Generating Noise for applications

DaveMSDevSA 26 Mar 2014 11:54 AM | 0

Abstract

This article goes into depth around four different types of noise generation algorithms. We cover the implementation as well as performance information for Perlin, Simplex, Wavelet, and Worley noise. This is an analysis of the implementation and the pro's and cons for each.

Keywords: Noise, Simplex, Wavelet, Value, Worley, Perlin, texturing

Introduction

Noise is a random disturbance in a sample which is not part of an expected result. Think of audio signals on images that you take with your Digital SLR. The noise is the pieces of information that are not desirable such as hiss or speckled spots on low light photos. In these instances this extra information is usually undesirable but in some application this noise makes things more natural and realistic when using random information.

There are many different applications of noise in game development from terrain generation, procedural textures, to artificial intelligence and many more. Noise is surprisingly interesting and is not necessarily just random numbers. Its about how are those numbers distributed how to they relate to previous information. This can be quite a complex topic and in this blog post I will be going through the following types of noise and providing source code and libraries you can leverage to create applications. The types I am going to cover are:

- Value
- Perlin
- Simplex
- Worley

Research Method

The process I am going to take here is focused around implementing and comparing results of each of the noise generation functions. We will compare the following qualitative values:

- Implementation Difficulty
- Resulting graphical noise

The quantitative values we will leverage are:

- Processing time for various image sizes
- Aggregate variance from white

Results

Noise can be a fairly complex topic with a large amount of information on the topic that varies from article to article. We aim to resolve a number of the difficulties with this article as well as provide a complete set of code and framework that can be reused or inspected. Noise functions do not necessarily generate those beautiful pictures you are used to seeing, it's the layering and adding those layers together which has those various effects.

In order for us to understand these various noise functions we need to compare it to a purely random function. For this we will be leveraging each of the languages random function to generate a number between 0.0f and 1.0f. We will attempt to stick to floating points as much as the language will allows us to. This is in an effort to ensure consistency between the results. Simply put:

```
function RandomNoise(){
    return random(0.0f,1.0f);
}
```

1. Random Noise

We take the result of the RandomNoise Function and convert it to an RGB value between 0 and 255. For this article we will stick to shades of grey so the RGB values will all be the same.

```
int r = g = b = randomvalue * 255
```

The results of the RandomNoise function look as follows:

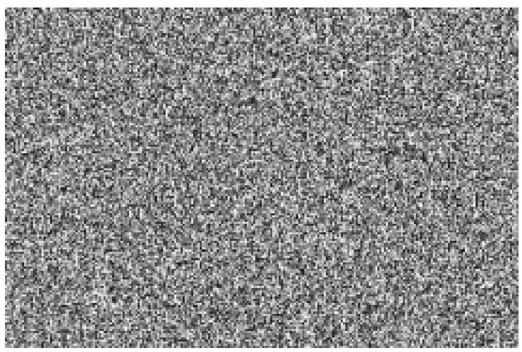


Figure 1.0 Noise Pattern

For an image 300px x 200px the average generation time sits in the 1600ms time range in JavaScript. As you can see there is no uniformity to the noise generated. The performance per language is broken down as follows:

Language	300x200	1024x768	1600x900	1280x1080
Javascript	7.6	44.8	70.6	65.6
C#	3.12358	9.37525	20.30747	20.31865
C++				

Table 1.0 Random Noise Average Time per resolution

As you can see the performance is purely based on the number of pixels you are trying to generate as well as the language you are using.

Before we go into Perlin Noise there is a bit of understanding of the different types of interpolation that we need to have. Interpolation calculates a projected value between a set of points based on various functions or techniques.

