Proposal for a Regional Conference on "Radial Basis Functions: Mathematical Developments and Applications"

June 20, 2011 to June 24, 2011

Overview

The recently developed field of Radial Basis Function (RBF) approximations for the solution of partial differential equations has shown much promise and generated enthusiasm among researchers. The impact of RBF methods is clearly evidenced by the large number of publications on RBF methods which have appeared in the past decade, not only in mathematics but also in physics and engineering journals. This is an active and growing field, and one which has included significant collaborations across disciplines. The open and free exchange of ideas in this field is seen clearly in the freely available RBF MATLAB research codes posted by its authors through MATLAB files exchange for the purpose of reproducible research. This field has made inroads in education as well: some departments have introduced RBF methods to undergraduate and graduate students in their beginning numerical analysis classes. In short, RBF methods have become mainstream research in numerical analysis and scientific computing. A conference devoted to these methods and their applications is long overdue.

The **goal of this conference is to educate and inspire researchers and students in RBF methods and to stimulate further studies in their analysis and applications.** The conference will feature ten lectures by two experts in this area, Bengt Fornberg and Natasha Flyer. These lectures will span the range from the numerical analysis of RBF methods to cutting-edge implementation. The advantage of this approach is that the audience will have a deep understanding of the methods from both a theoretical and practical perspective. The lectures will begin with an understanding of the RBF methods as a generalization of pseudospectral methods to non-orthogonal basis functions, and examine the issues of stability and efficient implementation. These issues are still the topics of research in progress, and will be presented with a focus on the open problems in this field. The transition to the issue of applications will be made through comparison with pseudospectral methods for partial differential equations. The final four lectures will address implementation issues and applications to problems in the geosciences.

In addition to these ten lectures by the principal lecturers, supplementary forty-minute talks will be given by invited speakers. The aim of these lectures is to provide a broader view of the range of current issues in RBF methods, which will enhance the informal discussion sessions and panel discussions on recent advances and open problems. This structure will facilitate energetic discussion which will benefit both the invited researchers and the attendees, and result in active interactions and collaborations among participants. This conference will also serve the purpose of amplifying and disseminating NSF-funded research in the field of RBF methods. Of the eight speakers (principal and secondary), seven have been funded by the NSF over the last decade for their work in this field. This conference will serve to disseminate their work and increase the impact of their research by fostering new research and collaborations on RBF methods, thus increasing the effect of the NSF's investment in research funding. Additionally, an expository monograph based on ten lectures will be prepared and made available for non-participants, and a web site devoted to the conference will make it accessible to those who could not attend. This will be of additional benefit to the students attending, who will be able to use these materials for self-study, and to the researchers who wish to convert this information to course materials.

Of major importance to the organizers is the focus on increasing diversity in the field, and encouraging young researchers. To this end, the organizers are committed to encouraging young minority and women researchers by providing them with diverse role models among the speakers. One of the principal speakers is a woman (as are two of the organizers), and the list of secondary speakers includes a researcher from underrepresented groups. Furthermore, the organizers will put extra efforts into recruiting and funding junior attendees (including graduate students and beginning researchers), women, and researchers from underrepresented groups. This recruitment will be accomplished by web-advertising, announcements in mailing lists such as NA-Digest, and speaking to colleagues from local universities and enlisting their help in identifying interested attendees and advertising the conference to them.

1. Subject: Radial Basis Functions

RBF methods have been praised for their simplicity and ease of implementation in multivariate scattered data approximation [7, 15, 74]. The first application of RBF was made in the 1970's by geophysicist R.L. Hardy [33], for topography on irregular surfaces. Recently, they have become increasingly popular for the numerical solution of PDEs [28, 43, 49], particularly in modeling phenomena in the geosciences [18, 19, 76, 78]. RBF-based methods offer numerous advantages when compared to classical methods such as finite difference, finite volume, and finite element. They do not require meshing or triangulation, do not need staircasing or polygonization for boundaries. Moreover, RBF methods are simple to implement, independent of dimension, and they can achieve high-order or spectral accuracy [6, 11, 58, 80], depending on the choice of RBFs.

Like all numerical methods, RBF methods require a study of their stability properties, and the development of techniques for their numerically efficient implementation. For applications, a deep understanding of both the physical and numerical properties of the model and the method is needed. In the following subsections, we briefly describe the background and range of issue which will be covered in the conference, giving some background and some results of numerical experiments as motivation.

