no. 3, pp. 613-628, 2003.

Jiong Yang, Wei Wang, Philip Yu, and Jiawei Han. Mining long sequential patterns in a noisy environment, ***Proceedings of the ACM SIGMOD International Conference on Management of Data (SIGMOD)***, pp. 406-417, 2002.

Synergistic Activities:

Associate Editor of the ***IEEE Transactions on Knowledge and Data Engineering*** (2003 - present)

Editorial Board Member of the ***Journal of Database Management*** (2000 - present)

Guest Editor of the ***IEEE Transactions on Knowledge and Data Engineering Special Issue on Mining Biological Data*** (2004)

Intensive Working Group Member of the ***ACM SIGKDD Curriculum Committee*** (2003 - present)

Program Committee Member of the ***ACM SIGMOD International Conference on Management of Data*** (2005)

Scientific Committee Member of the ***International Conference on Computational and Information Sciences*** (2004)

Program Committee Member of the ***13th ACM Conference on Information and Knowledge Management*** (2004)

Program Committee Member of the ***4th IEEE International Conference on Data Mining*** (2004)

Program Committee Member of the ***Workshop on Data Streams*** in conjunction with the ***15th European Conference on Machine Learning*** (2004)

Program Committee Member of the ***2nd International Workshop on Biological Data Management*** in conjunction with the ***15th International Conference on Database and Expert Systems Applications*** (2004)

Program Committee Member of the ***10th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*** (2004)

Program Committee Member of the ***5th International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing*** (2004)

Program Committee Member of the ***2nd International Conference on Software Engineering Research, Management & Applications*** (2004)

Program Committee Member of the ***6th Asia Pacific Web Conference*** (2004)

Scientific Committee Member of the ***IADIS International Conference on Applied Computing*** (2004)

Program Committee Member of the ***ACM Symposium on Applied Computing*** (2004)

Proceedings Chair and Program Committee Member of the ***4th International Conference on Web-Age Information Management*** (2003)

Program Committee Member of the ***15th International Conference on Scientific and Statistical Database Management*** (2003)

Program Committee Member of the ***International Workshop on Mining Spatial and Temporal Data*** (2001)

Collaborators & Other Affiliations:

Research Collaborators in the last 48 Months:

Dean Duncan (UNC)	Kimberly Flair (UNC)	Jiawei Han (UIUC)
Ming Lin (UNC)	Weiyi Meng (SUNY Binghamton)	Dinesh Manocha (UNC)
Richard Muntz (UCLA)	Silvia Nittel (Univ. Maine)	Andrew Nobel (UNC)
Susan Paulsen (UNC)	Jian Pei (SUNY Buffalo)	Jan Prins (UNC)
Naphtali Rishe (FIU)	Jack Snoeyink (UNC)	Alexander Tropsha (UNC)
Todd Vision (UNC)	Haixun Wang (IBM)	Jiong Yang (UIUC)
Clement Yu (UI Chicago)	Philip S. Yu (IBM)	

Graduate and Postdoctoral Advisors:

Richard Muntz — University of California at Los Angeles

Student Advisees:

Mithun Arora (UNC), Jun Huan (UNC), Hye-Chung Kum (UNC), Jinze Liu (UNC), Karl Strohmaier (UNC), Crystal Wright (UNC), Yi Xia (UCLA).

Charles K. Chui
Department of Mathematics and Computer Science
University of Missouri - St. Louis
St. Louis, MO 63121-4499
Office: 314-516-7294 Fax: 314-516-5400 chui@cs.umsl.edu

Education:

B.S. 1962, M.S. 1963, Ph.D. 1967, all from the University of Wisconsin, Madison

Academic Career:

Curator's Professor, University of Missouri, St. Louis, 2003 – present
Distinguished Professor, University of Missouri, St. Louis, 1999–2003
Consulting Professor of Statistics, Stanford University, 1997–present
Distinguished Professor, Texas A&M University, 1988–1999
Professor 1974–1988 and Associate Professor 1970–1974, Texas A&M University
Assistant Professor, State University of New York at Buffalo, 1967–1970

Professional Activities

Current editorial activities:

1. Co-editor-in-chief (with R. Coifman and I. Daubechies), *Appl. and Comp. Harmonic Anal.* (published by Elsevier Science/Academic Press), 1993–present
2. Editorial board member of other journals: *J. Approx. Theory, Analysis in Theory and Applications, Adv. Comp. Math., Elect. J. of Differential Equations, Int'l J. Wavelets, Multiresolution, and Information Processing,* and *Math. and Computers in Simulation*
3. Editor of three Book Series: *Studies in Comp. Mathematics*, *Approximations and Decompositions*, *Mathematics in Science and Engineering*

Organizer of recent conferences:

1. Eleventh International Conference on Approximation Theory, Gatlinburg, TN, May 18-22, 2004 (with L.L. Schumaker and M. Neamtu) and 2. Second International Conference on Computational Harmonic Analysis, Nashville, TN, May 24-30, 2004 (with A. Aldroubi)

Member and contributor of three working groups of Industry Standards:

1. DICOM (Digital Image Compression and Communication of Medical Images), 1995–1998, 2. MPEG-4 (Moving Pictures Expert Group) 1997–1998, and 3. JPEG-2000 (Joint Photographic Expert Group) 1997–2000

Member of the following professional societies:

American Mathematical Society, Society of Industrial and Applied Mathematics, and Institute of Electrical and Electronic Engineer (Elected Fellow, 1994)

Publications

A. Five Publications most closely related to the proposed project

1. Characterization of general tight wavelet frames with matrix dilations and tightness preserving oversampling (with W. Czaja, M. Maggioni, and G. Weiss), *J. Fourier Anal. and Appl.* **8** (2002), 173–200.