Linear interpolation performs curve fitting using linear polynomials. It takes in 3 inputs Point1, Point2 and t which is a range between 0.0 and 1.0. The function for linear interpolation we will leverage is:

```
function lerp(v0, v1, t)
{
      return v0+(v1-v0)*t;
}
```

Cosine interpolation is a form of trigonometric interpolation which will provide us with smoother interpolations than linear. The function we will leverage is:

```
function cosinerp(v0, v1, t)
{
     ft = t * 3.1415927
     f = (1 - cos(ft)) * .5
     return v0*(1-f) + v1*f
}
```

Cubic interpolation is a more complex form of interpolation but results in much higher amounts of smoothing between points. Its also one of the simpler options to implement although it does require 4 points and t a range which works similar to the other two versions of interpolation. CatmullRom is a variation of this with weighted multiples applied to the calculation (See source code). The implementation is as follows:

```
function cuberp(y0, y1,  y2, y3,  mu)
{
     a0,a1,a2,a3,mu2;
     mu2 = mu*mu;
     a0 = y3 - y2 - y0 + y1;
     a1 = y0 - y1 - a0;
     a2 = y2 - y0;
     a3 = y1;
     return(a0*mu*mu2+a1*mu2+a2*mu+a3);
}
```

Hermite interpolation is similar to Cubic except with the addition of two parameters Tension and Bias. Tension tightens up the curvature of the points and bias twists the curve around specific points. The formula for Hermite interpolation is:

```
    t3 = t2 * t;
    m0  = (v1-v0)*(1+bias)*(1-tension)/2;
    m0 += (v2-v1)*(1-bias)*(1-tension)/2;
    m1  = (v2-v1)*(1+bias)*(1-tension)/2;|
    m1 += (v3-v2)*(1-bias)*(1-tension)/2;

     a0 =  2*t3 - 3*t2 + 1;
     a1 =    t3 - 2*t2 + t;
     a2 =    t3 -   t2;
     a3 = -2*t3 + 3*t2;

     return(a0*y1+a1*m0+a2*m1+a3*y2);
}
```

We also need to understand some terminology before proceeding as I found that without a decent understanding of these terms the following explanations become somewhat difficult to understand first time round. These concepts are focused on how layers are added together and the various properties of the layers.

Octaves: this first term is how many layers of noise are we going to blend together. The more octaves or layers the more detail the noise has

Frequency: this is the number of segments that we are going to put into the space we are using. This is the same as frequency when it comes to sound waves or signal process. The lower the frequency the bigger the features and the higher the frequency the smaller the features.

Amplitude: this is the height of the details. The bigger the amplitude the bigger the height of the features. Generally one will decrease the amplitude for each octave to have a more general smoothing effect.

Persistence: This is the rate at which the amplitude will decrease with each octave that is added. The smaller the persistence the lower the amount of change

With these concepts we can multiply and add various layers of noise together to generate wood like textures, clouds and many other types of procedural textures.

2. Value Noise

The next one we will look at is Value noise which is one of the simplest. Value noise is a simple algorithm that leverages a grid of random values between 0 and 1 to work out what a pixel should be. Below is a picture of what Value Noise Looks like:

Figure 2.0 Value Noise

The way value noise works is by using a set of points which are randomized and then for each sample between points are interpolated between that set of randomized values. The general flow of this is as follows:

1. Generate a set of random values for points
2. For the given point calculate the points surrounding
3. Get the random value using the surrounding points
4. Calculate the difference between the points and use that for your interpolation value
5. Interpolate the values
6. Return the result

Lets have a look at each of the steps and understand them further. The first stage we generate an array of the appropriate dimension and we assign random values to this. The size of the array can vary quite widely and its worth having a look how the array size affects the out come. For a 2D noise function it will simply be:

```
for(int x = 0; x < size; x++){
      for(int y = 0; y < size; y++){
            RandomArray[x][y] = Random();
      }
}
```

Now we have an array populated with random values this is our noise information that we are going to use to interpolate to have smooth transitions. Lets have a look at how this works. Given a point we map that point to the RandomArray and interpolate the value from the surrounding values points. We also need to know the position of the point given relative to the surrounding points we use this relative information to determine the interpolation value between two points. Now we interpolate and return the value for the noise. Once we populate our grid it should be something similar to this:

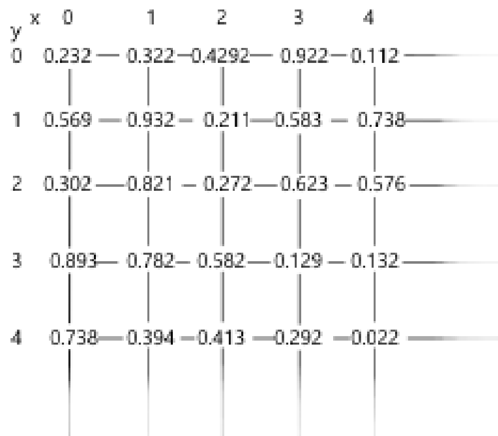


Figure 2.1 Populated Random Grid

Say we have a point 2,3 that we want noise for on an image that is 300x200 pixels wide we will pass in the x and y values multiplied by the inverse of the width and height of the area you wish to fill with noise. eg.

