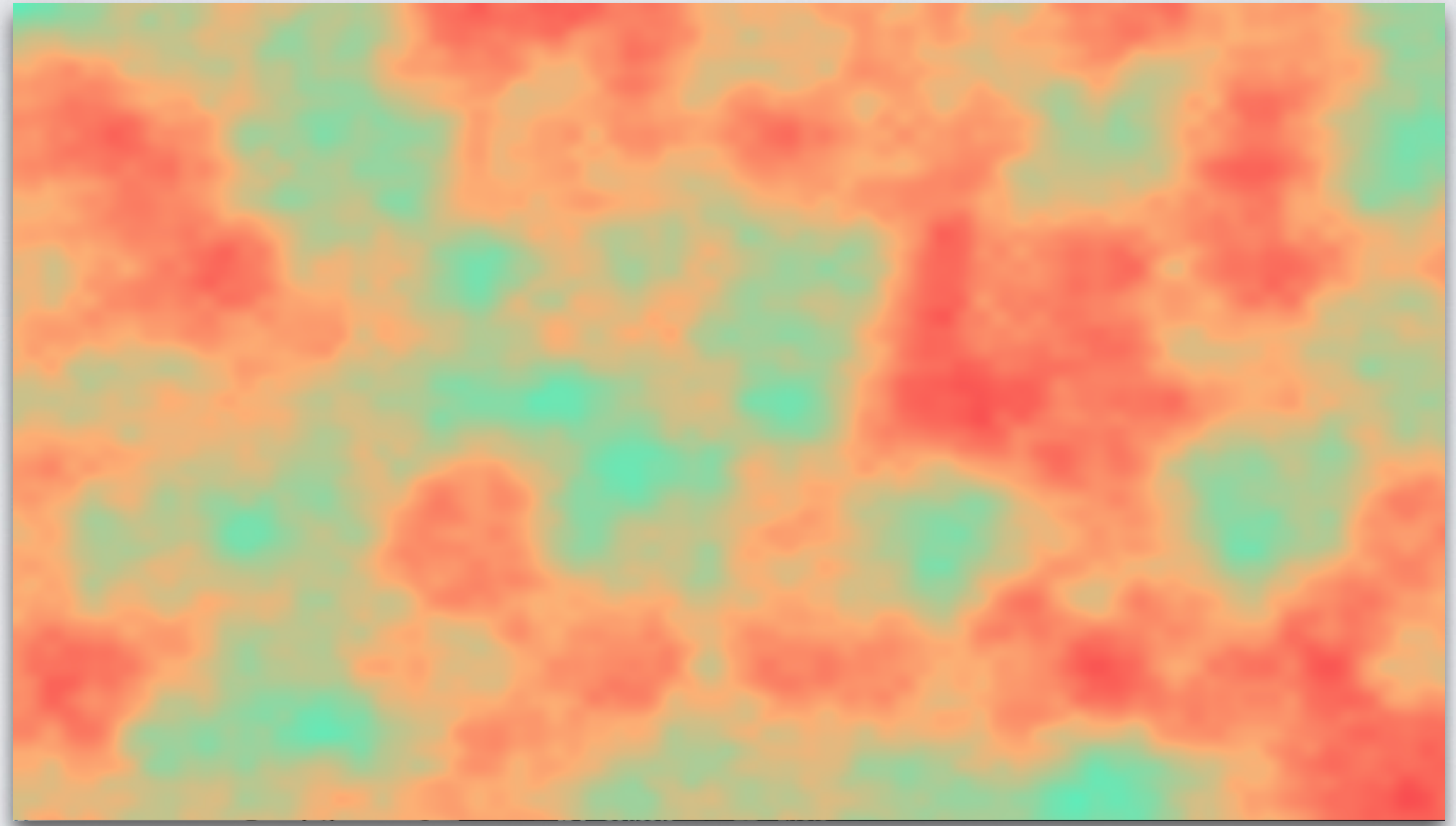
NOISE FUNCTIONS

engineering the appearance of randomness