1.1. Numerical Analysis of RBF Methods. RBF interpolation can be briefly explained as follows: Given the values of a function $F(\mathbf{x})$ at nodes $\mathbf{x}_1, \ldots, \mathbf{x}_N$ known as RBF *centers* in d dimensions, the basic form for an RBF approximation is

$$F(\mathbf{x}) \approx F_N(\mathbf{x}) = \sum_{j=1}^{N} \lambda_j \phi(\epsilon_j \|\mathbf{x} - \mathbf{x}_j\|), \tag{1}$$

where $\| \cdot \|$ denotes the Euclidean distance between two points, ϵ_j denotes a shape parameter, and $\phi(r)$ is a radial basis function defined for $r \geq 0$. Given scalar function values $f_i = F(\mathbf{x}_i)$, the expansion coefficients λ_j are obtained by solving a linear system

$$\begin{bmatrix} & & \\ & A & \\ & & \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \vdots \\ \lambda_N \end{bmatrix} = \begin{bmatrix} f_1 \\ \vdots \\ f_N \end{bmatrix}, \tag{2}$$

where the *interpolation matrix* A satisfies $(A)_{ij} = \phi(\epsilon_j \|\mathbf{x}_i - \mathbf{x}_j\|)$. Common choices of $\phi(r)$ are:

- Infinitely smooth with a free parameter: Multiquadrics ($\phi(\epsilon r) = \sqrt{1 + (\epsilon r)^2}$) and Gaussian ($\phi(\epsilon r) = e^{-(\epsilon r)^2}$);
- Piecewise smooth and parameter-free: Cubic ($\phi(r) = r^3$), thin plate splines ($\phi(r) = r^2 \ln r$);
- Compactly supported piecewise polynomials with free parameter for adjusting the support: Wendland functions [73].

In general, the *interpolation matrix* A is guaranteed to be nonsingular [55], for typical choices of ϕ, under mild restrictions. This property also carries over when the shape parameter is a constant ($\epsilon_j \equiv \epsilon$), and/or when the interpolation is subject to minor modifications such as adding a low order polynomial to (1). Under certain conditions, the infinitely smooth radial functions exhibit exponential (spectral) convergence as a function of center spacing, while the piecewise smooth ones give algebraic convergence [6, 11, 73, 80].

The study of different radial basis functions and the effect of the shape parameter is an ongoing active research field. For example, researchers have considered methods based on radial basis functions which have compact support; the appeal of compactly supported functions is that they lead naturally to banded interpolation matrices, although experience has shown that the matrices need to be large for good accuracy. Multiquadrics respond rather sensitively to the shape parameter ϵ. For example, in one dimension, the limit $\epsilon \to \infty$ produces piecewise linear interpolation, and the 'flat limit' $\epsilon \to 0$ produces global polynomial interpolation [12, 48]. Hence smaller values of ϵ are associated with more accurate approximations. Many rules of thumb for the shape parameter selection are known from numerical experiments and theories [9, 24, 44, 63].

Despite the advantages mentioned above, there are many open issues in the development and implementation of RBF methods. In particular, RBF methods have serious drawbacks when implemented directly through equations (1) and (2). As the number of centers grows, a relatively large algebraic system needs to be solved. Moreover, severe ill-conditioning of the interpolation matrix A leads to instabilities that make spectral convergence difficult to achieve. This behavior is manifested as a classic accuracy and stability trade-off or uncertainty principle; for instance, the condition number of A, $\kappa(A)$, grows exponentially with N [66]. For small N, it is possible to compute the interpolant $F(\mathbf{x})$ accurately, using complex contour integration [23]. Another approach that also bypasses the 'uncertainty principle', RBF-QR, works for thousands of nodes on the surface of a sphere [22] and appears to generalize to other geometries [27]. Besides RBF-QR, methods based on FFT decomposition have also been investigated [34, 45, 46]. If one wishes to use an iterative method to solve for the interpolation coefficients, ill-conditioning can also create a serious convergence issue. In such cases good preconditioners are highly needed [1, 17, 31].