2. Compactly supported tight and sibling frames with maximum vanishing moments, (with W. He and J. Stöckler), *Appl. Comp. Harmonic Anal.* **13** (2002), 224-262.
3. Tight frame oversampling and its equivalence to shift-invariance of frame operators (with Q. Sun), *Proc. of Amer. Math. Soc.* **131** (2003), 1527–1538.
4. Nonstationary tight frames, I: Bounded intervals (with W. He and J. Stöckler), *Appl. Comp. Harmonic Anal.* **17** (2004), in press.
5. Nonstationary tight frames, II: Unbounded intervals (with W. He and J. Stöckler), *Appl. Comp. Harmonic Anal.*, under review (65 pages ms).

B. Five other publications (Monographs)

1. *An Introduction to Wavelets*, Academic Press, Boston, 1992. (Japanese Translation, Tokyo Denki Univ. Publ., 1993; Chinese Translation, Xian Jiaotung Univ. Press, 1995; Russian Translation, Mir Publishers, 2001.)
2. *Wavelets: A Mathematical Tool for Signal Analysis*, SIAM Publ. Philadelphia, 1997. (Japanese Translation, Tokyo Denki Univ. Publ. 1997.)
3. *Multivariate Splines*, CBMS-NSF Series in Applied Mathematics #54, SIAM, Philadelphia, 1988. (Japanese Translation, Tokyo Denki Univ. Publ. 1991; Chinese Translation, Xian Jaotong Univ. Press, 1991.)
4. *Kalman Filtering with Real-time Applications* (with G. Chen), Springer-Verlag, Heidelberg, 1987; 2nd Edition, 1991; 3rd Edition, 1999.
5. *Discrete H^∞ Optimziation* with (G. Chen), Springer-Verlag, Heidelberg, 1992; 2nd Edition, 1997.

List of collaborators during the Last 4 years

1. K. Bittner (Ulm Univ., Germany), 2. W. Czaja (University of Maryland), 3. W. He (Univ. of Missouri–St. Louis), 4. Q. Jiang (Univ. of Missouri–St. Louis), 5. M.J. Lai (Univ. of Georgia), 6. J. Lian (Prairie View A&M Univ.), 7. M. Maggioni (Yale Univ.), 8. J. Stöckler (Univ. of Dortmund, Germany), 9. Q. Sun (Univ. of Central Florida), 10. Jianzhong Wang (Sam Houston State Univ.), 11. G. Weiss (Washington Univ.)

List of Advisor and Advisees

Ph.D. Thesis Advisor: Jaap Korevaar (Univ. of Amsterdam)
Former Mathematics Ph.D. Students: 1. Jeff Chow (Sandia National Lab), 2. Susie Shull (first professor at SMU, later at a prep school), 3. George Roberts (professor at Prairie View A&M University), 4. Loo-Yung Su (IBM, Poughkeepsie), 5. G. Ron Chen (professor at City University of Hong Kong), 6. Ming-Jun Lai (professor at University of Georgia), 7. Tien Xiao He (professor at Wesleyan University, IL), 8. Xin Li (professor at UNLV), 9. Dong Hong (professor at East Tennessee State University), 10. Jian-Ao Lian (professor at Prairie View A&M University), and 11. Jörg Hanisch (industrial mathematician).

Former Electrical Engineering Ph.D. Students: 1. Jun Zha, 2. Qian Liu, 3. S. Goswami, 4. Min Du, and 5. Howard Choe (all have industrial employments).

Former Computer Science Ph.D. Student: Hung-Ju Lee (SONY Research Labs)

Current Ph.D. Students: 1. Eric Mason, 2. Daba Niang, 3. Karen Wurdack.

Wenjie He
Department of Mathematics and Computer Science
University of Missouri - St. Louis
St. Louis, MO 63121-4499
Office: 314-516-6521 Fax: 314-516-5400 he@arch.cs.umsl.edu

Education:

B.S. 1988, Peking University, Beijing, China,
Ph.D. 1998, the Universityof Georgia, Athens, Georgia.

Academic Career:

Assistant Professor, University of Missouri, St. Louis, 1999–present
Postdoctoral Research Associate, Texas A&M University, 1988–1999

Industrial Career:

Consultant, Image and Text Processing Inc., Beijing, China, 1990–1992

Professional Activities

Member of the following professional societies:

Association for Computing Machinery (ACM), 2003–present
Institute of Electrical and Electronics Engineers (IEEE), 2004–present

Publications

A. Five Publications most closely related to the proposed project

1. Construction of multivariate tight frames via Kronecker products (with C. Chui), *Appl. Comp. Harmonic Anal.* **11** (2001), 305–312.

2. Compactly supported tight and sibling frames with maximum vanishing moments, (with C. Chui and J. Stöckler), *Appl. Comp. Harmonic Anal.* **13** (2002), 224-262.

3. Compactly supported tight affine frames with integer dilation and maximum vanishing moments (with C. Chui, J. Stöckler, and Q. Sun), Adv. Comp. Math. **18** (2003), 159–187.

4. Tight frames with maximum vanishing moments and minimum support, in *Approximation Theory X*, C.K. Chui, L.L. Schumaker, J. Stöckler (eds.), Vanderbilt Univ. Press, 2002, pp. 187–206.

5. Nonstationary tight wavelet frames, I: bounded intervals (with C. Chui and J. Stöckler), Appl. Comp. Harmonic Anal., accepted.

B. Five other publications

1. Compactly supported tight frames associated refinable functions, (with C.K. Chui), Appl. Comp. Harmonic Anal., **8** (2000), 293–319.
2. Construction of trivariate compactly supported biorthogonal box spline wavelets, (with M.J. Lai), J. of Approxi. Theory, **120** (2003), 1-19.
3. Examples of bivariate nonseparable continuous compactly supported orthonormal wavelets, (with M.J. Lai), IEEE Trans. Image. Process., **9**(2000), 949-953.
4. Construction of compactly supported bivariate box spline wavelets with arbitrarily high regularity, (with M.J. Lai), Appl. Comp. Harmonic Anal. **6** (1999), 53–74.
5. On filters of biorthogonal wavelets associated with box splines,(with M.J. Lai), J. Electronic Imaging **6** (1997), 453–466.