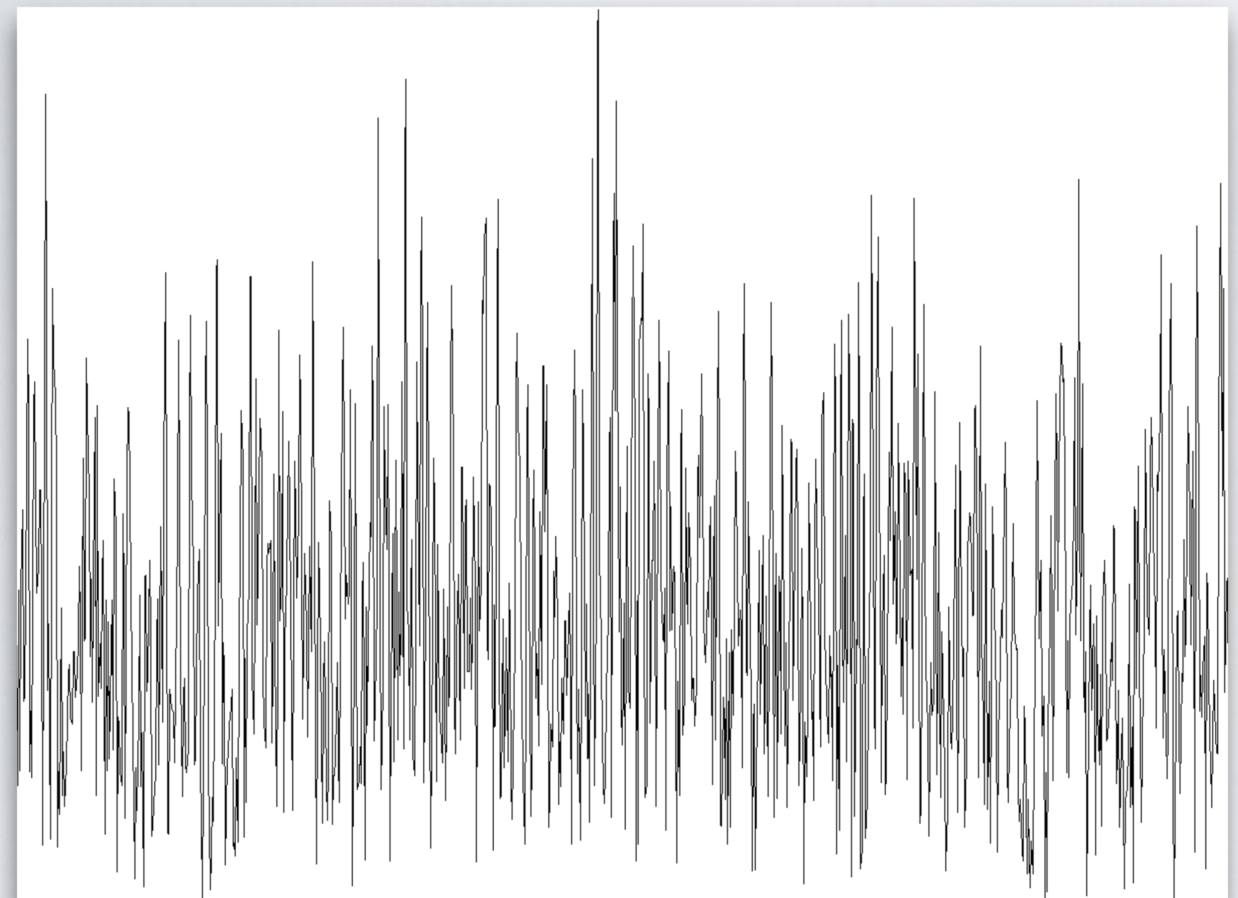
University of Pennsylvania - CIS 700 Procedural Graphics
Rachel Hwang