tx = 0,0033333 = 1/300
ty = 0,005 = 1/200

So we pass into the noise function 2.003333 and 3.005 (the red dot on the diagram). We now break down the point passed in into two components, its whole number and the remainder (tx and ty). With the remainder we use a smoothing function to get a new value that is used during interpolation. We then figure out which are the neighbouring points in the generated grid (the green dots on the diagram). We then interpolate the values with each other.

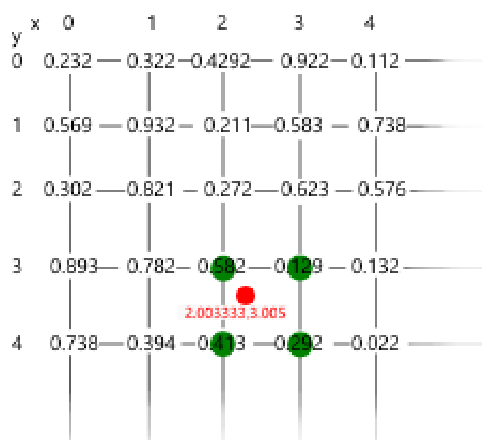


Figure 2.2 The Points used for interpolation to ensure smooth noise.

To view the source code for this please see the source code links in the references section. Below are the performance metrics for the different languages and resolutions.

Language	300x200	1024x768	1600x900	1280x1080
Javascript	8.2	94	174	173
C#	2.10057	58.16069	96.27747	94.56971
C++	1.6	4.7	3.1	0

Table 2.0 Value Noise Average Time per resolution

3. Perlin Noise

Perlin Noise is the award winning technique developed by Ken Perlin in 1982 and was leveraged in the motion

Picture Tron. It is a gradient noise which is a pseudo random technique. Instead of storing random numbers in the grid as in Value noise and interpolating, Perlin noise stores a gradient vector. To get the values we calculate the dot products of each gradient vector. The dot product is then interpolated to get our result which looks like:

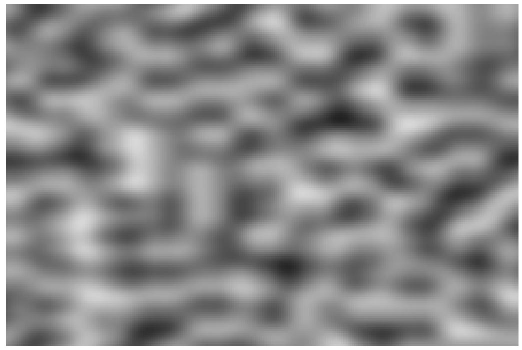


Figure 3.0 Perlin Noise

From the above image you can see Perlin noise is less uniform than Value. There are a number of great articles covering the theory behind Perlin noise which are found in the references section but I will do my best to sum up the jist of what is going on at each step. Looking at Ken Perlin's improved Perlin noise first step is initializing the array p[]. What is array p? The P array allows us to have a predefined pseudo random allocation of number we can use to generate gradients. We could generate this array using the original method defined by Ken Perlins C code but for performance sake we use a predefined list. This p array is populated to fill 512 items.

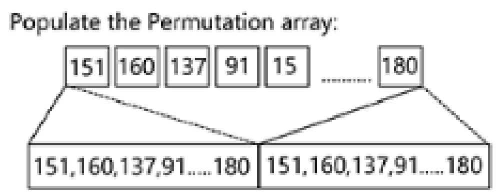


Figure 3.1 Populating the P array

Now we have an array that can be used for random numbers we will take our input values and begin processing. It is important to note that the input expected is a floating point (eg 0.0333 or 1.0333). This is why we divide the x and y values by the width and height. This gives us a percentage which is the distance across the width or height. Using this adjusted x and y value as input we then find the cube that surrounds the inputs.

