Optimization of Transform Coefficients via Genetic Algorithm

Steven Becke

CS 470 –Project Write-up

April 25, 2005

Table of Contents

Optimization of Transform Coefficients via Genetic Algorithm
Steven Becke

Abstract

As the old saying goes, "A picture's worth a thousand words." Well, it may be worth a thousand words, but storing it digitally as raw data it's probably going to take a lot more space than that, especially if it's of decent size and detail. That's where image compression comes in, and one of the most effective tools discovered in recent years for image compression is Wavelet Transforms. Wavelet transforms can dramatically reduce an image file size while often incurring relatively little loss of detail. These Wavelet transforms are defined by sets of coefficients that were chosen because of specific mathematical properties that they possess. For most purposes (such as compression) these coefficients are normally optimal due to their inherent properties, but it has been proven that when images are compressed and quantized - other, non-standard, coefficients can be found that perform better. This project was primarily a research project investigating the use of a genetic algorithm to find superior sets of coefficients than the standard wavelet coefficients in that they could be used to compress images with less mean squared error but similar levels of compression as the standard wavelet coefficients.

1. Introduction

This research work was performed for Dr. Frank Moore at UAA and with corroboration with Brendan Babb. It builds on work that Brendan Babb and I performed in Fall 2004, which in turn was based on the work of Dr. Moore and some of his prior graduate students.

It has been proved by Dr. Moore that a GA could be devised that can find sets of coefficients that perform in a superior manner than the standard wavelet coefficients when quantization was present. More specifically, when a forward and reverse transform operation were applied sequentially to sets of quantized data, evolved coefficients could be found that were able to reconstruct the data with less mean squared error (MSE) than the standard wavelet coefficients. Moore applied his GA only to evolving coefficients for the reverse transform, and left the forward transforms untouched.

The research that we performed extended upon Dr Moore's work to co-evolve both the forward and reverse transform coefficients via a GA while taking both the MSE and compressed file size into account in evaluating the fitness of potential solutions. The compressed file size is not an issue when dealing with evolving reverse transforms alone but as Brendan and I discovered it is definitely an issue when you start altering the forward transform. It was our hope that evolving both the forward and reverse transform coefficients would likely result in superior results than those obtained by Dr. Moore who evolved the reverse transform alone.

2. Project Overview

The primary goal of this research was to investigate whether a GA can be devised that will co-evolve both forward and reverse transform coefficients that provide both lower MSE and better compression than can be achieved with standard wavelets.

The transform function used was the same as the Daubechies D4 transformation and the initial population was seeded with slightly random mutations of the standard D4 coefficients. This was because it seemed likely that good solutions would to be found in the proximity of the standard coefficients.

Our secondary goal was too test whether coefficients evolved in such a manner against specific images would be give improved performance on other images as well, or if their improved performance was limited to the image that they were evolved against.

It was not out intention to develop the application entirely from scratch but rather extending the application that Brendan and myself worked upon the previous semester, which in turn was based on code that we obtained from Dr. Moore. Our main focus was on writing the genetic algorithm and testing it as opposed to major tweaking of the existing functionality & GUI.

2.1 Image Files

The test images that we were using was a set of 24bit RGB bitmap images (512x512pixels) that are classically used in image format and compression research.

Since these were the same images used by Dr Moore in his research this allowed us to compare our improvements in MSE to those that he obtained evolving on the reverse transform.

These images are loaded as 2D arrays of R,G,B [0-255] values that have to be converted to Y,U,V (double precision) values to facilitate the wavelet transformations. Y in this case is the intensity or brightness , and U and V form 2D colormap. *(see http://en.wikipedia.org/wiki/YUV)*

Technically we were not converting directly to YUV but to a colorspace that lies on the YUV colorspace but with the origin placed differently and the axis tilted. The exact reasoning for this I am not sure of, it was part of the legacy of the existing code, but in tests when I substituted more accurate YUV conversions it made little difference to no difference to the end results.

We used the following conversion, pixel for pixel to find the values of the Y array

$Y = (2G + R + B)/4$

U and V were downsampled to arrays a quarter of the size of Y. This is one of the advantages of YUV, in that most of the detail in the image is contained in the intensity map and the color maps can be decreased without making much visual difference to the image.

The following conversion was used for U and V, but here R, G and B are averages of the 4 pixels in the original image that are mapped to the downsampled U and V pixel arrays.

$U = B - G$
$V = R - G$

2.2 Coefficient Sets

To ease introduction of new sets of coefficients and to reapply evolved coefficients without recompiling the application each time a new set is found, coefficient sets are stored in a simple text file that can be modified with a text editor. Lines of whitespace are ignored. The text file has the following format:

```
name [name of the coefficient as appearing in application dialog]
hlength [length of h1 and g2 (integer)]
glength [length of g1 and h2 (integer)]
h1 [0],[1]...[hlen],
g1 [0],[1]...[glen],
h2 [0],[1]...[glen],
g2 [0],[1]...[hlen],
```

for example, the classic Daubeschie 4 transform could be defined as follows

```
name daub_4
hlength 4
glength 4
h1 -0.129409523,0.224143868,0.836516304,0.482962913,
g1 -0.482962913,0.836516304,-0.224143868,-0.129409523,
h2 0.482962913,0.836516304,0.224143868,-0.129409523,
g2 -0.129409523,-0.224143868,0.836516304,-0.482962913,
```

3.0 Project Requirements

The functional specifications of the application were pretty low key. There was an existing application which provided a GUI and all the requisite functionality to display the results. What was needed was testing and development of a GA that could co-evolve the coefficients while keeping file size in check. As such Dr Moore did not have any requirements in terms of extending GUI or interaction of the application. I came up with the following minimal specifications based off the prototype application and applied it to the design of my own version of the application that I created/ported in C# after the research work was completed.

3.1 Functional Specifications

1. A dialog that allows the user to select the source image to be loaded
2. A dialog that allows the user to save the loaded image in its current state
3. A dialog that allows the user to initiate the compression process
4. An image display panel that displays an image if loaded. If a compression transform has been run on the image the display should the transformed image.
5. A settings panel. This should allow the following to be set
    1. The type of wavelet to be used
    2. The Multi Resolution Level (MRL)
    3. Quantization Level
    4. Whether to use a GA to evolve transform coefficients
    5. Population size of GA
    6. Number of generations to run GA for
    7. The initial coefficient seeds [8] – display the defaults in the fields but allow them to be edited.
6. A results panel. This should display the following
    1. The original file size
    2. The compressed file size
    3. The MSE of the compressed and restored image from the original
    4. Display the set of coefficients for the evolved solution with the best fitness

3.2 System Specifications

The system requires MS Visual Studio .NET on Windows 2000 or Windows XP to be built. The resulting executable must also be able to run on a PC with Windows 2000 or XP and the .NET runtime environment installed (but not necessarily MS VS.NET). Due to the intensive calculations required it will require at least a Pentium 4 at 2Ghz and 512mb ram or higher for adequate performance. It is recommended to have a video adapter and monitor must be capable of a resolution of at least 1024 by 768 pixels.