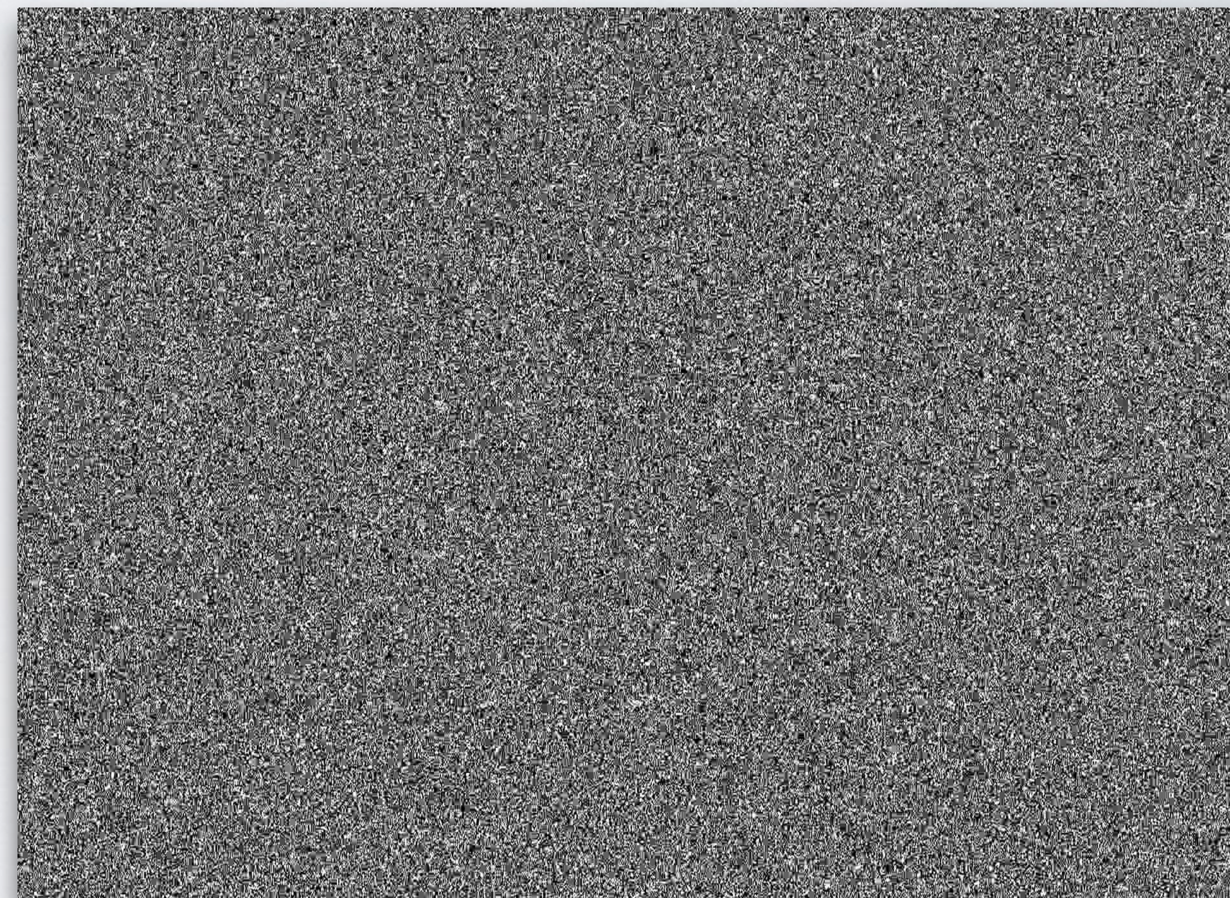
USES OF RANDOMNESS

Planet Earth - Jungles (source)

- Designed systems need variation
- Natural systems appear to combine structure & randomness
  - Which belies more underlying structure
  - …that we can fake with noise. Simulation is expensive!
- Any domain: location, color, transparency, normals…

IS RANDOM TOO RANDOM?