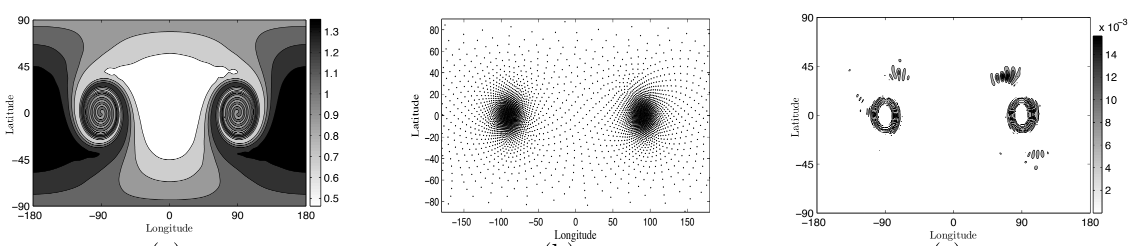
There are other open areas of research in RBF methods which are not related to the solution of the linear system. Node and center locations also play a crucial role through the classical problem of interpolation stability, as measured by Lebesgue constants and manifested through the Runge phenomenon. It is clear, for example by comparison to the flat limit of polynomial interpolation, that spectral convergence results such as those cited above must be limited to certain classes of functions that are well-behaved beyond analyticity in the domain of approximation. This is thoroughly described in [60] for the special case of Gaussian RBFs in one dimension. Just as in polynomial potential theory, for the limit $N \to \infty$ an interpolated function must be analytic in a complex domain larger than the interval of approximation, unless a special node density is used. This density clusters the nodes toward the end of the interval, in the same way as nodes based on Jacobi polynomials, in order to avoid Runge oscillations. The existence and construction of stable node sets in higher dimensions and general geometries, in particular with regards to proper clustering near the boundary, remain a very challenging problem.

Current active research topics in RBF (in addition to its implementations for the numerical solutions for PDEs) also include: RBF-Pseudospectral methods [14, 26], Gibbs phenomenon in RBF interpolation [21, 38], eigenvalue stability in time-dependent PDEs and least-squares RBF [61], consistent adaptive implementation [4, 13, 57, 64], hybrid methods [2, 5, 78], eigenvalue problem [59], edge detection methods [39, 40], post-processing of RBF approximations [65], anisotropic RBF [10], integrated RBF (iRBF) methods [53, 54], RBF methods for dynamical systems [29, 30], and local RBF methods [25, 67, 68, 77, 79]. Several books [7, 15, 74] emphasizing theoretical issues and implementations have been written by leading researchers in the field. The aim of this conference is to bring together some of these experts to describe the progress and state of the art of these current research topics.

1.2. Radial Basis Functions in the Computational Geosciences. An understanding of RBF methods would be incomplete without the recognition of how these powerful methods have been applied to large-scale physical problems. For this reason, the conference will describe how RBFs are being used for planetary-scale modeling of important geophysical phenomena, from the evolution of cold and warm frontal zones in meteorological modeling to translating pressure systems common in weather patterns to 3D convection of the Earth's mantle. These RBF results are being compared to state-of-the-art methods in the field, illustrating that RBF methods are ripe for a larger exposure to mathematicians and scientists.

1.2.1. Weather Fronts - Cyclogenesis with Local Node Refinement. A node refinement scheme should reflect the physics of the problem, while decreasing the computational cost to achieve a given accuracy. If the transition in node density is not smooth, numerical wave dispersion will occur. A quite simple approach is to simulate electrostatic repulsion [18]. By applying different charges to the nodes through a charge distribution function $Q(\mathbf{x})$ that reflects the physics (such as the gradient of the velocity), and letting them move until force equilibrium is reached, the node density will become smoothly varying over the domain.

It is also crucial to realize that variable node density can cause a Runge phenomena to occur [24]. To counteract this, the shape of the RBF needs to vary over the domain. A heuristic that has proved very successful is the nearest neighbor rule [13, 18, 24], defined by varying the RBF shape parameter by the inverse of the Euclidean distance between the node of interest and its closest neighbor node. An example of using these strategies is given in Figure 1 for translating vortex roll-up on a sphere, demonstrating the physics of the observed evolution of cold and warm frontal zones. Comparisons to Discontinuous Galerkin (DG) and Finite Volume (FV) with and without adaptive mesh refinement (AMR) after 12 days is given in Table 1. The result show RBFs give more accurate results than any other method previously published in the literature with refinement and that for a given accuracy, without refinement, RBFs require much less nodes while taking unusually large time steps [18].