4. System Design

The system was written in c++/c#. The original application – the c++ version - (and the application wherein most of the research took place) was definitely not an object orientated design. This was corrected somewhat in the porting of the application to c# where a more event driven and OO architecture was used, but in places for speed purposes or ease of moving variables about this was set aside.

4.1 User Interface Design

The initial entry to the application is a single form, GAWavelet. This form displays the loaded images and allows access to the different functions of the application. A screenshot is below as figure 1.

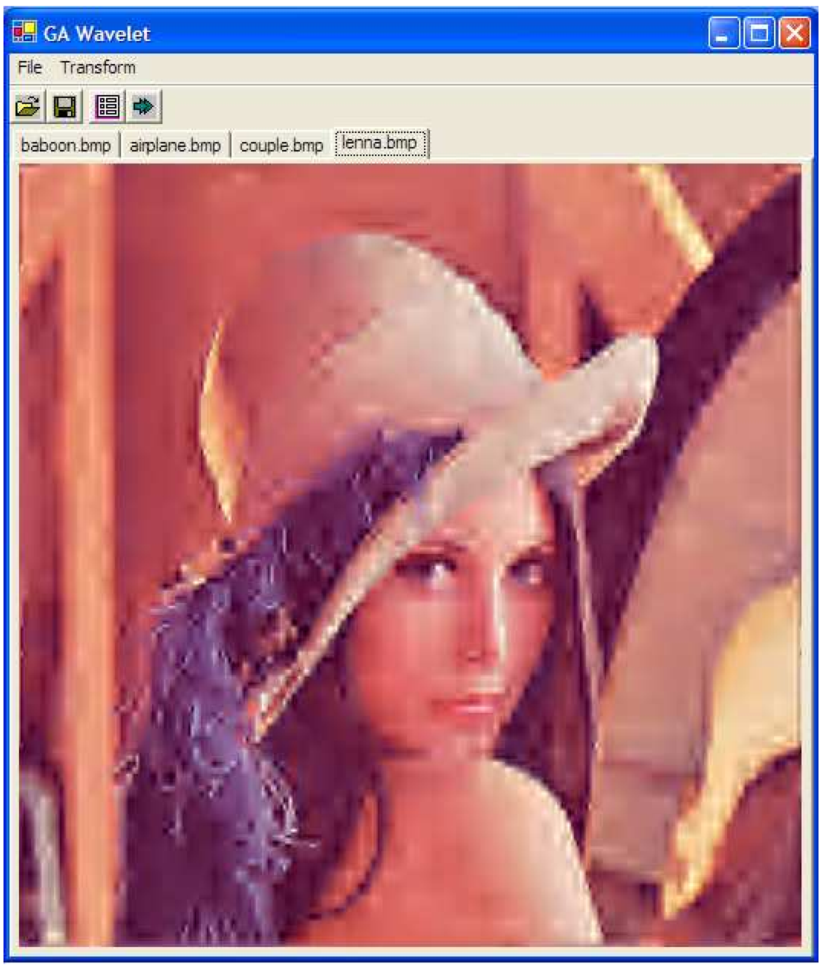


Figure 1. GAWavelet

The images are contained within PictureBox controls that are dynamically added along with their containing tabs to a central TabControl. The toolbar and menu provide the access to the same functionality, namely:

- File->Open Image [or folder icon] – brings up a dialog to open an image in a new tab
- File->Save Image [or disk icon] – brings up a dialog to save the image on the currently selected tab.
- Transform->Settings [or form icon] – brings up a dialog allowing you to change the transform settings
- Transform->Transform [or arrow icon] – brings up a dialog allowing you to begin the transform / initiate the GA

The open file dialog and save file dialog are just standard OpenFileDialog and SaveFileDialog controls.

The Dialog_Transform_Settings contains the transform settings and is pretty simple. It contains a ListBox control which allows selection of the wavelet transform to use. Selecting a wavelet transform sets the contents of the following textbox control with the details of the selected ListBox. There are some labels and textbox controls to handle the remainder of the parameters, such as MRL and Quantization. Input is validated and if incorrect values are entered into a TextBox, the value in the TextBox is reset and a MessageBox prompts the user that the input was not allowed. Changes are only accepted to the settings if the OK button is used. Clicking cancel or the red X will close the dialog without accepting any new settings.

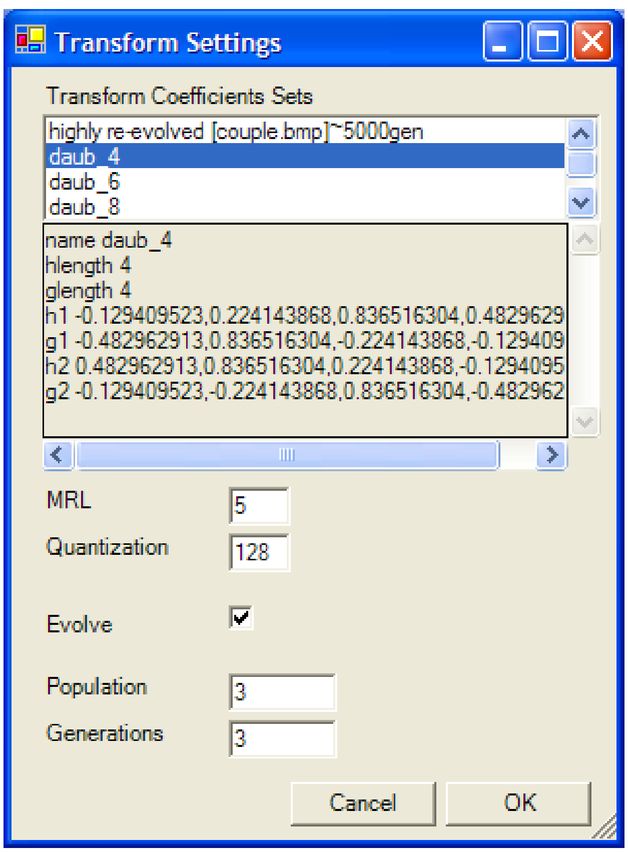


Figure 2. Dialog_Transform_Settings

When a selected image undergoes the transform/genetic algorithm a 3rd form is displayed

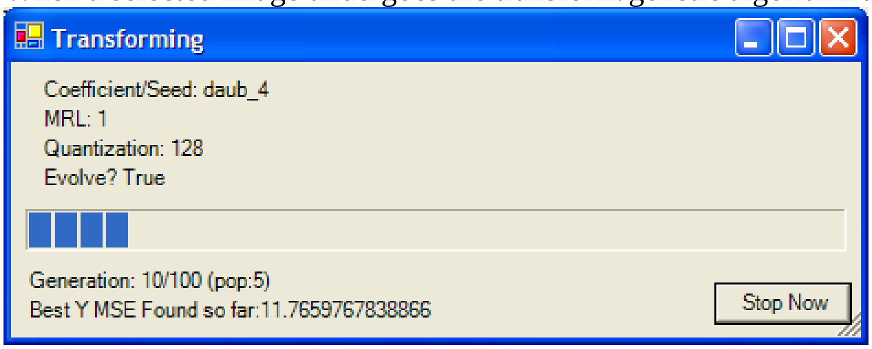


Figure 3. Transforming Form

This is run in a separate thread and shows the status of the genetic algorithm. It contains a number of Labels and a ProgressBar that are updated by a monitor thread that wakes up once a second prompts it to update itself with the latest values from the GA. The "Stop Now" button sets the max number of generations equal to the current generation, bringing the GA to a stop at the end of the current generation.