A) True random values don't guarantee the same results each time

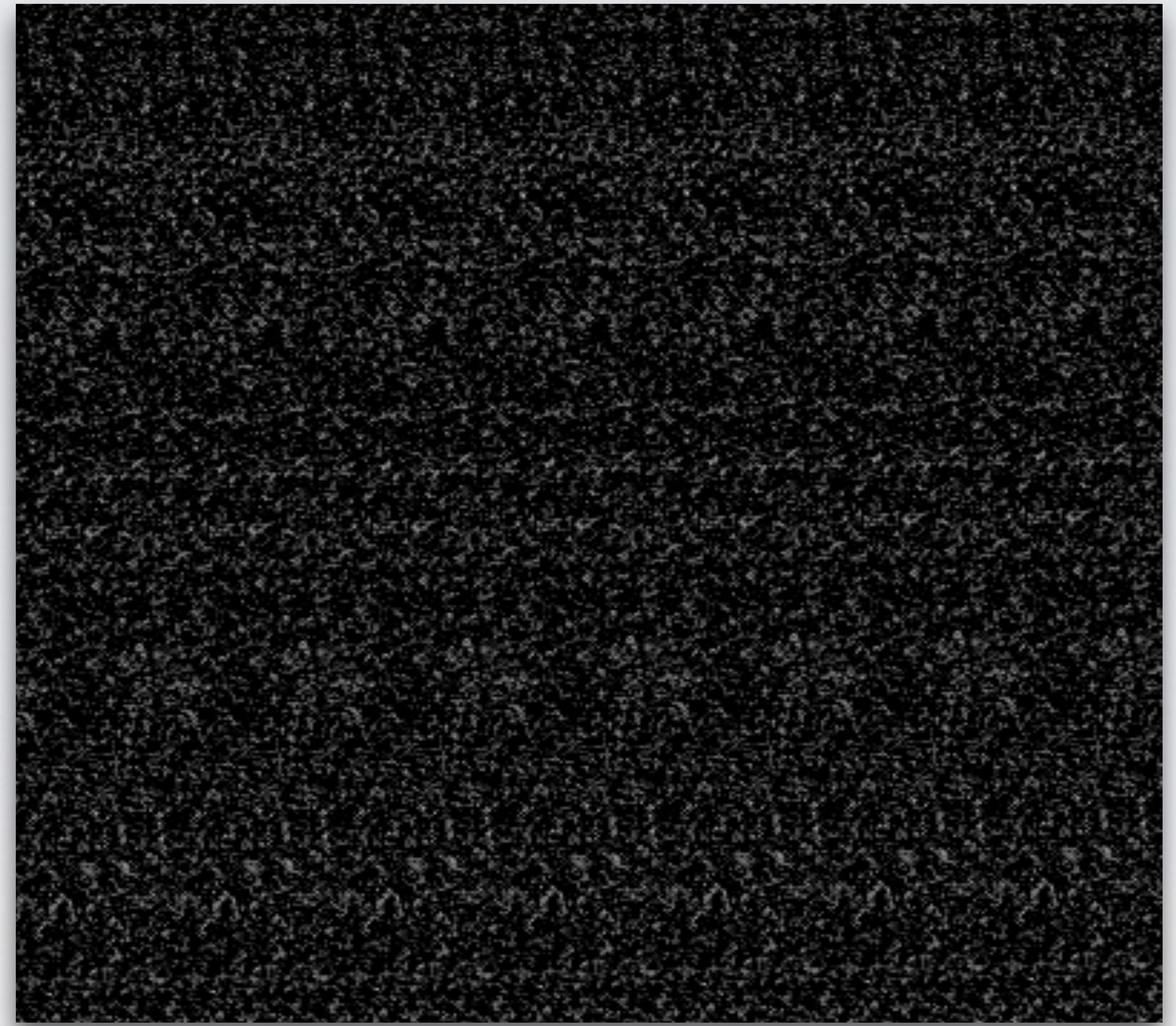
B) True randomness lacks coherency — no relationship between adjacent points.

NOISE FUNCTIONS

- A noise function is a seeded random number generator
  - Given some input parameters, returns a random-looking number: $y = noise(x)$
  - Same input parameters will always produce the same output.
- Good-looking, varied output depends on choosing and manipulating noise functions.
- Many generation methods, both implicit and explicit.

PSEUDO-RANDOM NOISE

hash functions!



Using math operations, we can transform input in a that looks random… but actually repeats after a long period.

