REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-06-0343

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
07/28/2006	Final	1 November 2004- 30 November 2005

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Quantum Simulation and Communication Games	
	5b. GRANT NUMBER FA9550-04-1-0466
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
David Meyer	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
University Of California, San Diego 9500 Gilman Drive La Jolla, CA 92093-0112	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
Air Force Office of Scientific Research /NM 4015 Wilson Blvd Mail Room 713 Arlington, VA 22203	AFOSR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution A; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Progress was made toward classification of differant algorithmic schemes in quantum image processing. Goal one is to identify quantum versions of isotropic and anisotropic diffusion processing. Secondly, novel quantum transforms for feature extraction were sought. Finally, image classification in the quantum domain was to be investigated.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
U	U	U	UU		19b. TELEPHONE NUMBER *(Include area code)*

Final Technical Report FA9550-04-1-0466

Quantum Simulation and Communication Games

David A. Meyer, University of California, San Diego

Objectives

The objective of this research is to develop quantum algorithms for computational mathematics. It expands on Feynman's original idea that a quantum computer can more efficiently simulate quantum systems than can a classical computer and includes investigation of properties of classical physical systems which might be efficiently computed with a quantum computer. One class of algorithms focuses on quantum lattic gas automata (QLGA). QLGA are known to simulate the Dirac and Schrodinger equations, and also certain properties of heat transfer and fluid flow. Furthermore, architectures for their implementation may be easier to fabricate than a full quantum computer.

It is critical to consider distinct stages of image processing. There is a need to identify quantum versions of isotropic and anisotropic diffusion processing algorithms. It is desirable and necessary to investigate novel quantum transforms for feature extraction. Quantum algorithms for image classification and feature extraction must be exploited.

Accomplishments

Progress was made toward classification of different algorithmic schemes in quantum image processing. Goal one was to identify quantum versions of isotropic and anisotropic diffusion processing. Secondly novel quantum transforms for feature extraction were sought. Finally, image classification in the quantum domain was to be investigated. Classical code for diffusion processing on a square lattice was compared to quantum algorithm simulations. Simulation of quantum diffusion on one-dimensional "images" shows quadratic improvement over the classical case. . Several issues were explored, including analysis of scaling limits in multi-particle sectors of QLGA, inclusion and analysis of noise and decoherence in QLGA, inclusion of error correction and development of QLGA algorithms for classical simulation. An innovative approach will involve a quantum version of "Parrondo's game". Simulations of QLGA on classical computers have proven useful in developments to date and will also be investigated as part of this research effort.

As progress toward feature extraction, but an important theoretical milestone was achieved through construction of a unitary Legendre transform. As initial progress toward quantum algorithms in classification, a method for highly structured search has been developed.

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Significant progress was made toward realizing two early links in the image processing chain, namely diffusion methods for noise removal and transform methods for feature extraction.

For the diffusion methods, UCSD code has been written to implement classical algorithms. Nearest-neighbor isotropic diffusion of color images with varying Gaussian kernel was employed. At Raytheon, code was developed for isotropic and anisotropic diffusion algorithms for 2D grey-scale images pixilated on hexagonal lattices. Simulation experiments verified that this gives superior performance to the square lattice configuration.

In object recognition the extraction of invariant features is critical. For 3D invariant features the analogous spherical harmonic transform is used. The spherical harmonic transform factors into a Fourier transform in the longitude and a Legendre polynomial transform in the latitude. By combining classical results on Gaussian quadrature, an exactly unitary discrete polynomial transform has been constructed for any family of orthogonal polynomials. This represents progress toward a corresponding quantum transform which by definition must have the unitary property. Classical algorithms which are not based on unitary transformation in this manner could see performance improvement and greater numerical stability.

The simplest classification problem is to identify an object that is specified by a set of features along different dimensions, e.g. {color, length, width, height}. The quantum algorithms exhibited in reference [1] solve this problem with complexity proportional to the square root of the number of possible feature values.

Personnel Supported

The UCSD component of the project consisted of Prof. David Meyer, the PI. Student workers included Dan Curtis and Frank Kuo. Dr. James Pommerheim is CIP Fellow, collaborating on the quantum transform work with Dr. Markus Hunziker (now permanently at the University of Georgia). The Raytheon component of this project consists of the PI, Dr. Ross Rosenwald and Dr. Harry Schmitt.

Publications

[1] M. Hunziker and D.A. Meyer, "Quantum algorithms for highly structured search problems", *Quantum Inform Processing* 1 (2002) 145-154

[2] D.A. Meyer, "Quantum cellular automata and quantum lattice gases", *J Stat Phys* 91 (2003) 551-574

[3] D.A. Meyer, "Quantum lattice gases and their invariants", *Int J Mod Phys* C 12 (2002) 717-745