List of collaborators during the Last 4 years

C.K. Chui, M.J. Lai, Joachim Stöckler and Q. Sun

Advisor and Advisees

Ph.D. Thesis Advisor: Ming-Jun Lai

Current PH.D. student: Eric Mason

Current Support

Jack Snoeyink:

- ITR/ACS+IM Computational Geometry for Structural Biology and Bioinformatics, co-PI, $1,825,588, NSF, 09/01/00 – 08/31/05
- Streaming Meshes for Storing, Transmitting, and Accessing Compressed Geometric Models, PI, $50,000, LLNL, 9/01/03 – 08/30/04
- Image Based Rendering in Forensics, Education & Historical Preservation, co-PI, $1,190,818, NSF, 10/01/02 – 09/30/05
- Enzyme Design, co-PI, $72,241 (UNC portion), DARPA, 5/15/03 – 5/15/04

Marc Pollefeys:

- CAREER: Visual 3D Acquisition, Modeling and Rendering of the Real World, PI, $400,695, NSF, 02/15/03 - 02/14/08
- ITR: Converting 2D Video to 3D with Applications in 3D-TV, Video Analysis and Compression, PI, $279,969, NSF, 08/15/03 - 08/14/06
- Heterogeneous networks of cameras for improving situational awareness, PI, $119,802, DARPA, 07/01/03 - 06/30/04

Leonard McMillan & Wei Wang

- Start-up funds, UNC Chapel Hill Computer Science

Charles Chui & Wenjie He:

- Spline-wavelet frames in computer graphics and other applications, PI, $292,000, NSF, 08/15/2001 - 07/31/2004

Pending Support

Jack Snoeyink

- Inverse Kinematics, Sterics & Data - To Fit RNA Backbone, co-PI, $461,740 (UNC portion), submitted to NIH, June 2004
- Collaborative Proposal: Fundamentals and Algorithms for Streaming Meshes, co-PI, $184,997 (UNC portion), submitted to NSF, Feb 2004.

Jack Snoeyink & Wei Wang:

- Protein Structural/Function Specific Packing Motifs, co-PI, $1,275,000, submitted to NIH, March 2004.

Marc Pollefeys:

- Equipment for Wide-Area 3D Scene Capture and Display, co-PI, $199,826, submitted to NSF, February 04.
- SST: Active Camera Networks for Wide-Area Surveillance, Tracking and Modeling, PI, $749,706, submitted to NSF, February 2004.

Pending Support (cont)
Leonard McMillan:

- Immersive Experiences for Team Training (STC), co-PI, $19,995,851, submitted to NSF, February 2004
- ITR-(ASE)-(Dmc+Sim): Capturing, Analyzing, Modeling and Simulating Appearance, PI, $ 1,085,730, submitted to NSF, February 2004
- Active Camera Network for Wide-Area Surveillance, Tracking and Modeling, co-PI, $749,706, submitted to NSF, February 2004
- Conference Support for a proposal for a 3 Year extension of the Triangle Distinguished Lecture Series, PI, $45,780, submitted to ARO, May 2004
- IXO/BAA 04-17: Enhanced Night-Vision Via a Combination of Poisson Interpolation and Machine Learning, PI, $1,067,589, submitted to DARPA, June 2004

Wei Wang:

- Identifying Structural Motifs for Classification of Protein Structure and Function, PI, $404,320, submitted to NSF, March 2004.
- The Carolina Center for Exploratory Genetic Analysis, co-PI, $1,750,000, submitted to NIH, March 2004.
- Predictive QSAR Modeling (Competitive Supplement to NIH R01GM066940-01), co-PI, $750,000, submitted to NIH, March 2004.
- Collaborative Research: A Framework for Revealing Intrinsic Clusters in Gene Expression Profiles, PI, $241,853, submitted to NSF, March 2004.
- North Carolina Child Welfare Performance System, co-PI, $606,487, submitted to NSF, March 2004.
- ITR-(ASE)-(Dmc+Sim): Capturing, Analyzing, Modeling, and Simulating Appearance, co-PI, $1,085,730, submitted to NSF, February 2004.
- Analysis of High Dimensional Data Using Subspace Clustering, co-PI, $310,651, submitted to NSF, November 2003.

Charles Chui:

- Development of multi-wavelet analysis for applications to signal/image processing and communication, PI, $228,425, submitted to NSF, 07/01/2004 to 06/31/07
- Design and analysis of vector subdivision schemes for surface generation, PI, $199,464, submitted to NSF, 06/01/2004 to 08/31/2006

Charles Chui & Wenjie He:

- Wavelets on scattered knot sets for highly complex image data representations, PI, $198,381, submitted to NSF, 07/01/2004 to 08/31/2006
- Wavelet approach to data analysis, manipulation, compression, and communication, PI, $289,202, submitted to ARO, 08/01/2004 to 07/31/2007

.

Volume 2 - Cost

A **Proposal** in Response to **BAA 04-12, Addendum 2** Technical Area: **DSO GEO***

Meshless wavelets and their application to terrain modeling

PIs: Jack Snoeyink (leader), Leonard McMillan, Marc Pollefeys, Wei Wang (UNC-CH)
Charles Chui, Wenjie He (UMSL)

Department of Computer Science
University of North Carolina at Chapel Hill
Sitterson Hall, CB #3175
Chapel Hill, NC 27599-3175
Type of Business: **OTHER EDUCATIONAL**

Technical	Administrative
Professor Jack Snoeyink Voice: 919-962-1969 Fax: 919-962-1799 snoeyink@cs.unc.edu	Ms. Victoria Moore Voice: 919-962-3397 victoria_moore@unc.edu

Award Instrument Requested: **GRANT**

Performance period	Primary focus	Cost
Phase 1 **18 months**	**Mathematical devel & feasibility**	**764,945**
Phase 2 **18 months**	**Application and prototype devel**	**841,900**
Phase 3 **12 months**	**Intensive devel of key applications**	**393,427**
Phase 4 **12 months**	**Transition to industry**	**354,417**

Offeror's DCMA and DCAA Office:
Department of Health and Human Services
Mid-Atlantic Office, Cohen Building
3330 Independence Avenue SW, Room 1067
Washington, D.C. 20201
202-260-7896

DUNS: 608195277, TIN: 56-6001393A1, CAGE CODE: 4B856

June 25, 2004

Cost description

The project and budget is partitioned into four phases:
Phase 1 focusses on mathematical development of the underlying technology and on feasibility studies for applications. The primary deliverables are papers and reports.
Phase 2 focusses on application development, including advancing the mathematics for the particular applications chosen, and developing extensive prototypes.
Optional **phase 3** gives the cost of intensive development of a key application or applications, based on the mathematical and prototype development of phases 1 & 2.
Optional **phase 4** gives the cost of intensive transition efforts. While phases 3 & 4 are costed for project years 4 & 5, respectively, they need not come in this order.