(a) (b) (c)

Figure 1: (a) Translating vortex roll-up after 24 days.(b) RBF refined nodes.(c) Magnitude of error.

1.2.2. Translating Pressure Systems-Nonlinear Unsteady Flow. The flow field comprises a translating low pressure center that is superimposed on a westerly jet stream. This setup resembles the observed properties of atmospheric flows in the

Method	No. of Nodes	Ang. Res.	Time step (min.)	ℓ_2 Error	Ref.
Without local refinement					
RBF	3,136	6.4°	60	$4 \cdot 10^{-3}$	[18]
FV (lat-long grid)	165,888	0.625°	10	$2 \cdot 10^{-3}$	[56]
FV (cubed sphere)	38,400	1.125°	30	$2 \cdot 10^{-3}$	[62]
DG	9,600	2.6°	6	$7 \cdot 10^{-3}$	[56]
With local refinement					
RBF	3,136	variable	20	$8 \cdot 10^{-5}$	[18]
FV (lat-long grid)	–	5° − 0.625°	1-3	$2 \cdot 10^{-3}$	[56]

Table 1: Comparison between the latest methods for cyclogenesis for a 12 day simulation.

Method	No. of nodes	Time step	ℓ_2 Error	Ref.
RBF	3,136	15 min	$8.8 \cdot 10^{-6}$	[19]
	5,041	6 min	$1.0 \cdot 10^{-8}$	
DF	8,192	3 min	$8.2 \cdot 10^{-4}$	[69]
	32,768	90 sec	$4.0 \cdot 10^{-4}$	
SH	8,192 (1849)	3 min	$2.0 \cdot 10^{-3}$	[37]
SE	6,144	90 sec	$6.5 \cdot 10^{-3}$	[71]
	24,576	45 sec	$4.0 \cdot 10^{-5}$	

Table 2: Comparisons for a standard 5 day run (in the spherical harmonic case (SH) case, discretizations were needed on both lat-long grids and SH coefficient space, using 8,192 and 1,849 parameters, respectively). SE=spectral elements. DF=Double Fourier.

middle troposphere (5km above ground) that are responsible for global weather patterns. The mathematical model is represented by the nonlinear shallow water equations on the sphere where forcing terms are added to keep the pressure system intact. The initial field is given in Figure 2.

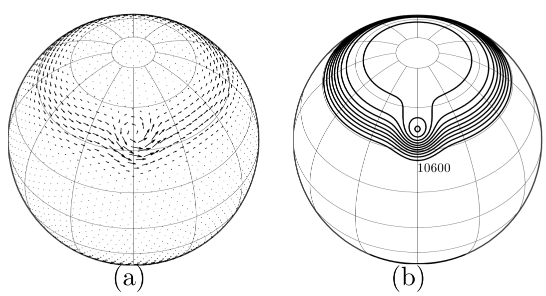


Figure 2: Initial (a) velocity field and (b) height field with $N = 3136$ for the unsteady flow test case plotted as orthographic projections centered at 45°N and 0°E. The contours in (a) range from 10600 m to 10100 m in intervals of 50 m.

Comparisons to high-order methods used today are given in Table 2 [19]. The RBF

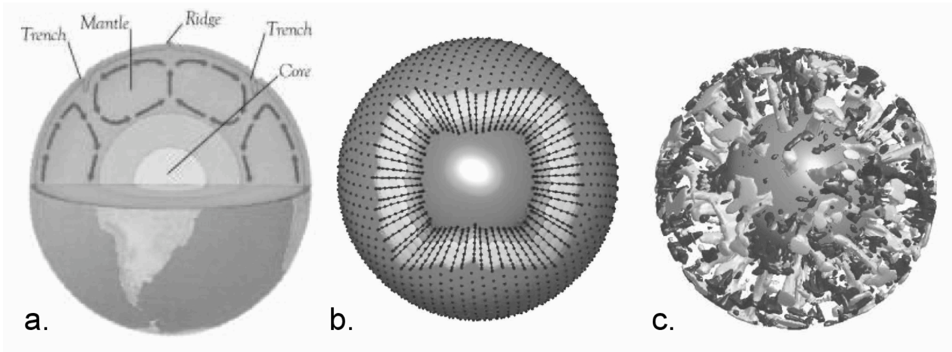


Figure 3: Mantle convection: (a) Schematic of problem geometry, (b) Discretization (RBFs over spherical shells; Chebyshev in radial direction, (c) Example of a turbulent flow field calculated by the RBF-CH method when starting from a highly regular initial condition (at Rayleigh number (Ra) = 500,000). Light gray corresponds to upwelling and dark gray to downwelling.