Finally there is the Results form. It contains a number of Labels and TextBoxes with the listing the results of the current transformation.

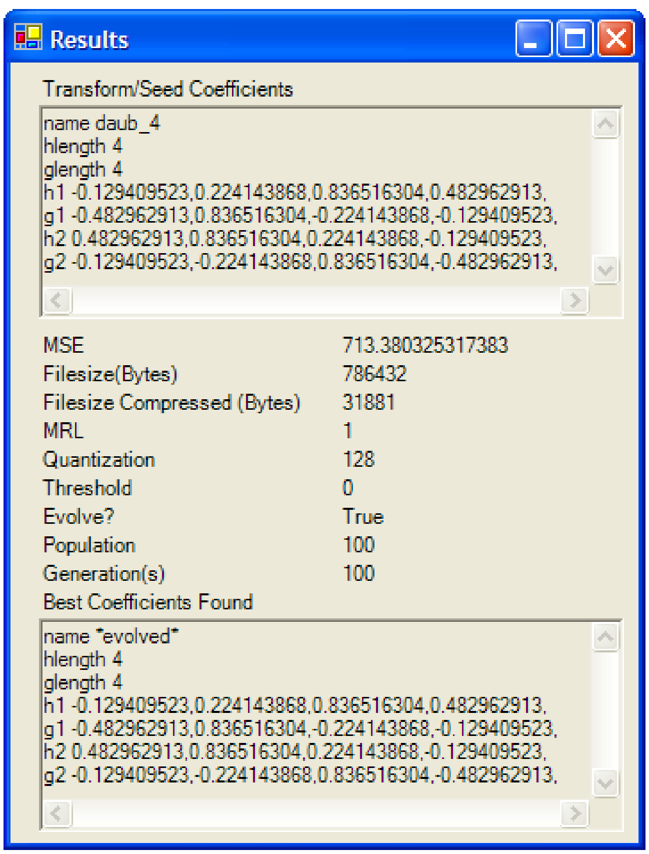


Figure 4. Results Form

4.2 System Architecture

The architecure is event driven. When the system is first started it will bring up the GAWavelet form (with no images loaded). From here the load image, save image, settings, and transform image options will be accessible.

- Load image will pull up the load image dialog allowing an image to be loaded – once selected and loaded it will be displayed in the GAWavelet form. Loading another image will create a new tab to be created to hold the new image (up to a maximum of 5.)

- Save image will pull up the Save image dialog only if an image is already loaded. (else it will display a warning message and abort that operation). On completion it return control to main display window.

- Settings will bring up change settings dialog and on completion return control to GAWavelet form.

- Transform image can only be used if an image is already loaded. (else will display a warning message and abort that operation). Once transform image has started the following sequence occurs before control is ceded -
    - Run genetic algorithm according to settings specified in Settings dialog.
    - Display Transforming progress bar for duration of transformation.
    - Show results dialog for best solution found
    - Update display window with the image resulting from forward transform/quantization/dequantization/reverse transform operations of best found solution.
    - Return control GAWavelet form.

4.3 Algorithms

The most important algorithm the application uses is itsgenetic algorithm. Without going into too much detail it has the following basic form:

```
G = 0;                  {Start at Generation 0}
initpop(P);             {create a population P of random solutions}
while not (G == max) do(
      G++;              {increment to next Generation}
      eval(P);          {evaluate the fitness of all solutions in P}
      P' = select(P);   {randomly select members of P but
                         weighted in proportion to their fitness}
      crossOver(P');    {swap random portions of the
                        solutions in P' with other solutions}
      mutate(P');       {mutate solutions}
      P = P';)
```

The most important aspect of the Genetic Algorithm is its fitness function. To calculate the fitness the following has to be applied to all potential solution sets

1. Forward D4 transform copy of original image with evolved forward co-efficients
2. Quantize image
3. Calculate compressed image size
4. Dequantize image
5. Reverse D4 transform with evolved reverse co-efficients
6. Calculate MSE from original Image
7. Calculate fitness as a function of MSE & compressed image size.

This is where the majority of the applications computational time is spent, as it needs to go through the entire process once for each member of the population for every single generation that is computed.

As to the actual fitness function used as step 7, we used and tested a large variety. For more details on this see section [6.3 Research Notes.]

4.4 Data Structures

The data structures used in the application are relatively simple, but care has to be taken not to introduce memory leaks, especially in the C++ research version of the application.

Each potential solution consists of an array of 16 doubles, the 1st 8 holding the forward transform coefficients, the 2nd 8 holding the reverse transform coefficients.

The population will consist of an array of the above solution arrays. A typical population size would be 200 to 500 potential solutions.

Images will be loaded as RGB bmps and converted to YUV. These are stored in memory as 3 2d arrays of doubles, one 2d array each for Y, U and V. See [2.1] The U and V arrays are downsized to arrays a quarter the size of their source arrays, upsampled again when converted back to RGB finally. This is done to conserve space and results in little loss of visible image quality.

5. Software Development Process

I'm not sure what methodology our research work would fall under. It was an iterative approach whereby we would make some changes and then observe the effectiveness of the results, and then try something else to see if it worked better. I suppose it would be classified most like the prototyping methodology, except instead of GUI's we were creating fitness, crossover and mutation methods. We weren't really sure what the best way to do many of the things we were trying to do, it was kind of a crawl in the dark. We met weekly with Dr Moore and he would offer suggestions and we would generally try them out. Ultimately we were able to create a functioning GA that obtained results that were very pleasing to us.

5.1 Testing and Debugging

The vast majority of my time was spent in a mix of research, testing and debugging. There were a number of experimental dead-ends that we wandered down that cost us large amounts of time. For example, we implemented a Linear Normalization alternative to Tournament selection (thinking that it would give us increased performance.) Many days later after finishing removing the last bugs from and it and verifying that yes, it was doing what we thought it was doing, we concluded that despite what our GA literature had advised us it performed substantially worse than Tournament selection had.

The existing code was written in C++, a language that neither Brendan or myself were familiar with, was largely uncommented, and held a variety of memory leaks and other strange bugs that we had a devil of a time tracking down. Being unfamiliar to wavelets on top of this led to endless of hours of going through code just trying to verify what it was doing, and if it was what it was supposed to be doing. We made frequent use of the debugging functionality built in VS.NET, tracing the various variables and contents around, but due to the complexity of the application this was a daunting task at times.