The first two phases are further partitioned into tasks, which are described more fully in the technical section. Briefly, **phase 1** has two core tasks (building irregular hierarchies of point sets and the mathematics of irregular spline/wavelets) that are the foundation of our work on terrain. Two other tasks: 3-d reconstruction, which was mentioned in the BAA addendum, but which is more involved than the core tasks, and additional application feasibility studies, which would support creation of more detailed demonstrations in the first phase. **Phase 2** continues the core tasks, with a more applied focus, and provides, for four tasks identified in the GEO* BAA addendum, the costs of additional prototype and demonstration development to the level specified in the technical volume.

Performance period	Primary focus	Cost
Phase 1	**Mathematical devel & feasibility**	**764,945**
18 months	Building hierarchies	295,526
	Spline/ wavelets	285,453
	3-d reconstruction	110,450
	Applic. feasibility studies	73,516
Phase 2	**Application and prototype devel**	**841,900**
18 months	Applying hierarchies	164,615
	Spline/ wavelets	294,487
	Compression	102,248
	Registration	120,630
	Database retrieval	100,393
	Iso-height Countours	59,528
Phase 3	**Intensive devel of key applications**	**393,427**
12 months		
Phase 4	**Transition to industry**	**354,417**
12 months		

The next pages give the detailed breakdown for the project phases, followed by the justification for each budgetted amount.

Phase 1 lays the mathematical foundations and explores feasibility. Two options explore applications is greater depth.

	Phase 1				
	18 mos				
	FY 04 - 05				
Personnel	**Totals**	Building hierarchies	Spline/ wavelets	3-d reconstr.	Applic. feasibility studies
# Faculty summer mo	*7.50*	*4.50*	*1.50*	*1.50*	-
Faculty summer salaries	**75,599**	44,080	17,501	14,018	-
Faculty fringe benefits	**14,363**	8,375	3,325	2,663	-
# person/years RA support	*8.25*	*3.75*	*1.50*	*1.50*	*1.50*
Student salaries	**204,359**	92,891	37,156	37,156	37,156
Student Health Benefits	**10,885**	4,948	1,979	1,979	1,979
Total Personnel Costs	**305,206**	150,294	59,961	55,816	39,135
	-				
Other Direct	**-**				
Tutition for RAs	**30,431**	13,832	5,533	5,533	5,533
Travel to PI mtgs, conf	**16,340**	11,020	3,800	760	760
Workshop Costs	**-**				
Consultants visit exp	**3,800**	2,280	760	760	-
Computer Services	**41,125**	19,340	7,558	7,558	6,669
Subcontract Costs	**155,641**		155,641		
Total Other Direct	**247,337**	46,472	173,292	14,611	12,962
	-				
Materials/Supplies	**-**				
Workstations (Dell 650)	**15,906**	7,953		7,953	
Laptop (Dell M60)	**3,647**		3,647		
Misc Suppllies	**7,600**	4,560	1,520	1,520	-
Total Matrl/Supplies	**27,153**	12,513	5,167	9,473	-
	-				
Total Direct costs	**579,696**	209,279	238,420	79,900	52,097
F&A Base	**402,718**	187,494	102,246	66,414	46,564
excludes tuition, equip>$5k, subcontract-$25k					
Indirect Costs	**185,249**	86,247	47,033	30,550	21,419
46% of F&A Base	**-**				
Total Costs	**764,945**	295,526	285,453	110,450	73,516

Phase 2 continues the two core tasks, and breaks out application development as options.

Personnel	Phase 2 18 mos FY 06 - 07 Totals	Applying hierarchies	Spline/ wavelets	Compr- ession	Registra- tion	Database retrieval	Contours
# Faculty summer mo	*8.25*	*3.00*	*1.50*	*0.75*	*1.50*	*0.75*	*0.75*
Faculty summer salaries	**90,713**	32,444	18,441	8,453	14,770	7,385	9,220
Faculty fringe benefits	**17,235**	6,164	3,504	1,606	2,806	1,403	1,752
# person/years RA support	*8.25*	*1.50*	*1.50*	*1.50*	*1.50*	*1.50*	*0.75*
Student salaries	**215,331**	39,151	39,151	39,151	39,151	39,151	19,576
Student Health Benefits	**11,468**	2,085	2,085	2,085	2,085	2,085	1,043
Total Personnel Costs	**334,747**	79,844	63,181	51,295	58,812	50,024	31,591
	-						
Other Direct	**-**						
Tutition for RAs	**32,065**	5,830	5,830	5,830	5,830	5,830	2,915
Travel to PI mtgs, conf	**22,021**	7,207	4,004	2,402	4,004	2,402	2,002
Workshop Costs	**16,000**	8,000	8,000				
Consultants visit exp	**4,404**	1,602	801	400	801	400	400
Computer Services	**43,801**	8,901	7,964	7,495	7,964	7,495	3,982
Subcontract Costs	**163,751**		163,751				
Total Other Direct Costs	**282,042**	31,540	190,350	16,127	18,599	16,127	9,299
	-						
Materials/Supplies	**-**						
Workstations (Dell 650)	**7,953**				7,953		
Laptop (Dell M60)	**7,293**			3,647		3,647	
Misc Suppllies	**8,810**	3,203	1,602	801	1,602	801	801
Total Materials/Supplies	**24,056**	3,203	1,602	4,448	9,555	4,448	801
	-						
Total Direct costs	**640,845**	114,587	255,133	71,870	86,966	70,599	41,691
F&A Base	**437,076**	108,757	85,552	66,040	73,183	64,769	38,776
excludes tuition, equip>$5k, subcontract-$25k							
Indirect Costs	**201,055**	50,028	39,354	30,378	33,664	29,794	17,837
46% of F&A Base	**-**						
Total Costs	**841,900**	164,615	294,487	102,248	120,630	100,393	59,528

Optional phases 3 and 4 are costed for the 4th and 5th project years, but depend only on work of phase 1 & 2.