result is the most accurate to date and is run on a PC desktop in under 12 minutes. It should be noted that the time steps reported for RBFs is not to maintain time stability, as in the other methods, but that spatial and temporal discretization errors match. For stability purposes, RBFs could double the time steps reported above with the loss of only an order of accuracy. Another striking note, is that unlike the other methods, RBFs use no filtering to maintain stability. Furthermore, mass and energy are conserved to 9 decimal places with only 3136 nodes and a 25 day run, without having it enforced as in a DG method.

1.2.3. Mantle Convection with RBFs in 3D Spherical Geometry. To date, this is the most advanced application of RBFs to geophysical modeling [78]. The flows, driven by the heat from the core of the earth, are of great practical interest due to their role in tectonic plate motions, with earthquakes, continental drifts, etc. as consequences. The governing PDEs require highly accurate nonlinear advection solvers, elliptic solvers, and treatment of thin boundary layers that near the inner shell (Earth's outer core) and near the outer shell (Earth's crust). They were approximated in [78] by RBF discretization on each of many concentric spherical shells, combined with Chebyshev pseudospectral discretization (CH) in the radial direction. The physically realistic situation, when energy transfer is strongly dominated by convection over diffusion, results in turbulent flows as pictured in Figure 3.

Since no analytic solutions are available, it is common practice to compare certain computed scalar global quantities from new methods to other published methods that are in current use in a steady state regime (low Rayleigh number (Ra)). Table 3 contains this comparison for the RBF-CH method. The only other method that is at least partially spectral is the SH-FD (FD=finite differences), on which Richardson's extrapolation was used as to get a highly accurate estimate of the expected solu-

Method	Number of nodes	Nu_o	$< V_{RMS} >$	$< T >$	Ref.
RBF-CH	36,800	3.6096	31.0823	0.21578	[78]
SH-FD	extrapolated	3.6096	31.0821	0.21578	[32, 70]
SH-FD	552,960	3.6086	31.0765	0.21582	[32, 70]
FE (CitCom)	393,216	3.6254	31.09	0.2176	[81]
FV	663,552	3.5983	31.0226	0.21594	[70]
FD (Japan)	12,582,912	3.4945	32.6308	0.21597	[42]

Table 3: Comparisons for the standardized Ra=7000 mantle convection benchmark. Nu_o denotes the Nusselt number, a measure of heat flux across the outer shell, $< V_{RMS} >$ the volume-averaged rms-velocity, and $\langle T \rangle$ the mean temperature. (CitCom) is the nationally-funded US model for mantle convection with the label (Japan) noted the analogue in that country.

tion. We note that the RBF-CH calculation here achieves near perfection in terms of accuracy even when using a far lower level of discretization. It was also the only implementation that was run on standard PC hardware.

At Ra=70,000, the present RBF calculations showed an instability that differed from what has been previously observed, yet theorized by [3] in 1989. It was subsequently confirmed on the Japanese Earth Simulator (until recently, the largest computer system in the world). This episode may have been the first case in which RBF solutions of PDEs provided new physical insights due to their abilities to highly resolve flows with a much lower number of degrees of freedom, even compared to pseudospectral methods. It also demonstrated quite strikingly how effective RBFs can be already on standard PCs.