Since we could take any coefficients we evolved and validate them in a separate application (which we did many times using an unmodified version of the original application) we were less concerned with making sure that the application was totally bug free than in evolving, and finding effective methods of evolving, the sets of coefficients that we were interested in. Thus any time we made major changes to the application we would validate that the coefficients and the resultant MSE and other details that we were calculating matched up when inserted into our baseline program. Stability was an issue, but with our limited familiarity with C++ we eventually conceded that our research version of the application would best be stabilized by porting it to a more stable programming environment upon completion of the research. This was beyond the scope of what Dr Moore was requiring from us.

This porting to C# I initiated on my own when we handed our results over to Dr Moore. There was very little time to do it. Mainly I did some rapid prototyping (to my own satisfaction) and converted code as best I could from C++ to C# while trying to put it into a more modular structure. It was much more painful that I had thought it would be, and if there's one thing I've learnt is that you shouldn't try port something from one language you're unfamiliar with to another language you're unfamiliar with. In retrospect I should not have grouped my research work and hobby port together into a single project, but at least I can say that the port is not less stable than the original application (no great claim to fame), and has a more functional GUI – so it was not a complete disaster.

Another thing that I learnt the hard way was to not try to add extra functionality to the product at the last minute. I had decided that it would be a relatively easy modification to allow the program to take sets of coefficients that were not all of equal length. This introduced several small but difficult to find errors that caused my program to crash repeatedly on software demo day. I never could quite figure out what change I'd made that was causing the problem. Eventually I found an older version of the program – when I tried again to adapt this restored version of the program I ran into another error - the way I had the program it was assumed that the length of h1 and h2 were the same, and g1 and g2 were the same, but in cases were the coefficients are of different lengths the length of h1 matches to g2, and g1 matches to h1. This was a relatively small error but took me forever to track down since I already had it fixed in my head the way that I thought different length coefficients were defined.

5.2 Work Breakdown

The Gantt chart in figure 5 shows the anticipated and actual work schedule. The values in red represent the projected amount of time per task determined during the planning stage of the project, and the values in blue represent the actual amount of time taken.

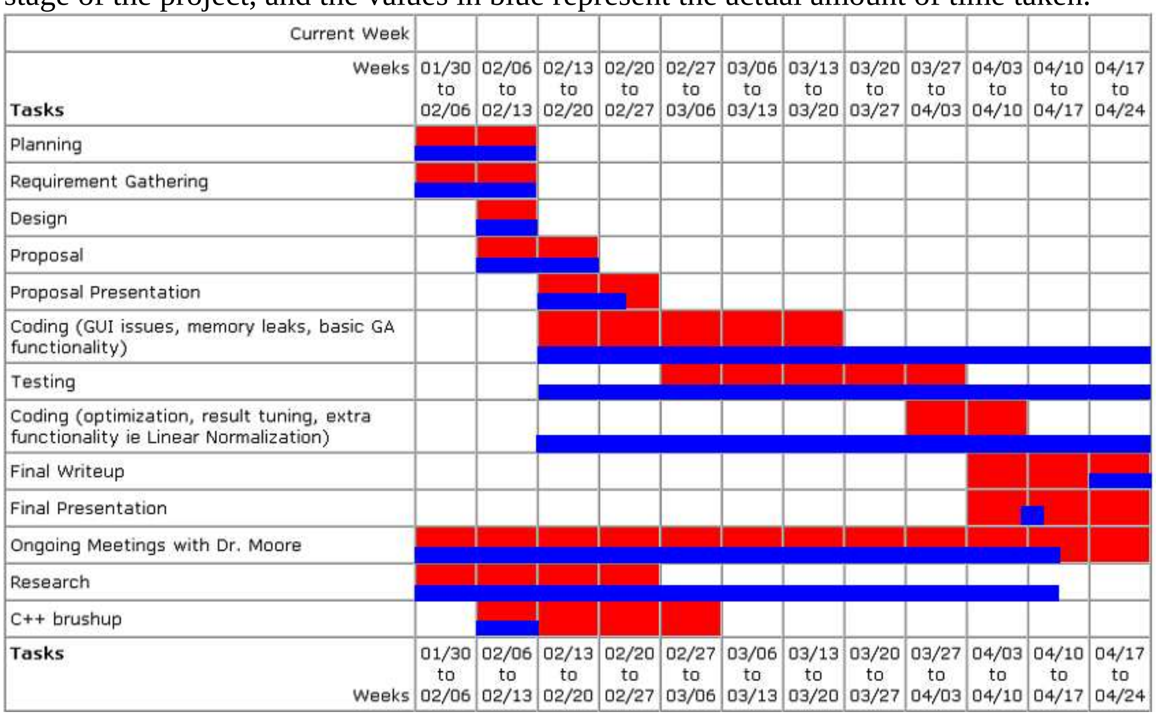


Figure 6. Projected timeline vs. Actual timeline

As you can see I spent a lot more time testing, coding and doing research that my plan had originally called for.

6. Results

The primary goal of this project, the research, was completed on time and the results turned over to Dr Moore. Generally we're happy with the results, which seem to show forward and inverse coefficient sets can be coevolved that out perform the standard wavelet coefficients and coefficient sets evolved only for the inverse transform. Further, there is a strong indication that these evolved coefficients are generalizable to other images when used at the same level of quantization.

6.1 Evolving for different file sizes

Couple.BMP

Using evolved co-efficients with D4 co-efficients as the initial seed, at quantization 64.

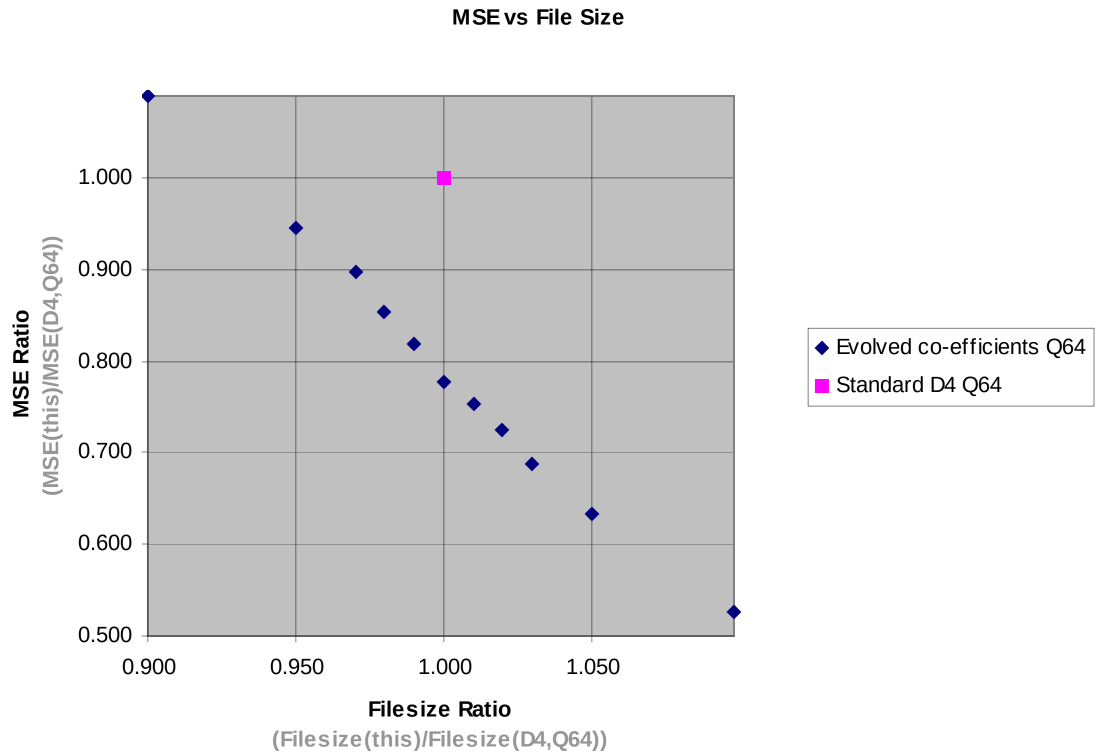
Evolved co-efficients were plugged back in as original seeds to evolve further. Aprox. 4000 generations