PSEUDO-RANDOM NOISE

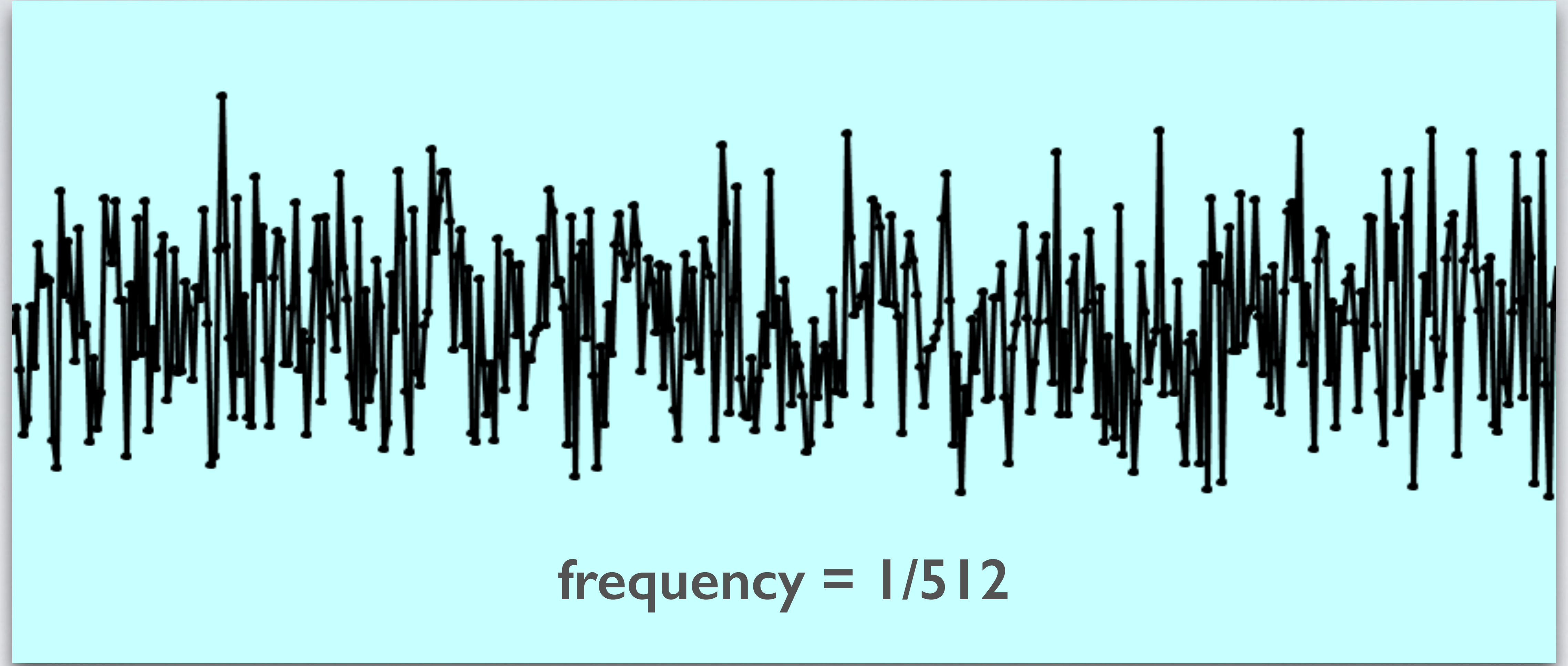
- Can be n-dimensional
- Typically uses bitwise operations and/or large prime numbers
- Warning: know your output range! Usually assume [-1, 1].
- This is the corner-stone of a lot of demos. See IQ's blog for optimization tips.

Examples:

```
float noise_gen1(int x) {
   x = (x << 13) ^ x;
   return (1.0 - (x * (x * x * 15731 + 789221) + 1376312589) & 7fffffff) / 10737741824.0);
}
```

```
float noise_gen2(int x, int y) {
   return fractional_component(sin(dot(vec2(x, y), vec2(12.9898, 78.233))) * 43758.5453);
}
```

FREQUENCY



- We can sample noise at different frequencies and interpolate between points.
- Controls 'bumpiness'
- Creates coherency — similar input creates similar output