2. Principal Lecturers

The principal lecturers, **Bengt Fornberg** and **Natasha Flyer**, are the leading researchers in the field. Bengt Fornberg is currently a Professor of Applied Mathematics at the University of Colorado at Boulder and Natasha Flyer is a scientist at the Institute for Mathematics Applied to Geosciences and Computational Mathematics Group of National Center for Atmospheric Research (NCAR). Dr. Fornberg's main research interests are in development, analysis, and implementation of numerical methods, in particular for solving PDEs with a high order accuracy, such as high order finite difference, pseudospectral and RBF methods. The main application areas include computational fluid dynamics, geophysical and astrophysical flows, and different types of wave phenomena. Dr. Flyer's main research interests in the area of RBFs are the analytical and numerical development for application to geophysical phenomena such as atmospheric flows, tsunami modeling, and mantle convection. Her work is the first to demonstrate the viability of the RBF method on the international stage of numerical modeling in the geosciences. Drs. Flyer and Fornberg have received NSF grants totaling over one million dollars for the study and application of RBFs. In the last five years, they have given over fifty invited talks on the subject of RBFs on four different continents. With more than one hundred scientific publications, both of them have set the research directions of RBF. Their advice and guidance will be beneficial for young researchers who are beginners in this field.

The CVs and letter of commitment from the principal lecturers can be found in the supplementary documents section. We will send their complete CVs and list of publications to the CBMS office.

3. Conference Organization

3.1. Description of Lectures. As mentioned previously in this proposal, a variety of methods have been developed for numerically solving PDEs, including finite differences (FD), finite elements (FE), and pseudospectral (PS) methods. We will start by following the main theme in the book "A Practical Guide to Pseudospectral Methods" [20] in showing how classical FD methods naturally evolve into PS methods when their order of accuracy is increased. Although PS methods can be extremely cost effective in many applications, they are severely restricted to very simple geometries (such as periodic intervals, rectangular 'boxes', or simple variations of such, that can be obtained through mappings).

We will next introduce the RBF approach as a major generalization of PS methods, completely abandoning the orthogonality of the PS basis functions in exchange for obtaining vastly improved simplicity as well as geometric flexibility. By means of the RBF approach, spectral accuracy becomes easily available also when using completely unstructured meshes, permitting local node refinements in critical areas. A very counterintuitive parameter range (making all the RBFs very flat) turns out to be of special interest. It is typically not an optimal one but, in simple cases, RBFs then reduce to PS methods. This confirms that they naturally can be seen as a major generalization of the PS approach.

Once we have developed this perspective, we will turn our attention to a number of issues that are relevant for their fast and stable numerical implementation. A direct use of equations (1) and (2) is inappropriate in both these regards (stability and speed), but a number of alternative opportunities have been discovered in the last few years. After surveying some of these developments (which all are best characterized as research in progress), we will focus on numerical comparisons between RBFs and a range of earlier approaches for solving different PDEs, starting with simple elliptic ones and then gradually progressing towards large scale simulations of flows in various spherical geometries, as these arise in applications taken from the geosciences.

The principal lectures will cover these areas of interest as follows:

PL1.	Introduction to finite difference (FD) methods and their generalization into pseudospectral (PS) methods.
PL2.	PS methods in periodic and non-periodic cases; Time stepping and stability considerations.
PL3.	Introductions to RBFs
PL4.	Issues and algorithms related to numerical conditioning and computational speed.
PL5.	The Runge phenomenon and the Gibbs phenomenon for RBFs.
PL6.	RBFs for PDEs.
PL7.	Convective flows in spherical geometries.
PL8.	Local node refinement: method and application.
PL9.	Test problems from the geosciences (with respect to RBFs).
PL10.	Modeling in the geosciences (with respect to RBFs).

These principal lectures will be supplemented by talks by the other invited lecturers. These lecturers will be given by Toby Driscoll (University of Delaware), Greg Fasshauer (Illinois Institute of Technology), Jae-Hun Jung (State University of New York at Buffalo), Rodrigo Platte (Arizona State University), Scott Sarra (Marshall University), and Grady Wright (Boise State University).

The conference will begin at 9 am on Monday, June 20, 2011 and run through noon on Friday, June 24, 2011 (5 days).