	Phase 3 12 mos FY 08 Intensive Development	Phase 4 12 mos FY 09 Transition Path
Personnel		
# Faculty summer mo	*2.00*	*4.00*
Faculty summer salaries	22,786	47,396
Faculty fringe benefits	4,329	9,005
# person/years RA support	*4.00*	*2.00*
Student salaries	109,989	57,194
Student Health Benefits	5,858	3,046
Total Personnel Costs	142,962	116,641
Other Direct		
Tutition for RAs	16,378	8,517
Travel to PI mtgs, conf	6,749	10,529
Workshop Costs	-	8,000
Consultants visit exp	1,125	2,340
Computer Services	21,057	13,003
Subcontract Costs	114,847	119,320
Total Other Direct Costs	160,156	161,709
Materials/Supplies		
Workstations (Dell 650)	7,953	-
Laptop (Dell M60)	-	-
Misc Suppllies	2,250	4,679
Total Materials/Supplies	10,203	4,679
Total Direct costs	313,321	283,029
F&A Base	174,143	155,192
excludes tuition, equip>$5k, subcontract-$25k		
Indirect Costs	80,106	71,388
46% of F&A Base		
Total Costs	393,427	354,417

With all phases and all options, the first year and total project costs are as follows:

Personnel	**Year 1**	**Project Totals**
# Faculty summer mo	*5.00*	*21.75*
Faculty summer salaries	49,736	236,494
Faculty fringe benefits	9,450	44,932
# person/years RA support	*5.50*	*22.50*
Student salaries	134,448	586,873
Student Health Benefits	7,161	31,257
Total Personnel Costs	200,801	899,556
Other Direct		
Tutition for RAs	20,020	87,391
Travel to PI mtgs, conf	12,750	55,639
Workshop Costs		24,000
Consultants visit exp	2,500	11,669
Computer Services	27,056	118,986
Subcontract Costs	102,435	553,559
Total Other Direct Costs	164,761	851,244
Materials/Supplies		
Workstations (Dell 650)	15,906	31,811
Laptop (Dell M60)	3,647	10,940
Misc Suppllies	5,000	23,339
Total Materials/Supplies	24,553	66,091
Total Direct costs	390,115	1,816,891
F&A Base	276,754	1,169,129
excludes tuition, equip>$5k, subcontract-$25k		
Indirect Costs	127,307	537,798
46% of F&A Base		
Total Costs	517,422	2,354,689

Budget Justification

All costs are given for the first year, and are inflated by 4% in subsequent years.

Personnel
Principal Investigators

Jack Snoeyink (20%)	Project leader, perform and oversee research on geometric algorithms, attend DARPA PI meetings, liason with UMSL, other partners
Leonard McMillian (15%)	Critical point selection, data-dependent representations, compression, route planning.
Marc Pollefeys (15-20%)	Image and geometry registration, feature point selection, optional 3-d reconstruction from images and feature points
Wei Wang (15%)	Data organization and database retrieval

Research associates

Graduate students	Stipends for each graduate research associate are $14,500 for 50% effort during the academic terms, and $765 a week for 13 weeks full-time in summer. The number of RA person/years estimated per task are indicated on the budget pages.

Benefits

Staff benefits are calculated at 19% of salary.
Student benefits include health care only at a rate of $1,302/year.

Other Direct Costs

Tuition: All supported students have their tuition of $3,640 per annum paid from their source of support.

Travel: PI travel to agency meetings and interact with subcontractors. Partial support for travel of PIs and RAs to technical conferences to present results.

Workshop: $8,000 is requested to organize a workshop on irregular spline/wavelets and their application in terrain modeling in Phase 2. A like amount is requested in optional Phase 4.

Consultants: A token $500 per PI is requested to pay travel expenses of visits by experts on the relevant mathematics and application areas. E.g., M. Neamtu (Vanderbuilt), M. van Kreveld (Utrecht).

Computer Services: The Department of Computer Science distributes the cost of maintaining its shared computing infrastructure among all projects through its Computer Services Recharge Center. This Recharge Center is reviewed by the University each year to ensure that it is in compliance with all applicable federal and state regulations, including OMB Circulars A-21 and A-110, as well as the Federal Cost Accounting Standards. Rates are adjusted annually to ensure that the Recharge Center is operating on a strict cost recovery basis. The rate for the first year is $585 per Full Time Equivalent (FTE) per month. Rates apply to each user and are charged based upon each person's salary distribution, e.g., if a person works 50% on one project and 50% on another during the month, each project pays 50% of the fee for that month. All employees and students are assessed the same rate without regard to their salary source (federal, state, foundation, commercial). No additional fees are charged and all services included within the Recharge Center are available to all users. The Department's computing environment includes more than 500 computers integrated by means of high-speed networks, including an integrated voice/data switch and video switches. E-mail, internet access, routine backups, a host of personal productivity and development software, the services of the TSC (Technical Support Center) Help Desk, UNIX System Administration, PC (Windows and NT) and Macintosh System Administration and the labor for most hardware repair are examples of the available services. This Recharge Center is subject to, and has passed, both federal and state audits. All records are available for review by authorized federal and state representatives.

Subcontract costs: Costs for the subcontract to UMSL are detailed separately. Administrative F&A (overhead) is charged only on the first $25,000 of a subcontract.

Equipment/Supplies

Workstations: (2-4) The data and compute intensive tasks and optional phases include funds for high end workstations with sufficient memory and cache. The prices come from a Dell E-Quote E004623894 to snoeyink@cs.unc.edu, which can be retrieved online from Dell's Higher Education division. We expect to substitute equal or better Dell equipment for the same price at the time that funds become available. As equipment items over $5,000, these workstations are not subject to overhead charges.