Quantization	Filesize (Raw)	Filesize (Bytes)	MSE	Filesize Ratio	MSE Ratio	PSNR	MSE of Y
64	40220	40324	170.060	0.900	1.090	-	44348582
64	42457	42561	147.340	0.950	0.945	-	38423762
64	43346	43450	139.880	0.970	0.897	-	36395391
64	43798	43902	133.080	0.980	0.853	-	34687912
64	44241	44345	127.670	0.990	0.819	-	33248418
64	44687	44791	121.290	1.000	0.778	-	31560219
64	45141	45245	117.490	1.010	0.753	-	30632164
64	45583	45687	112.970	1.020	0.724	-	29305053
64	46033	46137	107.180	1.030	0.687	-	27843961
64	46928	47032	98.670	1.050	0.633	-	25697595
64	49078	49182	81.930	1.098	0.525	-	21372568

Couple.BMP

Using standard D4 co-efficients, MRLevel 1, at different levels of quantization, no evolution.

Quantization	Filesize (Raw)	Filesize (Bytes)	MSE	Filesize Ratio	MSE Ratio	PSNR	MSE of Y
64	-	44795	155.963	1.000	1.000	26.2	42261254



This graph shows the ratios of the file size of the evolved coefficients to the standard D4 coefficient file size on one axis, and on the other axis the ratio of the MSE of the evolved coefficients to the standard D4 coefficient MSE. It clearly shows that a range of improved results can be found with either better compression, better MSE, or both.

6.2 Testing how well coefficients generalize

Table 2.

This table shows results for all images using coefficients that were evolved against couple for filesize 100%, quantization 64 for population 100 over aprox. 4000 generations The results seem to generalize quite well, giving percentage improvements of MSE between 15% (boat) and 23% (fruits)

	Filesize (using D4)	MSE (using D4)	Filesize (evolved)	MSE (evolved)	Filesize as % of D4 Filesize	MSE as % of D4 MSE	Percentage Improvement of MSE
airplane	48125	112.4558	47993	88.973	99.726	79.119	20.881
baboon	48536	279.5612	49758	230.606	102.518	82.488	17.512
barb	49116	307.6155	49392	257.087	100.562	83.574	16.426
boat	44429	158.9024	44349	134.718	99.820	84.781	15.219
couple	44795	155.9632	44792	121.281	99.993	77.763	22.237
fruits	48640	115.8036	48414	88.458	99.535	76.386	23.614
goldhill	42814	135.7847	42351	104.912	98.919	77.263	22.737
lenna	56519	177.5059	56245	137.575	99.515	77.505	22.495
park	42324	168.9597	42020	133.664	99.282	79.110	20.890
peppers	39843	121.2649	39683	97.813	99.598	80.661	19.339
susie	45859	132.5596	45924	106.596	100.142	80.414	19.586
zelda	38257	134.5674	37903	106.003	99.075	78.773	21.227
				Averages	99.89036	79.81961	20.1803875

This table shows results for all images using co-efficients that were evolved against baboon for filesize 100%, quantization 64 for population 100 over 500 generations
As with couple, the coefficients seem to generalize quite well, giving percentage improvements of MSE between 5 to 7 %.

	Filesize (using D4)	MSE (using D4)	Filesize (evolved)	MSE (evolved)	Filesize as % of D4 Filesize	MSE as % of D4 MSE	Percentage Improvement of MSE
airplane	48125	112.4558	48099	104.6	99.94597	93.01432	6.985677929
baboon	48536	279.5612	48531	260.97	99.9897	93.34986	6.650135999
boat	44429	158.9024	44399	150.9	99.93248	94.96395	5.036047284
fruits	48640	115.8036	48588	107.26	99.89309	92.62234	7.377663561
lenna	56519	177.5059	56465	164.33	99.90446	92.5772	7.422795524
peppers	39843	121.2649	39803	115.22	99.89961	95.01513	4.984871962
zelda	38257	134.5674	38211	125.42	99.87976	93.20237	6.797634494
				Averages	99.92072	93.53502	6.46497525

This table shows results for all images using co-efficients that were evolved against

susie for filesize 100%, quantization 64 for population 100 over 500 generations
As with couple, the coefficients seem to generalize quite well, giving percentage improvements of MSE between 5.4 to 8 %.

	Filesize (using D4)	MSE (using D4)	Filesize (evolved)	MSE (evolved)	Filesize as % of D4 Filesize	MSE as % of D4 MSE	Percentage Improvement of MSE
baboon	48536	279.5612	48545	263.59	100.0185	94.28705	5.712953014
barb	49116	307.6155	49126	291	100.0204	94.59861	5.401385821
couple	44795	155.9632	44768	144.87	99.93973	92.8873	7.11270351
goldhill	42814	135.7847	42883	124.09	100.1612	91.38732	8.612678748
park	42324	168.9597	42394	157.26	100.1654	93.07545	6.924550647
susie	45859	132.5596	45854	121.95	99.9891	91.99635	8.003645153
				Averages	100.049	93.03868	6.961319482