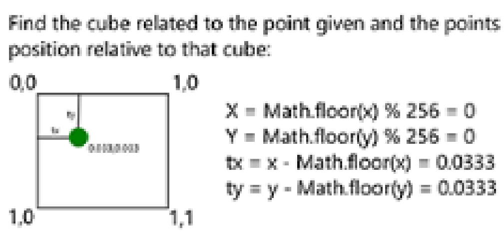


Figure 3.2 Components used for the Perlin Noise calculation

Once we have the required components we now calculate the value that we will be using for the interpolation between the various gradients. This is done using a smoothing function which given a value will return the corresponding value that is on a smoothed curve.

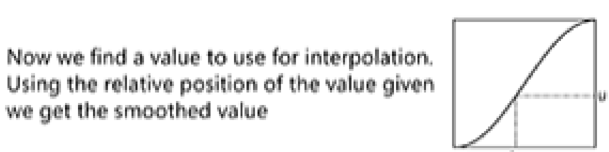


Figure 3.3 Smooth curve values for the Lerp

Using this information we use the values in the p[] array to get hash values that we can leverage to generate the gradients for each point. For example given that our x and y values are (0.0333, 0.0333) for x = 0 and y = 0 the hashes would look as follows:

```
A = p[0] + 0 = 151
AA = p[A] + 0 = p[151] = 17
…
```

Using those points we now calculate the various gradients for AA,AB,BA,BB and AA+1, AB+1, BA+1, BB +1.

```
x = 0.0333
y = 0.0333
 AA = 17
 h = 17 & 15 = 1
 u = 1 < 8 ? 0.0333 : 0.0333 = 0.0333
 v = 1 < 4 ? 1 == 12 || h == 14 ? 0.0333 : 0 = 0
 a = h & 1 == 0 ? u : -u = 0.0333
 b = h & 2 == 0 ? v : -v = 0;

return a + b = 0.0333
```

With each of those gradients we now perform a Linear Interpolation between those using the smoothed values and that's about it.

Language	300x200	1024x768	1600x900	1280x1080
Javascript	22.1	259.6	447.7	440.5
C#	10.91993	178.67824	329.77866	318.2969
C++	4.6	40.7	70.3	78.2

Table 3.0 Perlin Noise Average Time per resolution

4. Simplex

Simplex Noise developed by Ken Perlin in 2001 has similar results to Perlin Noise with less computational requirements than Perlin. The idea of Simplex is to divide the N dimensional space into triangles that reduces the number of data points. In Perlin noise we would find the cube that the point we are given in resides and find the points related. Visually the result is not much different from Perlin noise.

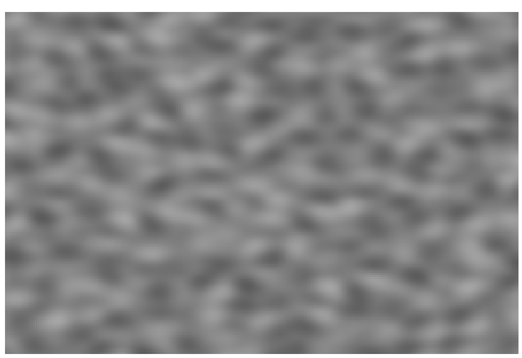


Figure 4.0 Simplex Noise

With simplex we are finding the shape that is based on a equilateral triangle and returning fewer points. The major difference Basically it takes the previous grid and skews it and forms triangles for the simplex representation. The gradients for each of the points are then generated and then the rest of the implementation is pretty much the same.

[TODO – Diagram showing the difference between Perlin and Simplex]

The results are good and the performance is much better than Perlin with higher dimensions but it is quite complex to understand

Language	300x200	1024x768	1600x900	1280x1080
Javascript	36.2	475.7	847.7	820.5
C#	15.75991	230.19422	418.06524	393.17309
C++	3	107.6	192.4	182.6

Table 4.0 Simplex Noise Average Time per resolution

5. Worley

Worley Noise (Aka Cell Noise) was developed by Steven Worley in 1996 which is very useful in generating stone, water or cell noise textures. The way Worley noise works is that is has a random set of feature points. Given a specific point it calculates the distance of that point to the nearest feature point and uses that for the information. The result is seen below:

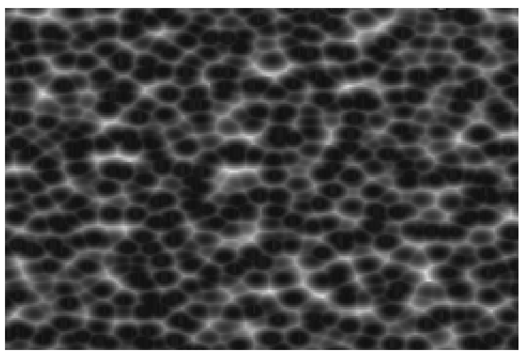


Figure 5.0 Worley Noise

What is needed is a set of random points which we compare against. Then we calculate the distance from to the nearest point from the point supplied. Worley’s algorithm has a more efficient implementation of this concept which performs the following steps:

1. Calculates which cube a point is in
2. Create a random number generator for the cube
3. Calculate how many points are inside the cube
4. Randomly assign points in the cube
5. Find the point closest to the point given
6. Check neighboring cubes
7. Calculate the distance

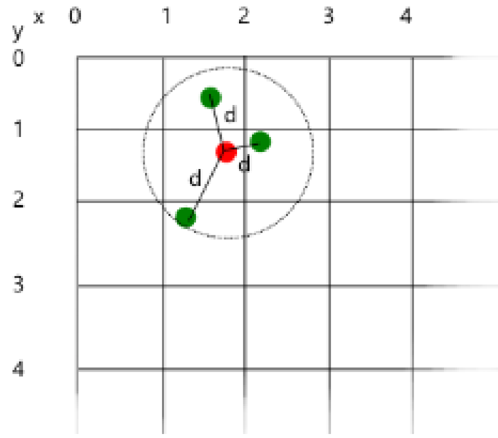


Figure 5.1 How the noise value is determined

We can change our results by changing the number of feature points, the way distance is computed and the size of the grid used. If you invert the image you can see the points and the distance information clearly.

Language	300x200	1024x768	1600x900	1280x1080
Javascript	764.8	10003.2	18879	17875.9
C#	906.9245	11532.654	21078.3585	20539.72
C++	290.1	3866.4	7078.4	6615

Table 5.0 Worley Noise Average Time per resolution

Conclusion

The various types of noises all have different visual and performance benefits. Below is a visual comparison of each of the different types of noise covered in this article.

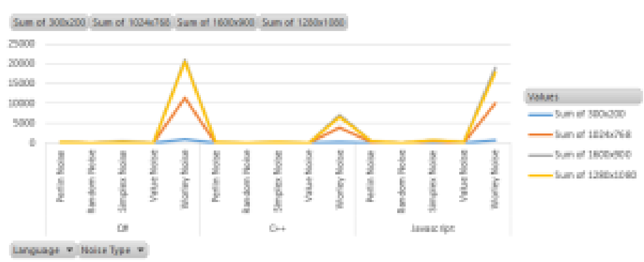
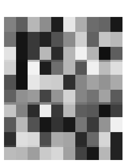


Chart 1.0 Comparison of each of the performance factors across the various languages.By far C++ has the best performance compared to the other languages and C# was typically slower than JavaScript but this can be explained by the direct porting of code instead of using appropriate data structures. The last table summarizes the findings.

Technique	Resulting Image	Implementation Difficulty	Processing time	Variance	Pros	Cons
Random		Easy	Low amount of processing required	Hi amount of variance with no smoothing	Random information	No smooth transitions between points

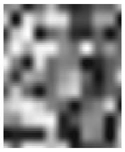
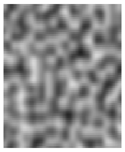
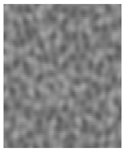
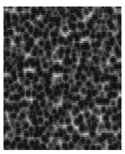
Value		Easy	More expensive than Random	Minimal Smoothing		Not a very organic pattern
Perlin		Moderate	Slightly slower but not considerably	Hi amount of variance	Great smoothing	A little complex to understand
SImplex		Moderate	Fast	Similar result to Perlin	Fast to compute east to implement in hardware	Complex to understand
Worley		Complex	Slow	Hi variance	Nice effects, various different items to change	Not a simple to implement and requires more processing

Table 6.0 Summarized findings

Source Code:

Sharp Noise : **https://sharpnoise.codeplex.com/**

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Available: **http://www.carljohanrosen.com/share/CellNoiseAndProcessing.pdf** [26 Mar 2014]

Appendix A – Data Results

	300x200	1024x768	1600x900	1280x1080
Sample 1	51	136	141	73
Sample 2	3	38	65	70
Sample 3	2	34	62	61
Sample 4	2	33	61	59
Sample 5	3	33	62	61
Sample 6	2	37	62	59
Sample 7	4	34	64	69
Sample 8	3	36	63	85
Sample 9	3	35	63	61
Sample 10	3	32	63	58
Average	7.6	44.8	70.6	65.6

Table A.0.1 Javascript Random Noise in milliseconds

	300x200	1024x768	1600x900	1280x1080
Sample 1	13	105	157	142
Sample 2	6	87	156	140
Sample 3	7	81	214	237
Sample 4	14	112	236	229
Sample 5	10	115	209	215

Sample 6	6	104	152	150
Sample 7	6	84	147	148
Sample 8	7	88	159	148
Sample 9	7	83	153	168
Sample 10	6	81	157	153
Average	8.2	94	174	173

Table A.0.2 Javascript Value Noise in milliseconds

	300x200	1024x768	1600x900	1280x1080
Sample 1	26	266	414	403
Sample 2	28	364	449	423
Sample 3	23	227	432	405
Sample 4	17	246	430	452
Sample 5	16	232	436	468
Sample 6	23	243	442	469
Sample 7	30	258	448	435
Sample 8	17	280	468	448
Sample 9	15	234	482	462
Sample 10	26	246	476	440
Average	22.1	259.6	447.7	440.5

Table A.0.3 Javascript Perlin Noise in milliseconds

	300x200	1024x768	1600x900	1280x1080
Sample 1	41	498	869	827
Sample 2	35	457	863	874
Sample 3	36	491	893	815
Sample 4	35	474	861	837
Sample 5	36	499	872	849
Sample 6	35	463	822	788
Sample 7	33	440	813	771
Sample 8	33	464	849	862
Sample 9	45	520	823	797
Sample 10	33	451	812	785
Average	36.2	475.7	847.7	820.5

Table A.0.3 Javascript Simplex Noise in milliseconds

	300x200	1024x768	1600x900	1280x1080
Sample 1	773	9800	17970	17342
Sample 2	752	10066	18735	18308
Sample 3	754	10432	18401	18257
Sample 4	889	11035	20495	17651
Sample 5	761	9555	18507	18100
Sample 6	753	9934	18518	18836
Sample 7	748	10001	20718	17671
Sample 8	715	9465	17875	17159
Sample 9	760	10047	19054	17786
Sample 10	743	9697	18517	17649

Average	764.8	10003.2	18879	17875.9

Table A.0.4 Javascript Worley Noise in milliseconds

	300x200	1024x768	1600x900	1280x1080
Sample 1	15,6219	15,6259	15,6243	31,2802
Sample 2	0	0	31,2503	15,6251
Sample 3	0	15,6264	15,6251	15,6267
Sample 4	0	15,6239	15,6247	15,626
Sample 5	15,6239	0	15,6259	31,2503
Sample 6	0	0	31,251	15,6264
Sample 7	0	15,6243	15,5984	15,6518
Sample 8	0	15,6264	15,6259	15,6243
Sample 9	0	15,6256	15,598	31,2781
Sample 10	0	0	31,2511	15,5976
Average	3,12458	9,37525	20,30747	20,31865

C# Random Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	0	62,4993	93,7827	93,7233
Sample 2	0	62,5292	93,7515	93,7524
Sample 3	0	62,5009	93,754	93,7216
Sample 4	0	62,5309	93,7228	93,7819
Sample 5	0	62,5017	93,7516	98,6821
Sample 6	4,0003	54,0036	99,9782	94,0085
Sample 7	4,0003	55,0332	99,006	94,0094
Sample 8	3,9999	53,0043	101,0083	95,0069
Sample 9	5,0008	53,0039	97,008	95,0032
Sample 10	4,0044	53,9999	97,0116	94,0078
Average	2,10057	58,16069	96,27747	94,56971