Laptops: (2-3) Funds for two to three high-end laptops are requested for effective presentation and collaboration.

Misc supplies: We estimate $1,000 per PI of additional funds for project-specific supplies and expenses (including batteries, extra disk storage, and communication charges such as couriers). No general or departmental expenses are charged to research projects.

Indirect Costs

The University of North Carolina at Chapel Hill has an approved indirect cost rate agreement providing for an indirect cost rate of 46% of MTDC effective 1 July 2003. This rate is not applied to graduate student tuition, equipment purchases over $5,000, or to subcontract costs beyond the first $25,000.

Volume 2 - Cost

A **Proposal** in Response to **BAA 04-12, Addendum 2** Technical Area: **DSO GEO***

Subcontract: Meshless spline/wavelet representation from irregular samples

Charles Chui, Wenjie He (UMSL)

Dept. of Math and CS
302 Computer Center Bldg.
One University Blvd.
St. Louis, MO 63121

Type of Business: **OTHER EDUCATIONAL**

Technical	Administrative
Asst. Prof. Wenjie He Voice: 314-516-6521 Fax: 314-516-5400 he@cs.umsl.edu	Dr. Nasser Arshadi Voice: 314-516-4499 Fax: 314-516-6759 ora@umsl.edu

Award Instrument Requested: **GRANT**

	Performance period	Cost
Phase 1	**18 months**	**155,641**
Phase 2	**18 months**	**163,751**
Phase 3	**12 months**	**114,847**
Phase 4	**12 months**	**119,320**

Offeror's DCMA and DCAA Office:
Department of Health and Human Services
Henry Williams, Director
Division of Cost Allocation-Central States Field Office
Dallas, TX 75202
214/767-3764 (telephone)

DUNS: 804883825, TIN: 56-436003859, CAGE CODE: 4G315

SUMMARY

PROPOSAL BUDGET

YEAR-1

OFFEROR **Curators of the University of Missouri on Behalf of the University of Missouri – St. Louis**						
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR (PI/PD) **Wenjie He**						
A. SENIOR PERSONNEL, PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title. A.7. show number in parentheses)	Man Hrs/Mo	Rates	CAL	ACAD	SMR	Funds Requested by Offeror
1. **Wenjie He**					**2.0**	**14,813**
2. **Charles Chui**					**1.5**	**30,410**
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION)						
7. (2) TOTAL SENIOR PERSONNEL (1-6)						**45,223**
B. OTHER PERSONNEL (SHOW NUMBERS IN PARENTHESES)						
1. ( ) POST DOCTORAL ASSOCIATES						
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (1) GRADUATE STUDENTS						**5,000**
4. ( ) UNDERGRADUATE STUDENTS						
5. ( ) SECRETARIAL - CLERICAL (If charged directly)						
6. ( ) OTHER						
7. TOTAL SALARIES AND WAGES (A + B)						**50,223**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						**14,402**
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						**64,625**
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.00. ATTACH ADDITIONAL EXPLANATION PAGES, IF NECESSARY.)						
TOTAL PERMANENT EQUIPMENT						
E. TRAVEL (LIST ON BUDGET EXPLANATION PAGE)						
1. DOMESTIC (INCLUDE CANADA, MEXICO, AND U.S. POSSESSIONS)						**2,000**
2. FOREIGN						
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER						
( ) TOTAL PARTICIPANT COSTS						
G. OTHER DIRECT COSTS (ITEMIZE ON BUDGET EXPLANATION PAGE)						
1. MATERIALS AND SUPPLIES						
2. PUBLICATIONS COSTS/DOCUMENTATION/DISSEMINATION						
3. CONSULTANT SERVICES						
4. COMPUTER (ADPE) SERVICES						
5 SUBAWARDS						
6. OTHER						**1,831**
7. TOTAL OTHER DIRECT COSTS						**1,831**
H. TOTAL DIRECT COSTS (A THROUGH G)						**68,456**

I. INDIRECT COSTS		Rate	Base	Total		
	Overhead	**51%**	**66,625**	**33,979**		
	G&A					
	Fringe					
TOTAL INDIRECT COSTS	FCCM					**33,979**
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)						**102,435**
K. FEE (%) BASE $						
L. COST SHARING						
M. AMOUNT OF THIS REQUEST						**102,435**

PI/PD NAME (TYPED) & SIGNATURE **Wenjie He**	DATE
OFFEROR'S AUTHORIZED REP. NAME (TYPED) & SIGNATURE **Nasser Arshadi**	DATE June 25 04

SUMMARY

PROPOSAL BUDGET

YEAR-2

OFFEROR **Curators of the University of Missouri on Behalf of the University of Missouri – St. Louis**						
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR (PI/PD) **Wenjie He**						
A. SENIOR PERSONNEL, PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in parentheses)	Man Hrs/Mo	Rates	CAL	ACAD	SMR	Funds Requested by Offeror
1. **Wenjie He**					**2.0**	**15,406**
2. **Charles Chui**					**1.5**	**31,626**
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION)						
7. (2) TOTAL SENIOR PERSONNEL (1-6)						**47,032**
B. OTHER PERSONNEL (SHOW NUMBERS IN PARENTHESES)						
1. ( ) POST DOCTORAL ASSOCIATES						
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (1) GRADUATE STUDENTS						**5,200**
4. ( ) UNDERGRADUATE STUDENTS						
5. ( ) SECRETARIAL - CLERICAL (If charged directly)						
6. ( ) OTHER						
7. TOTAL SALARIES AND WAGES (A + B)						**52,232**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						**14,978**
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						**67,210**
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.00. ATTACH ADDITIONAL EXPLANATION PAGES, IF NECESSARY.)						
TOTAL PERMANENT EQUIPMENT						
E. TRAVEL (LIST ON BUDGET EXPLANATION PAGE)						
1. DOMESTIC (INCLUDE CANADA, MEXICO, AND U.S. POSSESSIONS)						**2,000**
2. FOREIGN						
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER						
( ) TOTAL PARTICIPANT COSTS						
G. OTHER DIRECT COSTS (ITEMIZE ON BUDGET EXPLANATION PAGE)						
1. MATERIALS AND SUPPLIES						
2. PUBLICATIONS COSTS/DOCUMENTATION/DISSEMINATION						
3. CONSULTANT SERVICES						
4. COMPUTER (ADPE) SERVICES						
5 SUBAWARDS						
6. OTHER						**1,904**
7. TOTAL OTHER DIRECT COSTS						**1,904**
H. TOTAL DIRECT COSTS (A THROUGH G)						**71,114**