Table 4: **Conference Schedule**

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
8:00 - 9:00	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
9:00-9:15	Opening Remarks	Opening Remarks	Opening Remarks	Opening Remarks	Opening Remarks
9:15-10:15	PL1	PL4	PL7	PL9	SL5
10:15-10:30	Q & A	Q & A	Q & A	Q & A	Q & A
10:30-11:00	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:00-12:00	PL2	PL5	SL1-SL2	SL3	SL6
12:00-12:15	Q & A	Q & A	SL1-SL2	Q & A	Concluding Remarks
12:15-1:15	Lunch	Lunch	Lunch	Lunch	
1:15- 2:15	Panel	Panel	Panel	Panel	
2:15-3:15	Informal Discussion	Informal Discussion	PL8	PL10	
3:15-3:30	Coffee Break	Coffee Break	Coffee Break	Coffee Break	
3:30-4:45	PL3	PL6	Informal Discussion	SL4	

3.2. Conference Schedule. The conference will feature ten principal talks (PL), three each on the first and second days, and two each on the third and fourth days. Six supplementary talks (SL) will complement these principal talks, two on the third day, two on the fourth day, and two on the fifth day. Each talk will be followed either by a question and answer period (Q & A) or by a period of informal discussion. Conference schedule can be seen in Table 4. As can be seen in Table 5, in each of the first four days we will have a panel discussion on a topic related to that day's principal lecture. There will also be time set aside for informal discussions.

Table 5: **Panel Discussion Schedule**

Monday	Pseudospectral methods, stability, and time-stepping.
Tuesday	Numerical issues related to the implementation of RBFs and discussion of open issues and problems in the efficient and accurate implementation.
Wednesday	Implementation of RBFs in complex geometries.
Thursdays	Various types of RBF applications, and discussion of future directions of RBFs.

3.3. Advertising and Reaching Underrepresented Groups. The conference will be widely advertised by announcements in the SIAM, AMS, and MAA newspapers and websites, and by email lists such as NA-Digest. The PI and Co-PIs will also send emails to their colleagues at other institutions, and will collaborate closely with other departments in the region to ensure that faculty and students are aware of this opportunity. A separate travel fund will be allocated for graduate students and underrepresented group participants.

The PI and Co-PIs will set up a website for the conference to update participants and will use this website to publish the results of the conference, including the powerpoint or pdf slides of the speakers where available. Lecture notes will also be made available through the website.

3.4. Local Arrangements. The conference will be held on the campus of University of Massachusetts Dartmouth (UMASSD), one of the five campuses of the University of Massachusetts state system. Our 700-acre UMASSD campus is located on the South Coast of Massachusetts, between Providence and Cape Cod. This campus is located in southeastern Massachusetts, one hour from Boston, and 30 minutes from Providence, Rhode Island. It is thus conveniently placed near two international airports, Logan (BOS) and T.F. Green (PVD).

The buildings of the campus were designed by internationally renowned Modernist architect Paul Rudolph beginning in the early 1960's. Both the exterior and interior of each building of rough concrete, with large windows bringing in the beauty of the outdoors, and open atriums providing places to socialize. The university also has hundreds of acres of undeveloped green space, including extensive wooded areas, grasslands, wetlands and ponds, as well as numerous footpaths to enable exploration of these natural areas of the campus.

The PI, Dr. Saeja Kim, and Co-PIs Drs. Sigal Gottlieb, Alfa Heryudono, and Cheng Wang, are all faculty members at the University of Massachusetts Dartmouth and have made the local arrangements for the conference.

Conference Arrangements: The conference will be held on campus, with lecture halls and seminar rooms available for the lectures, coffee breaks, and panel discussions.

Accomodations: A block of ten apartments will be reserved for this conference at Woodlands Residence Hall. Each apartment has either two bedrooms or four bedrooms, 2 full baths, and a central air system which is controllable. The apartments are fully furnished with a double bed, desk, chair, and built-in closets. The living/common space area has a television stand, couch, chair, and tables. The kitchen area of the apartment is equipped with a ceramic-top stove, refrigerator/freezer, ample cabinet space, 4 barstool chairs, as well as an eat-in alcove. The bedrooms, kitchen, and bathroom areas are all tiled. The living/common areas and hallways of the apartment are carpeted. Participants will have access to both wired and wireless internet service. Ample parking is available.

Lecture Rooms: The Woodlands residence hall features a 3,000 square foot function room capable of seating 300 people which can be separated into 3 sections at 1,000 sq. feet a piece, and is equipped with audio/visual equipment for the lecturers to present their talks. This venue also has six other smaller meeting rooms/areas which will be available to us for lectures, coffee breaks, informal gatherings, and panel discussions.

Dining: Meals will be served either at the Cafeteria or in the Woodlands residence hall by the campus catering service. Coffee and pastries will also be provided. A conference banquet will be held on Wednesday night.