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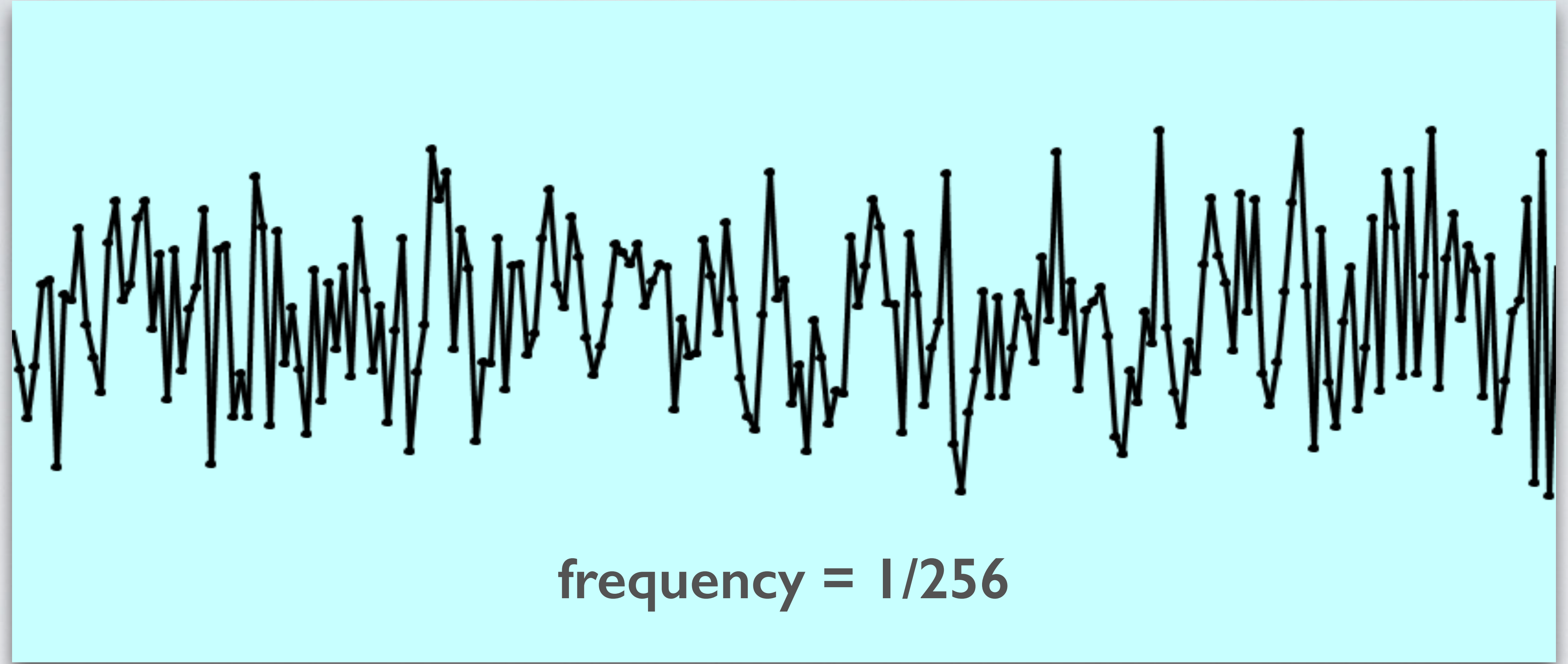