I. INDIRECT COSTS		Rate	Base	Total		
	Overhead	**51%**	**69,210**	**35,297**		
	G&A					
	Fringe					
TOTAL INDIRECT COSTS	FCCM					**35,297**

J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**106,411**
K. FEE (%) BASE $	
L. COST SHARING	
M. AMOUNT OF THIS REQUEST	**106,411**

PI/PD NAME (TYPED) & SIGNATURE **Wenjie He**	DATE
OFFEROR'S AUTHORIZED REP. NAME (TYPED) & SIGNATURE **Nasser Arshadi**	DATE Jun 25'04

SUMMARY

PROPOSAL BUDGET

YEAR-3

OFFEROR **Curators of the University of Missouri on Behalf of the University of Missouri – St. Louis**							
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR (PI/PD) **Wenjie He**							
A. SENIOR PERSONNEL, PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in parentheses)	Man Hrs/Mo	Rates	CAL	ACAD	SMR	Funds Requested by Offeror
1. **Wenjie He**					**2.0**	**16,022**
2. **Charles Chui**					**1.5**	**32,891**
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION)						
7. (2) TOTAL SENIOR PERSONNEL (1-6)						**48,913**
B. OTHER PERSONNEL (SHOW NUMBERS IN PARENTHESES)						
1. ( ) POST DOCTORAL ASSOCIATES						
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (1) GRADUATE STUDENTS						**5,408**
4. ( ) UNDERGRADUATE STUDENTS						
5. ( ) SECRETARIAL - CLERICAL (If charged directly)						
6. ( ) OTHER						
7. TOTAL SALARIES AND WAGES (A + B)						**54,321**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						**15,577**
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						**69,898**

D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.00. ATTACH ADDITIONAL EXPLANATION PAGES, IF NECESSARY.)	
TOTAL PERMANENT EQUIPMENT	
E. TRAVEL (LIST ON BUDGET EXPLANATION PAGE)	
1. DOMESTIC (INCLUDE CANADA, MEXICO, AND U.S. POSSESSIONS)	**2,000**
2. FOREIGN	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER	
( ) TOTAL PARTICIPANT COSTS	
G. OTHER DIRECT COSTS (ITEMIZE ON BUDGET EXPLANATION PAGE)	
1. MATERIALS AND SUPPLIES	
2. PUBLICATIONS COSTS/DOCUMENTATION/DISSEMINATION	
3. CONSULTANT SERVICES	
4. COMPUTER (ADPE) SERVICES	
5 SUBAWARDS	
6. OTHER	**1,980**
7. TOTAL OTHER DIRECT COSTS	**1,980**
H. TOTAL DIRECT COSTS (A THROUGH G)	**73,878**

I. INDIRECT COSTS		Rate	Base	Total	
	Overhead	**51%**	**71,898**	**36,668**	
	G&A				
	Fringe				
TOTAL INDIRECT COSTS	FCCM				**36,668**

J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**110,546**
K. FEE (%) BASE $	
L. COST SHARING	
M. AMOUNT OF THIS REQUEST	**110,546**

PI/PD NAME (TYPED) & SIGNATURE **Wenjie He**	DATE
OFFEROR'S AUTHORIZED REP. NAME (TYPED) & SIGNATURE **Nasser Arshadi**	DATE Jun 25 '04

SUMMARY

PROPOSAL BUDGET

YEAR-4

OFFEROR
Curators of the University of Missouri on Behalf of the University of Missouri – St. Louis

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR (PI/PD)
Wenjie He

A. SENIOR PERSONNEL, PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in parentheses)	Man Hrs/Mo	Rates	CAL	ACAD	SMR	Funds Requested by Offeror
1. **Wenjie He**					**2.0**	**16,663**
2. **Charles Chui**					**1.5**	**34,207**
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION)						
7. (2) TOTAL SENIOR PERSONNEL (1-6)						**50,870**
B. OTHER PERSONNEL (SHOW NUMBERS IN PARENTHESES)						
1. ( ) POST DOCTORAL ASSOCIATES						
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (1) GRADUATE STUDENTS						**5,624**
4. ( ) UNDERGRADUATE STUDENTS						
5. ( ) SECRETARIAL - CLERICAL (If charged directly)						
6. ( ) OTHER						
7. TOTAL SALARIES AND WAGES (A + B)						**56,494**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						**16,200**
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						**72,694**
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.00. ATTACH ADDITIONAL EXPLANATION PAGES, IF NECESSARY.)						
TOTAL PERMANENT EQUIPMENT						
E. TRAVEL (LIST ON BUDGET EXPLANATION PAGE)						
1. DOMESTIC (INCLUDE CANADA, MEXICO, AND U.S. POSSESSIONS)						**2,000**
2. FOREIGN						
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER						
( ) TOTAL PARTICIPANT COSTS						
G. OTHER DIRECT COSTS (ITEMIZE ON BUDGET EXPLANATION PAGE)						
1. MATERIALS AND SUPPLIES						
2. PUBLICATIONS COSTS/DOCUMENTATION/DISSEMINATION						
3. CONSULTANT SERVICES						
4. COMPUTER (ADPE) SERVICES						
5 SUBAWARDS						
6. OTHER						**2,059**
7. TOTAL OTHER DIRECT COSTS						**2,059**
H. TOTAL DIRECT COSTS (A THROUGH G)						**76,753**

