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tum and classical aspects, and therefore, it will be useful for implementation of quantum computing.

Recent advances in quantum information theory have inspired an explosion of interest in new quantum algorithms for solving hard computational problems. Three basic "non-classical" properties of quantum mechanics — superposition, entanglement, and direct tensor-product decomposability — were main reasons for optimism about capabilities of quantum computers and quantum communications as well as for a new approach to cryptography. However, one major problem is keeping the components of a quantum computer in a coherent state, as the slightest interaction with the external world would cause the system to decohere. Another problem is measurement: by the laws of quantum mechanics, a measurement yields a random and incomplete answer, and it destroys the stored state.

This proposed reinterpretation of quantum formalism opens up new advantages of quantum computers: if the Madelung equations are implemented on a classical scale (using, for instance, electrical circuits or optical devices), all the quantum effects important for computations would be preserved; at the same time, the problems associated with decoherence and measurement would be removed.

*This work was done by Michail Zak of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46731*

# Optimal Padding for the Two-Dimensional Fast Fourier Transform

## Appending data to an optimum length decreases computing runtime.

*Goddard Space Flight Center, Greenbelt, Maryland*

One-dimensional Fast Fourier Transform (FFT) operations work fastest on grids whose size is divisible by a power of two. Because of this, padding grids (that are not already sized to a power of two) so that their size is the next highest power of two can speed up operations. While this works well for one-dimensional grids, it does not work well for two-dimensional grids.

For a two-dimensional grid, there are certain pad sizes that work better than others. Therefore, the need exists to generalize a strategy for determining optimal pad sizes. There are three steps in the FFT algorithm. The first is to perform a one-dimensional transform on each row in the grid. The second step is to transpose the resulting matrix. The third step is to perform a one-dimensional transform on each row in the resulting grid. Steps one and three both benefit from padding the row to the next highest power of two, but the second step needs a novel approach.

An algorithm was developed that struck a balance between optimizing the grid pad size with prime factors that are small (which are optimal for one-dimensional operations), and with prime factors that are large (which are optimal for two-dimensional operations). This algorithm optimizes based on average run times, and is not fine-tuned for any specific application. It increases the amount of times that processor-requested data is found in the set-associative processor cache. Cache retrievals are 4–10 times faster than conventional memory retrievals.

The tested implementation of the algorithm resulted in faster execution times on all platforms tested, but with varying sized grids. This is because various computer architectures process commands differently. The test grid was 512×512. Using a 540×540 grid on a Pentium V processor, the code ran 30 percent faster. On a PowerPC, a 256×256 grid worked best. A Core2Duo computer preferred either a 1040×1040 (15 percent faster) or a 1008×1008 (30 percent faster) grid.

There are many industries that can benefit from this algorithm, including optics, image-processing, signal-processing, and engineering applications.

*This work was done by Bruce H. Dean, David L. Aronstein, and Jeffery S. Smith of Goddard Space Flight Center. Further information is contained in a TSP (see page 1).*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center, (301) 286-7351. Refer to GSC-15678-1.*

# Spatial Query for Planetary Data

## This technology is extensible to Earth science and satellite monitoring and surveillance.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Science investigators need to quickly and effectively assess past observations of specific locations on a planetary surface. This innovation involves a location-based search technology that was adapted and applied to planetary science data to support a spatial query capability for mission operations software.

Conventional databases of planetary datasets are indexed and searchable by various metadata, such as acquisition time, phase of mission, and target. Searching these datasets will produce enormous datasets that are difficult, or impractical, to browse through to identify observations of very specific targets. For queries at specific locations, it is fundamentally more efficient to specify the location as the target of the query; and to have the database search based on the location of the data rather than metadata that is only indirectly or tangentially related to location.