4. PI's and Co-PIs' Experience and Contributions

PI and Co-PIs have successful experiences in organizing minisymposiums related to RBF and higher order methods in PDEs at SIAM annual meeting, ICOSAHOM, International conference on advances in Scientific Computing, SIAM regional meeting, etc.

PI Saeja Kim (Associate Professor of Mathematics at UMass Dartmouth):
Dr. Kim's research is focused on the areas of computational algebra, applied mathematics, and scientific computing. Recently she and her collaborators have published papers in the area of solid mechanics [8, 47]. She is currently carrying out research on edge detection, the development of post-processing methods, and a stability study of adaptive RBF simulations of convective flows [40, 41], as part of a team of computational mathematicians at UMass Dartmouth. Dr. Kim has been central to the

NSF-funded CSUMS project where she serves as Director of Assessment and Student Research.

Co-PI Sigal Gottlieb (Professor of Mathematics at UMass Dartmouth):
Dr. Gottlieb's overall research focus is the development of spatial and temporal methods for the efficient simulation of hyperbolic partial differential equations with shocks. She is internationally recognized as an expert on strong stability preserving (SSP) time discretizations, and is currently funded by AFOSR grant FA9550-0610255 to develop SSP methods for the time evolution of hyperbolic partial differential equations, including problems requiring efficient and stable treatment of multi-scale phenomena. Together with Jae-Hun Jung of SUNY Buffalo and Anne Gelb of Arizona State University, Dr. Gottlieb is funded by NSF grant DMS-0608844 to develop hybrid spatial discretizations including spectral multi-domain penalty methods and weighted essentially non-oscillatory (WENO) methods, as well as radial basis function methods (with Alfa Heryudono and Saeja Kim). Dr. Gottlieb is the leader of the NSF-funded CSUMS project *Research in Scientific Computing in Undergraduate Education (RESCUE)* (grant number DMS-0802974) for the training of undergraduates in the computational sciences.

Co-PI Alfa Heryudono (Assistant Professor of Mathematics at UMass Dartmouth):
Dr. Heryudono's research interest is scientific computing and numerical methods for partial differential equations, specifically radial basis function methods, pseudospectral methods, and tear film dynamics. He is doing research in RBF interpolation on irregular geometry [34] and is developing a new adaptive method for radial basis function methods in time independent and time dependent problems [13, 57]. He is interested in the implementation of pseudospectral methods to solve a fourth-order nonlinear equation arising as a model of the blink cycle process in human eyes [35]. He is also working on RBF methods for time-dependent PDEs, in collaboration with Cheng Wang, Sigal Gottlieb, and Saeja Kim from UMass Dartmouth, Jae-Hun Jung from SUNY Buffalo, and Scott Sarra from Marshall University. Dr. Heryudono has a joint research with Elisabeth Larsson and Axel Målqvist from the division of scientific computing of Uppsala University in Sweden working on a hybrid method finite element and RBF for problems in plate mechanics, for which they were recently awarded a Marie Curie FP7 grant beginning in June 2010.

Co-PI Cheng Wang (Assistant Professor of Mathematics at UMass Dartmouth):
Dr. Wang's primary research interest is the numerical solutions of nonlinear PDEs arising in natural sciences. He has accumulated experiences of the fourth order finite difference and pseudospectral schemes in the numerical simulation of fluid dynamics, geophysical fluid, electro-magnetics, and epitaxial thin film growth (see [16, 36, 50–52, 72, 75] for more details). He is currently focusing on two areas. The first is computation of incompressible fluid, including both 2-D and 3-D Navier-Stokes Equations (NSE), along with various models in Geophysical Fluid Dynamics (GFD). In partic-

ular, the fourth order finite difference, collocation spectral method and radial basis function (RBF) method are taken into consideration. The second is the numerical simulations of a set of bistable gradient system arising in material science and mathematical biology, such as phase field crystal (PFC) equation, Cahn-Hilliard-Hele-Shaw (CHHS) equation with a potential application in tumor growth model, and various epitaxial thin film growth models, with or without slope selection. Numerical solvers for the potentially highly nonlinear convex splitting schemes with an optimal efficiency for these equations are the main challenges. For both areas, large scale 3D numerical simulations with the aid of MPI parallel implementation are carried out.