6.3 Collection of Data from various runs

Filesize(Bytes)	MSE of Y	MSE actual	Filesize ratio	Actual MSE ratio	MSE Y ratio
40220	44348582	170.060	0.900	1.090	1.049
42457	39220123		0.950	0.000	0.928
42457	38423762	147.340	0.950	0.945	0.909
43346	36395391	139.880	0.970	0.897	0.861
43798	34687912	133.080	0.980	0.853	0.821
44241	33248418	127.670	0.990	0.819	0.787
44688	31855580		1.000	0.000	0.754
44691	33536432		1.000	0.000	0.794
44691	42261254	155.960	1.000	1.000	1.000
44692	40944903		1.000	0.000	0.969
44692	32968625		1.000	0.000	0.780
44692	34090899		1.000	0.000	0.807
44692	34344159		1.000	0.000	0.813
44693	35798204		1.000	0.000	0.847
44694	36237520		1.000	0.000	0.857
44704	33184110		1.000	0.000	0.785
44714	33772535		1.001	0.000	0.799
44726	37912702		1.001	0.000	0.897
44747	34887747		1.001	0.000	0.826
44748	32259232		1.001	0.000	0.763
44875	31616817		1.004	0.000	0.748
44956	37180316		1.006	0.000	0.880
44963	31009858		1.006	0.000	0.734
45067	30743200		1.008	0.000	0.727
45141	30632164	117.490	1.010	0.753	0.725
45423	31120747		1.016	0.000	0.736
45583	29305053	112.970	1.020	0.724	0.693
45956	36249410		1.028	0.000	0.858
45971	29904153		1.029	0.000	0.708
46033	27843961	107.180	1.030	0.687	0.659
46928	25697595	98.670	1.050	0.633	0.608
47598	30538990		1.065	0.000	0.723
47628	30535188		1.066	0.000	0.723
47860	24461469		1.071	0.000	0.579
48191	32934630		1.078	0.000	0.779
48334	23093989		1.082	0.000	0.546
49028	21591410		1.097	0.000	0.511
49078	21372568	81.930	1.098	0.525	0.506
49112	21825591	86.670	1.099	0.556	0.516
49460	26959405		1.107	0.000	0.638
49463	27945553		1.107	0.000	0.661
59365	19997947		1.328	0.000	0.473
68237	12037914		1.527	0.000	0.285
44687	31560219	121.290	1.000	0.778	0.747

6.3 Research notes

This section [6.3] is taken from a summary that Brendan Babb and myself wrote for Dr. Moore in regards to some of our results.

The initial fitness function that we used was of the form

a * MSE ratio + b* FS ratio (File size)

Picking a and b were tricky in that we wished to limit file size growth severely but significant MSE improvements would often occur with increased file size. At Dr Moore's suggestion we picked a fixed file size (in this case the filesize of the D4 transform at quantization at 64) and used it as a baseline to see what increases in MSE we could obtain while keeping the file size relatively fixed to that point.

Most of this work we performed on Couple.BMP. A lot of fitness functions were tested and we ended up using the ratio of 100 * MSE/ (the original MSE for couple with quantization 64 and the D4 coefficients) = MSE Ratio. We also used the ratio of 100 * File size / (original File size for couple with quantization 64 and the D4 coefficients) = FS ratio.

Then many combinations of a* MSE ratio + b * FS ratio were tried. Often we could get good coefficients and then plug them back into the program change a and b slightly and get better results. It was almost a tuning of sorts. If you made them too loose a solution that was close to 100% FS ratio and 85% MSE ratio would escape to 70% MSE ratio but 108% FS ratio.

In order to look for a particular FS percentage we altered the fitness function to take the difference from the goal FS ratio say 90%, take the absolute value of that and add it to 1 and square it. Then this was multiplied by c. So for this example:

MSE ratio + 400 * (1+ abs(.90 - (FS/original FS)))^2

This helped zero in on the desired file size by the effect of squaring the difference.

From repeatedly doing runs of 200 population and 500 generations and taking the coefficients and plugging them back into the program as the starting coefficients, we were able to evolve over 3000 + generations or more. This method does introduce slight bias as you start with the best coefficients from the last run, but the program randomly perturbs the initial population of best coefficient copies.

In the previous term we had evolved against the same image over and over, and the improvements had been roughly the same for other images. We also found that to be the case, with this GA.

We were able to get a 22% increase in MSE for couple with quant 64 over the D4 coefficients and the same file size. The average over all the images was a 20% improvement and the file size was less that 100% on average.

We also tried various other file size ratios with various point from 90% to 110% of file size and noticed a trend line that fits the values fairly well. We are evolving against the same coefficients and for couple each time so that might bias the trend line but there appear to be solutions around the area that correspond to a certain increase in MSE for a decrease in File size

Finally we tested whether these evolved coefficients would produce generally good results when used to transform other images. We first tested the highly evolved coefficients that had been evolved exclusively against couple over approximately 4000 generations. At quantization 64 they produced an average improvement of 20% for MSE while maintaining compressed file size at an average of 99.9% when compared to the standard D4 transform. There were some instances where file size was slightly larger, the largest being 102.52% of the D4 compressed file but on average it appears likely that this will even out. The lowest improvement in MSE over the D4 transform was 15% against boat, the highest was 23% for fruit (note that this is a greater improvement than for Couple). [These results are contained in the attached spreadsheet under improvements for images.] Thus the highly evolved coefficients proved quite effective at giving improved MSE when transforming other images at quantization 64 while keeping file size in check.

We also evolved coefficients against Baboon, and then Susie, to see if coefficients evolved against other images would also provide good results when applied to other images. Though we evolved for a relatively low number of generations for both of these images we got good results that seemed to show good generalization of these coefficients as well.

Evolving against Baboon over 500 generations yielded us coefficients that gave us a 6.65% improvement in MSE over D4 at quantization 64. When applied to our other test images we received an average improvement of 6.64 % in MSE. The lowest improvement was 4.9% and the highest was 7.4%.

Evolving against Susie over 500 generations yieled us coefficients that gave us an 8% improvement in MSE over D4 at quantization 64. When applied to our other test images we received as average improvement of 6.96% in MSE. The lowest improvement was 5.4% and the highest was 8.6%.

Although most of our test runs were seeded with the D4 coefficients, a run seeded with random coefficients for population 200 over 500 generations (values constrained between -1 and 1) evolved down to 130% of MSE and to the same file size as the standard D4 transform, leading us to believe it is viable to have more explorative searches of the search space that may find more effective coefficients that are not located so close to the D4 coefficients.

6.4 Future Steps

There is plenty of possible work that could be worked on. The most advantageous would be to integrate our application and Chris Wedge's so that we could take advantage of the massive speedup that use of sub images allows, since he has shown that using sub images can have improvements at almost the same level as evolving against the entire image but with a speedup of several orders of magnitude.

Also, most of our research involved evolving coefficients against a single image, and then testing it against other images to see how generalizable it was. Although all coefficients tested in this manner proved to be highly generalizable, it would be interesting to evolve coefficients against multiple images simultaneously and see if coefficients could be found that had even better generalizable characteristics. The GUI of course could also be improved, and cleaning up the code and speeding it up in any other ways possible would also be nice.

Finally, I think the greatest improvement would be to implement alternative fitness measures than ones based on MSE, sinceis rather poor in terms of being an accurate predictor of what humans perceive as visual quality and even 20% improvements are difficult to discern by the naked eye.

7. Summary and Conclusions

The primary goal of this project was to research for Dr Moore whether forward and inverse coefficients could be coevolved that performed better than standard wavelet transforms at high levels of quantization, and if so, how generalizable were they. This research was concluded on time and the results showed that yes indeed, an improvement of 20% in MSE could be achieved while keeping the same file size as the standard wavelet . This is a significant increase over improvements in MSE that were obtained previously evolving only against the reverse transform which gave results ranging from 6 – 10 % increase in MSE. While we did not prove it conclusively, our results also offer strong evidence that that these evolved coefficients are very generalizable and effective on images of similar levels of quantization. Dr Moore is happy with the results and I think we did a good job of investigating the questions he set out for us.