C# Value Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	3,0671	187,5339	328,1042	312,5086
Sample 2	0	187,5314	312,4794	328,1621
Sample 3	0	187,4756	328,1596	296,8797
Sample 4	15,6276	187,5044	328,1329	296,8814
Sample 5	15,6259	171,8792	328,105	312,5053
Sample 6	15,6256	171,9055	328,1324	323,6092
Sample 7	14,001	179,0144	329,0262	328,0242
Sample 8	14,0022	164,5815	328,1325	312,5077
Sample 9	15,6252	187,4768	312,5345	312,5077
Sample 10	15,6247	171,8797	374,9799	359,3831
Average	10,91993	179,67824	329,77866	318,2969

C# Perlin Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	15,6272	265,6312	468,759	390,6362

Sample 2	15,6235	218,785	399,3286	390,6338
Sample 3	15,6255	218,755	421,8578	400,3869
Sample 4	16,9734	223,7623	406,2314	453,1643
Sample 5	15,6255	281,228	437,5071	390,6379
Sample 6	15,6226	218,7575	406,2581	375,0374
Sample 7	15,6255	218,7275	421,9124	374,9803
Sample 8	15,6252	218,7841	406,2589	375,0087
Sample 9	15,6251	218,7562	406,2528	390,6395
Sample 10	15,6256	218,7554	406,2593	390,6059
Average	15,75991	230,19422	418,06254	393,17309

C# Simplex Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	875,0507	11721,8289	21159,6973	20796,8689<
Sample 2	881,7512	11395,9728	21601,9663	21163,0641<
Sample 3	937,5188	11781,6182	21021,7052	20026,9773<
Sample 4	875,0204	11425,826	20934,028	20934,7304
Sample 5	968,7906	11538,2469	20978,2407	20503,3906<
Sample 6	875,015	11437,8304	21050,5453	20282,7218
Sample 7	859,3624	11500,553	21201,9371	20710,8594
Sample 8	1046,8467	11692,1106	21034,7107	20608,7085
Sample 9	874,9585	11458,6809	20889,1269	19987,1211<
Sample 10	874,931	11373,8703	20911,6274	20382,7533<
Average	906,92453	11532,6538	21078,35849	20539,7195

C# Worley Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	0	0	0	0
Sample 2	0	0	0	0
Sample 3	0	0	0	0
Sample 4	0	0	0	0
Sample 5	16	0	0	0
Sample 6	0	15	0	0
Sample 7	0	16	0	0
Sample 8	0	16	0	0
Sample 9	0	0	15	0
Sample 10	0	0	16	0
Average	1.6	4.7	3.1	0

C++ Random Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	0	47	78	79
Sample 2	15	31	79	78
Sample 3	15	32	78	78
Sample 4	0	32	78	78
Sample 5	0	46	63	78
Sample 6	0	47	62	78

Sample 7	0	47	62	78
Sample 8	0	47	62	78
Sample 9	16	47	62	79
Sample 10	0	31	79	78
Average	4.6	40.7	70.3	78.2

C++ Value Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	16	109	187	188
Sample 2	16	109	187	188
Sample 3	16	109	187	172
Sample 4	16	93	203	170
Sample 5	16	109	188	187
Sample 6	0	109	188	187
Sample 7	0	109	188	187
Sample 8	0	109	188	187
Sample 9	16	93	194	188
Sample 10	16	94	203	187
Average	11.2	104.3	191.3	184.1

C++ Perlin Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	15	110	187	172
Sample 2	15	94	203	172
Sample 3	0	109	188	187
Sample 4	0	109	188	187
Sample 5	0	109	188	187
Sample 6	0	109	188	187
Sample 7	0	109	188	187
Sample 8	0	109	203	172
Sample 9	0	109	188	187
Sample 10	0	109	203	188
Average	3	107.6	192.4	182.6

C++ Simplex Noise

	300x200	1024x768	1600x900	1280x1080
Sample 1	281	3776	6672	6992
Sample 2	312	3719	7014	6674
Sample 3	281	4266	7453	6719
Sample 4	281	4156	7954	6922
Sample 5	281	3859	7385	6484
Sample 6	297	4063	6797	6487
Sample 7	313	3894	6992	6435
Sample 8	281	3619	6915	6365
Sample 9	277	3705	6728	6634
Sample 10	297	3607	6874	6438
Average	290.1	3866.4	7078.4	6615