High-performance location-based searching requires the use of spatial data structures for database organization. Spatial data structures are designed to organize datasets based on their coordinates in a way that is optimized for location-based retrieval. The particular spatial data structure that was adapted for planetary data search is the R+ tree. The R+ tree arranges data as a set of nodes that represents bounding rectangles. Every leaf node in the tree is a particular datum with coordinates. The root node represents a bounding box containing the entire set of data. Each level of the tree subdivides the search space into smaller and smaller bounding rectangles, each containing a smaller subset of the data. A query on the R+ tree for a set of coordinates will follow one unique path from the root to the leaf, and return the data contained in the coordinates. The complexity of the search is bounded by the depth of the tree, so the R+ tree insertion algorithm maintains a balanced tree such that the depth is minimized.

A map view provides an intuitive way to specify a set of coordinates for a location-based query. The software will let the user select any location on the map of the rover's traverse path to date and return all of the results in under a second. This was particularly useful during tactical activity planning when the question of "what data do we have of this location" is asked every day. The wrong answer to this question is very expensive: false negatives result in missed science opportunities that may never come again, while false positives results in a waste of spacecraft time and bandwidth resources.

*This work was done by Khawaja S. Shams, Thomas M. Crockett, Mark W. Powell, Joseph C. Joswig, and Jason M. Fox of Caltech for NASA's Jet Propulsion Laboratory.*

*The software used in this innovation is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-46637.*

# Higher Order Mode Coupling in Feed Waveguide of a Planar Slot Array Antenna

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A simple technique was developed to account for the higher order mode coupling between adjacent coupling slots in the feed waveguide of a planar slot array. The method uses an equation relating the slot impedance to the slot voltage and a reaction integral involving the equivalent magnetic current of the slot aperture and the magnetic field coupled from an adjacent slot.

Most waveguide-fed slot antennas use centered-inclined coupling slots in the feed waveguides. In the proposed method, one uses the Elliott's design technique to determine tilt angles and lengths of the coupling slots. The radiating slots are modeled as shunt admittances, and the coupling slots are modeled as series impedances.

By using reaction integrals to account for higher order mode coupling between adjacent coupling slots, the "active impedance" of each coupling slot is obtained, which differs from the original impedance by a small amount due to higher order mode coupling. The tilt angle and length of each coupling slot are perturbed so that the active impedance of each slot is the same as the corresponding starting value of the impedance before the iterative process started. This process converges after three or four iterations and uses algebraic equations and fast reaction integrals.

Because of desirable features of waveguide arrays such as low volume, ease of design and manufacture, and ease of deployment, these antennas find applications in aeronautical and space activities. In addition, these all-metal antennas can withstand high radiation environments encountered in space.

*This work was done by Sembiam Rengarajan of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47419*

# Evolutionary Computational Methods for Identifying Emergent Behavior in Autonomous Systems

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A technique based on Evolutionary Computational Methods (ECMs) was developed that allows for the automated optimization of complex computationally modeled systems, such as autonomous systems. The primary technology, which enables the ECM to find optimal solutions in complex search spaces, derives from evolutionary algorithms such as the genetic algorithm and differential evolution. These methods are based on biological processes, particularly genetics, and define an iterative process that evolves parameter sets into an optimum.

Evolutionary computation is a method that operates on a population of existing computational-based engineering models (or simulators) and competes them using biologically inspired genetic operators on large parallel cluster computers. The result is the ability to automatically find design optimizations and trades, and thereby greatly amplify the role of the system engineer.

The ECM technique is extremely effective at quickly finding not only individual best solutions, but also an entire collection of best solutions for all possible ranges of conditions. ECM provides an efficient standard of performance that specifies the best solution given a set of requirements or goals for all possible environmental variables. The ECM derived standard of performance can be directly compared to actual performance to provide a test standard of reference. Comparison of the ECM best solutions with actual performance will identify where the deviations from optimum occurred leading to localization of problem areas. This includes illuminating deficiencies in simulation capabilities. Examination of the full set of ECM derived best performance will enable the identification and characterization of unexpected or emergent behaviors.

*This work was done by Richard J. Terrile and Alexandre Guillaume of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46686*