Overall I found this to be very challenging project, but nonetheless interesting. It taught me a lot about C++ and C# and Visual Studios, all of which I have had very little experience with prior to this. Also, I found the whole world of wavelet transforms to be very interesting and as my understanding of them has increased I see that they can be used for all kinds of interesting projects.

Though outside of the scope of the work required by Dr Moore, I had hoped to port the application to C# for my own education both of the C# and the internals of the application. However most of my time was spent on the research, especially since the duration of each experiment was long and often would crash prior to completion. Considering that to test any new fitness function would often require 12 hours or so of running to see if it was getting any kind of significant results was more than a little tiresome. Hence the ported application got little of the attention that I had hoped to lavish on it. In retrospect I should have constrained myself simply to the work that Dr Moore was requesting, since the porting was more a duplication of effort than forging new ground. Nonetheless it provided an excellent opportunity to learn C# and become familiar with VS.NET and GUI's.

8. References

[1] Walker, James. (1999). Wavelets and their Scientific Applications. Chapman & Hall/CRC Washington DC

Appendix A: User Manual

Minimum System Requirements

.NET runtime environment
Windows 2000 or Windows XP
Pentium 4 at 2Ghz and 512mb ram for adequate performance.
Video Resolution 1024 by 768

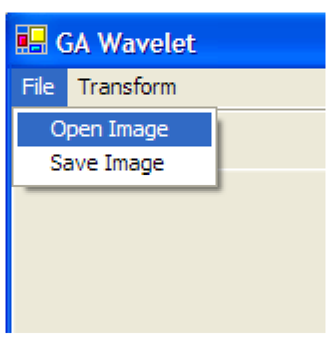
Installation

Copy GAWavelet.exe and coefficients.txt to the location that you wish the application to run it from.

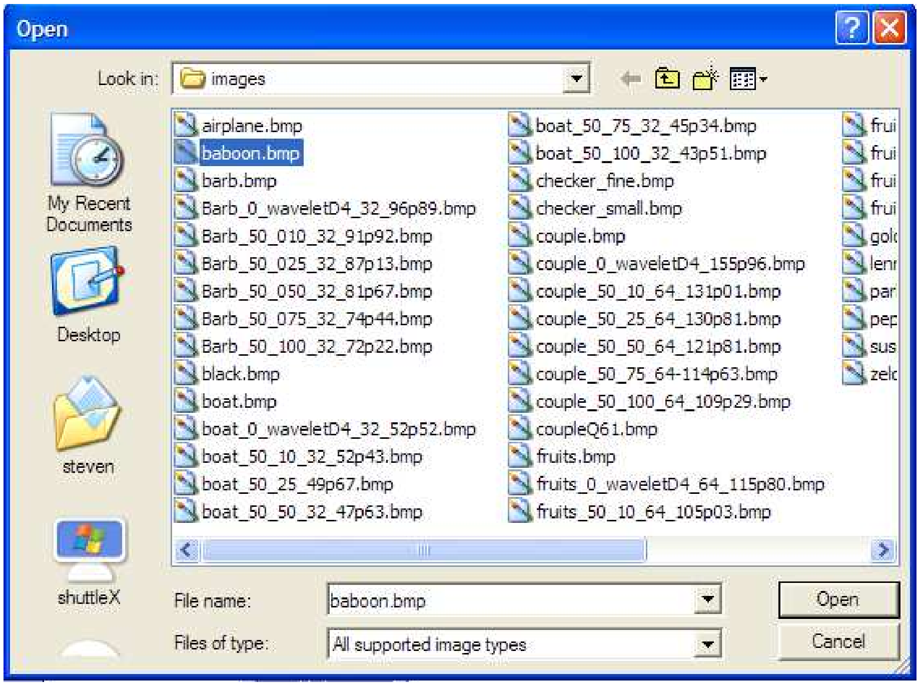
Starting the Program

Double click GAWavelet.exe

The program will launch and bring up an empty screen. Select F)ile and O)pen to select an image to load.

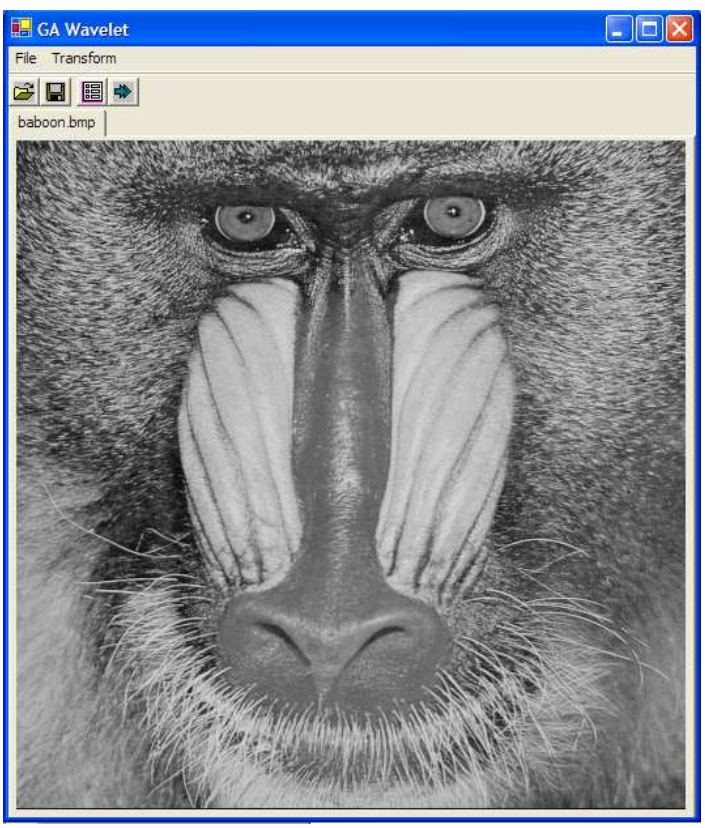


Navigate to the **image** file of the basin you would like to read. Acceptable formats are .bmp, .jpg, .jpeg, gif.



Select “Open” and the image will be loaded.

The image will be displayed in a new tab in the main window.

