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13. ABSTRACT (Maximum 200 words) This project is developing a system to compress data such as imagery and speech to near-maximum levels. We use Cottrell/Munro/Zipser neural networks to implement a vector quantization method (called <i>data neutronium</i> , in analogy with solid neutronium, the densest possible form of matter) that uses a mathematically defined codebook on the <i>data manifold</i> from which the data to be compressed is drawn. The C/M/Z neural network (which is trained off-line, once) is computationally simple and can carry out both data compression and decompression in real-time using low-cost hardware. In Phase I we demonstrated 64:1 compression of 8-bit per pixel imagery at an RMS pixel error of 20.7 grey scale levels (our goal was 50:1 with an RMS pixel error below 25). We also developed a mathematical proof that, for the case of large compression problems (e.g., large image tiles or long speech sample time windows), the mean squared error distortion of the data neutronium method will be no more than 43% greater than that of an optimal source coding system with the same number of code bits. Thus, data neutronium is the only potentially practical data compression method that is provably near-optimal.				
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Data Neutronium

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Foreword

This project is developing a system to compress data such as imagery and speech to near-maximum levels. We are using the Cottrell/Munro/Zipser neural network technique to implement a vector quantization method (which we call *data neutronium* in analogy with solid neutronium, the densest possible form of matter) that uses a mathematically defined codebook defined on the *data manifold* from which the data to be compressed is drawn. Unlike fractal compression (another compression method which may be able to achieve near-maximum compression, but which is computationally impractical), the C/M/Z neural network (which is trained off-line, once) is computationally simple and can carry out both data compression and decompression in real-time using low-cost hardware. Our Phase I goal was to demonstrate a 50:1 compression ratio for imagery with an RMS pixel grey-scale error of less than 25 (10% of the 256 total brightness quantization levels). We exceeded this by demonstrating 64:1 compression at an RMS pixel error level of 20.7 grey scale levels. During Phase I we also developed a precise mathematical definition of the data neutronium compression method. We also proved, for the case of large compression problems (e.g., large image tiles or long speech sample time windows) that the mean squared error distortion of the data neutronium method will be no more than 43% greater than an optimal source coding system with the same number of transmitted bits. This puts data neutronium in a category by itself, as it is the only potentially practical data compression method that is provably near-optimal.

1. Statement of the Problem Studied

Data compression has a long history. Almost 60 years ago the first analog vocoders (speech signal compressors) were built [Dudley]. These systems took ordinary speech (which has a bandwidth of about 3000 Hz — 200 Hz to 3200 Hz) and reduced its bandwidth by about a factor of 10. Modern vocoders [O'Shaughnessy] can reduce the normal 64 kbit/second speech data rate used in telephony down to 580 bits/second (a compression ratio of 110) while retaining good speech quality. Unfortunately, the hardware required to carry out the associated processing is much too expensive for general use. Methods suitable for widespread use (such as Linear Predictive Coding [O'Shaughnessy]) achieve compression ratios of little more than 10. Similar statements hold for image compression, where the best known technique (fractal compression [Stark]) can, at least for many images, achieve compression ratios around 100 (given unlimited compression time), but practical techniques (such as the JPEG algorithm) can only achieve a compression ratio of about 10.

All data compression problems are special cases of the of the source coding problem of information theory. The general theory of source coding was developed by Claude Shannon about 45 years ago [McEliece]. Source coding theory provides upper bounds on the achievable compression ratio for each type of information source. It also provides performance bounds for particular coding schemes. Typically, researchers in source coding study general mathematical theories and not specific data compression problems. Researchers in data compression typically study their specific data compression problem without much regard for source coding theory. It would seem desirable to bring these two research streams into closer contact, but this has not happened yet.

What is clear is that there is still great potential for increased performance in data compression. Many researchers in source coding and data compression believe that both telephone speech and television imagery will someday be routinely compressed at ratios exceeding 1,000. This is two orders of magnitude beyond what can be practically achieved today. The problem addressed by this project is the development of a general-purpose practical data compression method that can push compression ratios at least an order of magnitude beyond the best practical systems today;

and do so at low implementation cost. This method should exploit both data compression research insights as well as source coding theory insights.

2. Summary of Results

This project is exploring a new approach to data compression. In a nutshell, this new approach exploits a generalization of principal component analysis to create a grid of points in the data space. This grid is then used as a vector quantization codebook. During Phase I we demonstrated that the mean squared error distortion of such a source coding system would asymptotically (as the dimensionality of the data vectors and the number of vector quantization codebook vectors go to infinity) approach 1.423... times that of an optimal source coder with the same number of codes. We also proved that the Cottrell/Munro/Zipser neural network technique [Cottrell, Hecht-Nielsen, Kramer] can be used to approximate a data neutronium compression and decompression system to any desired degree of accuracy. Thus, the data neutronium method has a potential performance advantage over all other known practical data compression methods (as no other such method has had a comparable mathematical result established for it).

Although theoretical results are of great importance, for any data compression method the true test is its performance on real data. During Phase I of this project we developed and iteratively improved an experimental data neutronium compression system based upon Cottrell/Munro/Zipser neural networks. The data used for these experiments were 100 video images of indoor office scenes. These neural network systems were each trained using three of the 100 images (another three were used as a training test set to monitor training progress). The best systems (of which there were three all having nearly the same performance) were then tested using the remaining 94 fresh images. The best performance achieved was a compression ratio of 64 at a per pixel RMS grey scale error level of 20.7 (which thus exceeded our Phase I technical objective of a compression ratio of 50 at an RMS error level of 25).

3. Publication List

Hecht-Nielsen, R., "Data neutronium: a near-optimal real-time neural network data compression method", draft manuscript currently being privately circulated for comments, to be submitted for publication in Spring 1993.

4. Scientific Personnel

The following scientific personnel participated in Phase I of this project:

- Dr. Robert Hecht-Nielsen, Principal Investigator
- Dr. Shinmin Wang, Project Scientist

5. Inventions

The following invention was conceived in Phase I of this project:

- Data Neutronium Source Coding and Data Compression Process

A patent for this invention is expected to be filed by HNC, Inc. later in 1993.

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