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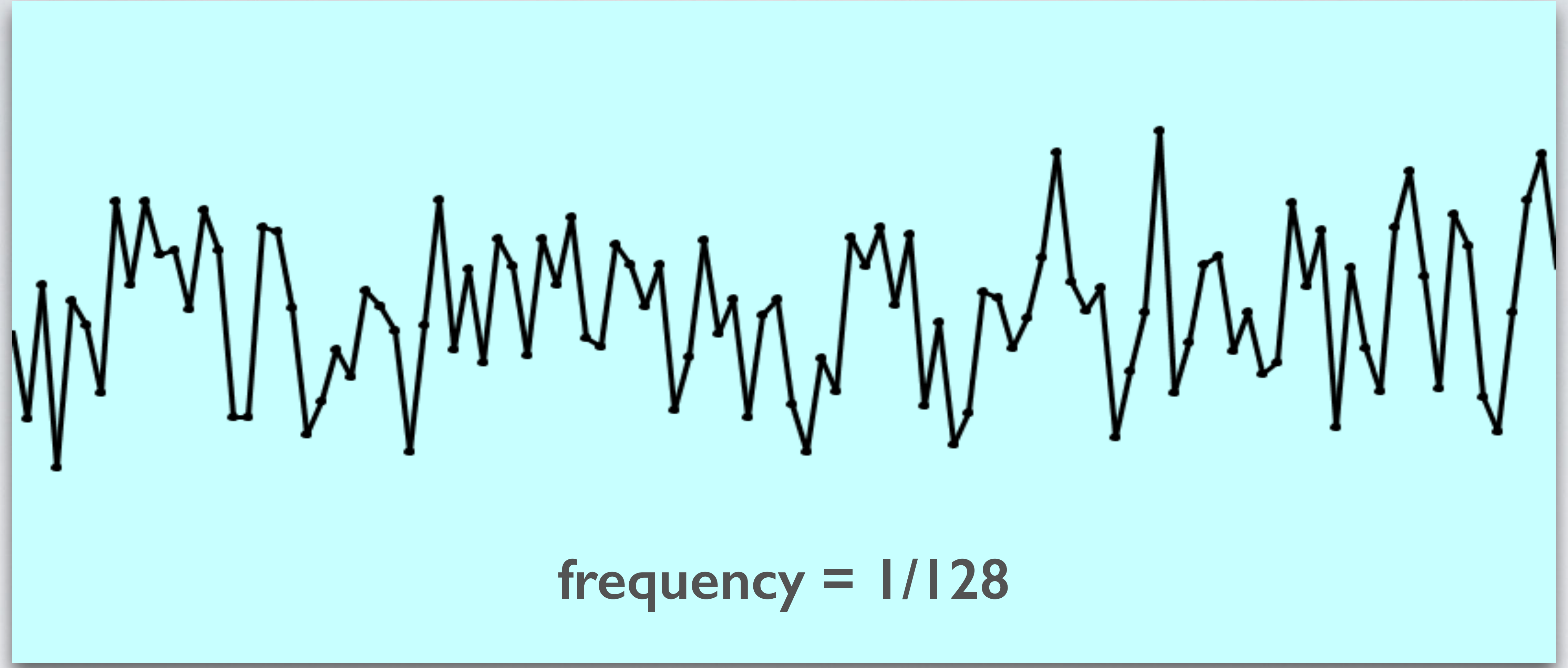

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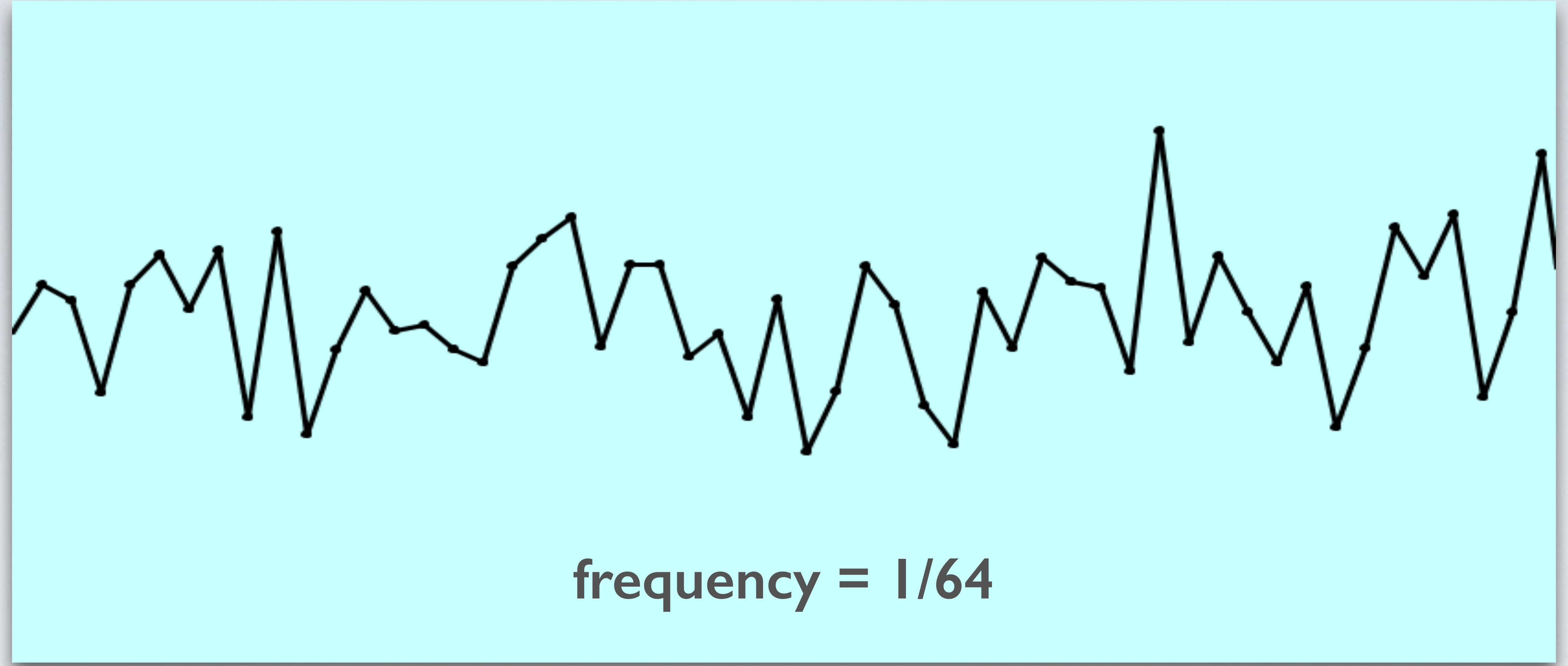