I. INDIRECT COSTS		Rate	Base	Total		
	Overhead	**51%**	**74,694**	**38,094**		
	G&A					
	Fringe					
TOTAL INDIRECT COSTS	FCCM					**38,094**

J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**114,847**
K. FEE (%) BASE $	
L. COST SHARING	
M. AMOUNT OF THIS REQUEST	**114,847**

PI/PD NAME (TYPED) & SIGNATURE **Wenjie He**	DATE
OFFEROR'S AUTHORIZED REP. NAME (TYPED) & SIGNATURE **Nasser Arshadi**	DATE Jun 25'04

SUMMARY

PROPOSAL BUDGET

YEAR-5

OFFEROR
Curators of the University of Missouri on Behalf of the University of Missouri – St. Louis

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR (PI/PD)
Wenjie He

A. SENIOR PERSONNEL, PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in parentheses)	Man Hrs/Mo	Rates	CAL	ACAD	SMR	Funds Requested by Offeror
1. **Wenjie He**					**2.0**	**17,330**
2. **Charles Chui**					**1.5**	**35,575**
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION)						
7. (2) TOTAL SENIOR PERSONNEL (1-6)						**52,905**
B. OTHER PERSONNEL (SHOW NUMBERS IN PARENTHESES)						
1. ( ) POST DOCTORAL ASSOCIATES						
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (1) GRADUATE STUDENTS						**5,849**
4. ( ) UNDERGRADUATE STUDENTS						
5. ( ) SECRETARIAL - CLERICAL (If charged directly)						
6. ( ) OTHER						
7. TOTAL SALARIES AND WAGES (A + B)						**58,754**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						**16,848**
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						**75,602**
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.00. ATTACH ADDITIONAL EXPLANATION PAGES, IF NECESSARY.)						
TOTAL PERMANENT EQUIPMENT						
E. TRAVEL (LIST ON BUDGET EXPLANATION PAGE)						
1. DOMESTIC (INCLUDE CANADA, MEXICO, AND U.S. POSSESSIONS)						**2,000**
2. FOREIGN						
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER						
( ) TOTAL PARTICIPANT COSTS						
G. OTHER DIRECT COSTS (ITEMIZE ON BUDGET EXPLANATION PAGE)						
1. MATERIALS AND SUPPLIES						
2. PUBLICATIONS COSTS/DOCUMENTATION/DISSEMINATION						
3. CONSULTANT SERVICES						
4. COMPUTER (ADPE) SERVICES						
5 SUBAWARDS						
6. OTHER						**2,141**
7. TOTAL OTHER DIRECT COSTS						**2,141**
H. TOTAL DIRECT COSTS (A THROUGH G)						**79,743**

I. INDIRECT COSTS		Rate	Base	Total	Funds Requested by Offeror
	Overhead	**51%**	**77,602**	**39,577**	
	G&A				
	Fringe				
TOTAL INDIRECT COSTS	FCCM				**39,577**

J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**119,320**
K. FEE (%) BASE $	
L. COST SHARING	
M. AMOUNT OF THIS REQUEST	**119,320**

PI/PD NAME (TYPED) & SIGNATURE **Wenjie He**	DATE
OFFEROR'S AUTHORIZED REP. NAME (TYPED) & SIGNATURE **Nasser Arshadi**	DATE June 25'04

SUMMARY

PROPOSAL BUDGET

CUMULATIVE YEARS 1-5

OFFEROR
Curators of the University of Missouri on Behalf of the University of Missouri – St. Louis

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR (PI/PD)
Wenjie He

A. SENIOR PERSONNEL, PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title. A.7. show number in parentheses)	Man Hrs/Mo	Rates	CAL	ACAD	SMR	Funds Requested by Offeror
1. **Wenjie He**					**10.0**	**80,234**
2. **Charles Chui**					**7.5**	**164,709**
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION)						
7. (2) TOTAL SENIOR PERSONNEL (1-6)						**244,943**
B. OTHER PERSONNEL (SHOW NUMBERS IN PARENTHESES)						
1. ( ) POST DOCTORAL ASSOCIATES						
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)						
3. (5) GRADUATE STUDENTS						**27,081**
4. ( ) UNDERGRADUATE STUDENTS						
5. ( ) SECRETARIAL - CLERICAL (If charged directly)						
6. ( ) OTHER						
7. TOTAL SALARIES AND WAGES (A + B)						**272.024**
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)						**78.005**
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)						**350.029**
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.00. ATTACH ADDITIONAL EXPLANATION PAGES, IF NECESSARY.)						
TOTAL PERMANENT EQUIPMENT						
E. TRAVEL (LIST ON BUDGET EXPLANATION PAGE)						
1. DOMESTIC (INCLUDE CANADA, MEXICO, AND U.S. POSSESSIONS)						**10.000**
2. FOREIGN						
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER						
( ) TOTAL PARTICIPANT COSTS						
G. OTHER DIRECT COSTS (ITEMIZE ON BUDGET EXPLANATION PAGE)						
1. MATERIALS AND SUPPLIES						
2. PUBLICATIONS COSTS/DOCUMENTATION/DISSEMINATION						
3. CONSULTANT SERVICES						
4. COMPUTER (ADPE) SERVICES						
5 SUBAWARDS						
6. OTHER						**9.915**
7. TOTAL OTHER DIRECT COSTS						**9.915**
H. TOTAL DIRECT COSTS (A THROUGH G)						**369.944**

I. INDIRECT COSTS		Rate	Base	Total		
	Overhead	**51%**	**360.029**	**183.615**		
	G&A					
	Fringe					
TOTAL INDIRECT COSTS	FCCM					**183.615**

J. TOTAL DIRECT AND INDIRECT COSTS (H + I)	**553.559**
K. FEE (%) BASE $	
L. COST SHARING	
M. AMOUNT OF THIS REQUEST	**553.559**

PI/PD NAME (TYPED) & SIGNATURE **Wenjie He**	DATE
OFFEROR'S AUTHORIZED REP. NAME (TYPED) & SIGNATURE **Nasser Arshadi**	DATE Jun 25 '04

ARO Form 99 (MAY 97)