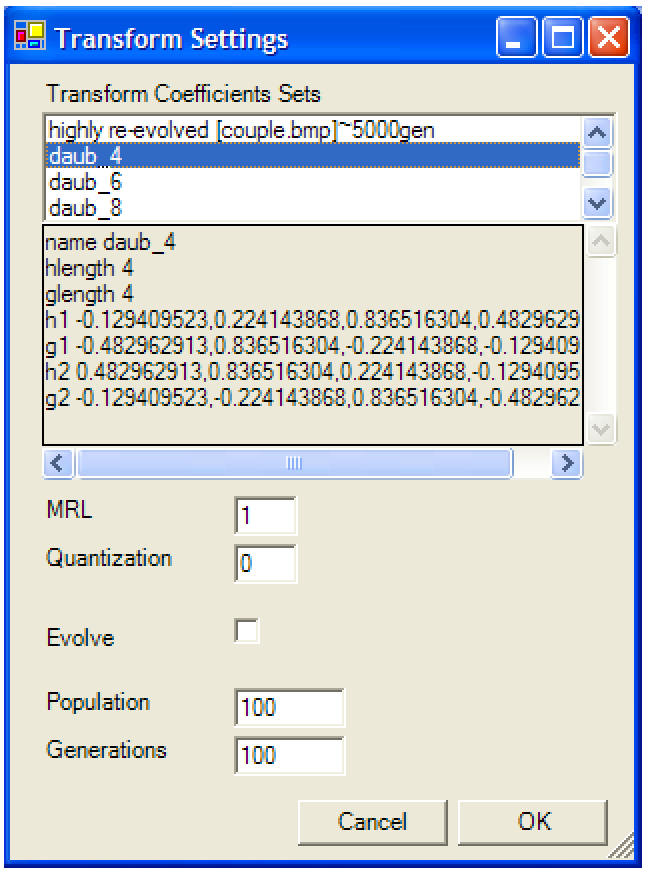


Multiple images can be loaded in this manner. Select the tab of the image you wish to work with by clicking on it. Up to 5 images can be loaded at once.

Saving images is achieved in the same manner. Select F)ile S)ave, and a similar dialog to the load image dialog will appear. Type in the name of that you wish to save the file under, and click save.

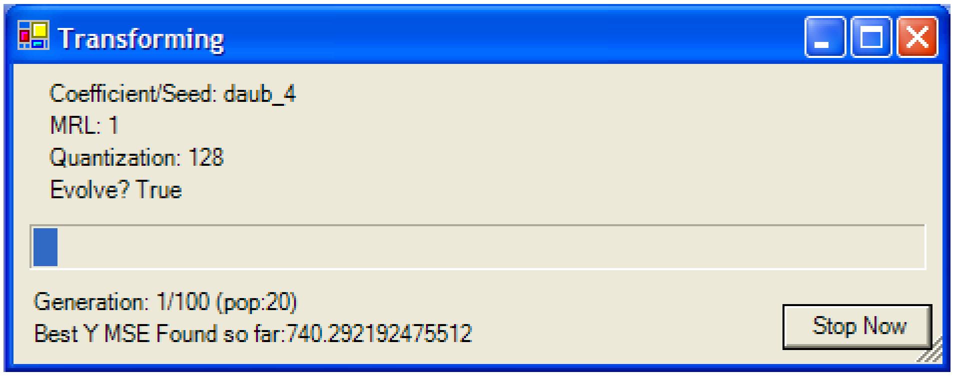
Selecting Transform Options

Click T)ransform S)ettings
The following dialog will appear



You can select what transform coefficient set to use by selecting one in the white list area at the top of the dialog. daub_4 is currently selected – this is the Daubeschie 4 wavelet transform. The coefficient details are shown in the gray area immediately under the the white list area.
Type the desired values for MRL, Quantization, Population and Generations into the appropriate text entry boxes. If you wish to use a genetic algorithm to evolve coefficients, check the Evolve checkbox.

To begin the transform, go Select T)ransform T)ransform. This will initiate the transform. While the transform is taking place the following dialog will be displayed.

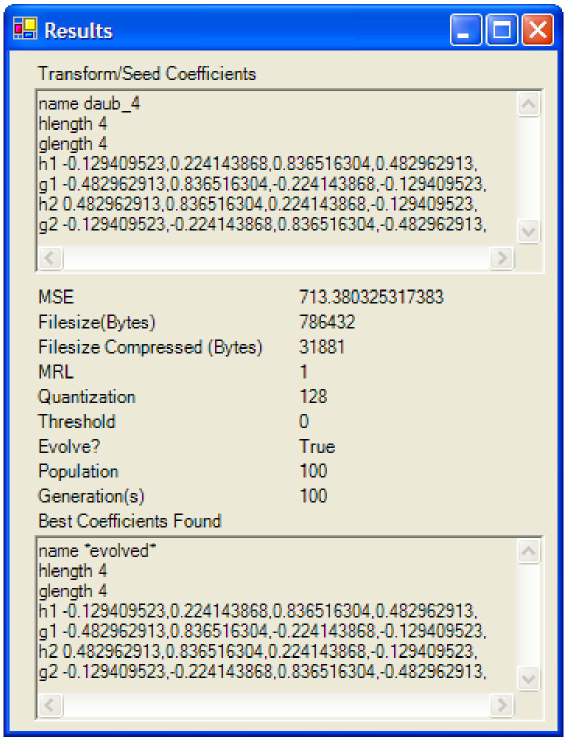


This shows you a progress bar giving you an indication of how much longer the transformation will require to complete. If you're using evolve and have a population of several hundred over several hundred generations, expect it to take in the order of several hours (to several days if you get carried away). If you did not select the evolve option in the settings dialog then it should take only a few seconds as it will do just a straight transform with the specified coefficient set.

If you're evolving you can use the "Stop Now" button to cause the GA to come to an early end. It will finish the current generation that it is on and then end the GA.

This dialog shows some helpful information about some of the settings you chose. This is particularly useful when performing a GA that takes several hours – you can make sure before you get the results several hours later that you entered the correct parameters.

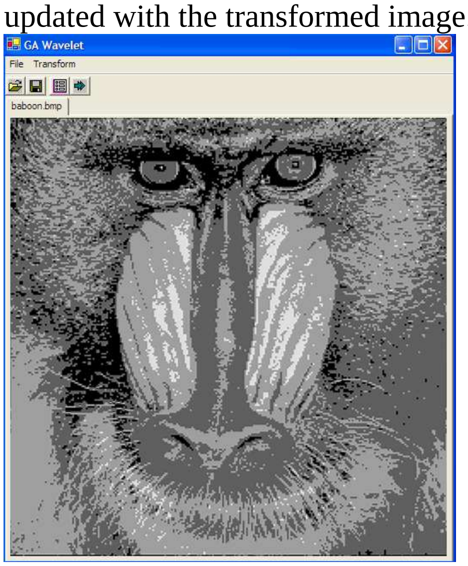
Results



Once the transform is complete a results dialog will be displayed listing the resultant MSE and file size and the parameters you chose for the transformation.

The values listed in the top textbox are the seed coefficient set that was selected. If the transform was not evolved then this will be the actual set of coefficients used to transform the image.

If you chose to evolve then the best set of coefficients that were evolved are displayed in the lower text box. Finally the image displayed in the main GAWavelet window is updated with the transformed image.



Screen Shots

To copy a screenshot to the clipboard press the print scrn button on the keyboard. You may then paste the image into your graphical editor of choice. Use the save image feature documented earlier if you wish to simply save a copy of a transformed image.

Exiting

When you would like to exit the application, click the X in the upper right corner of the main GAWavelet window.