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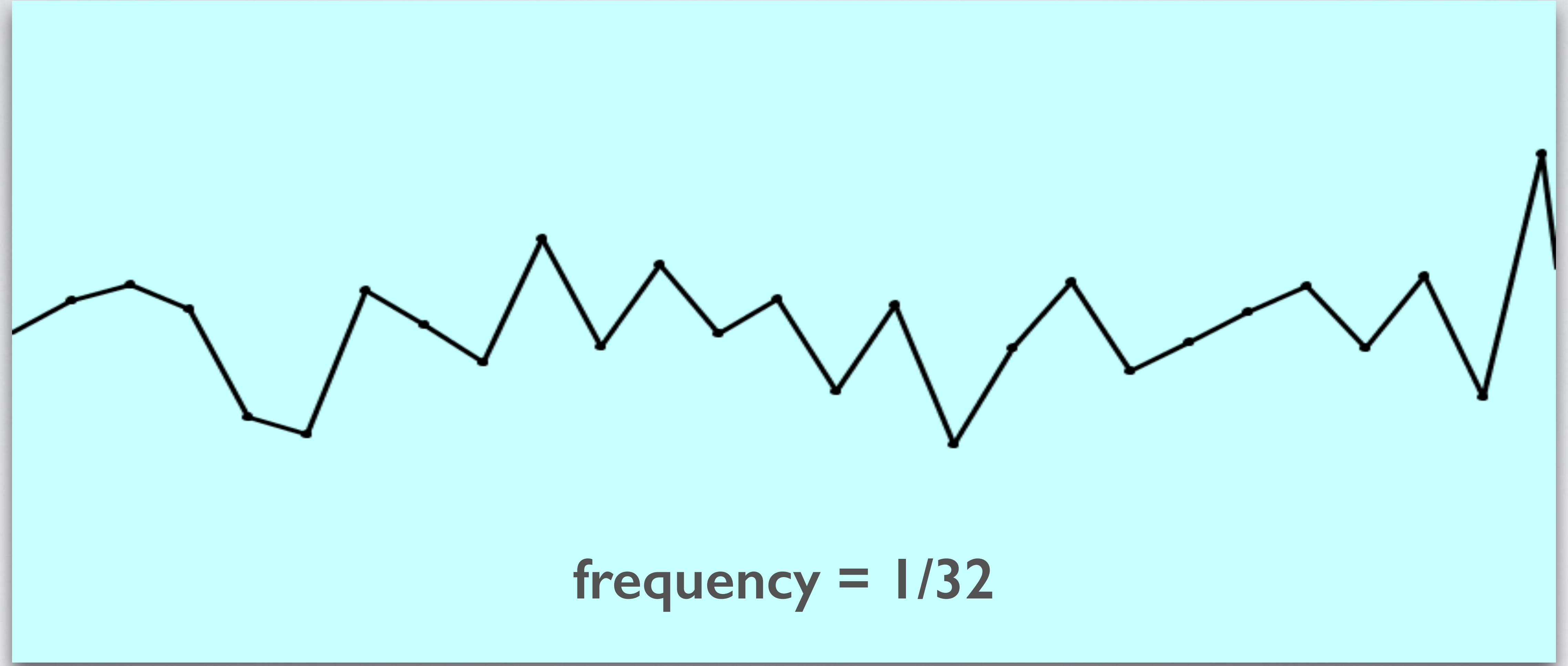

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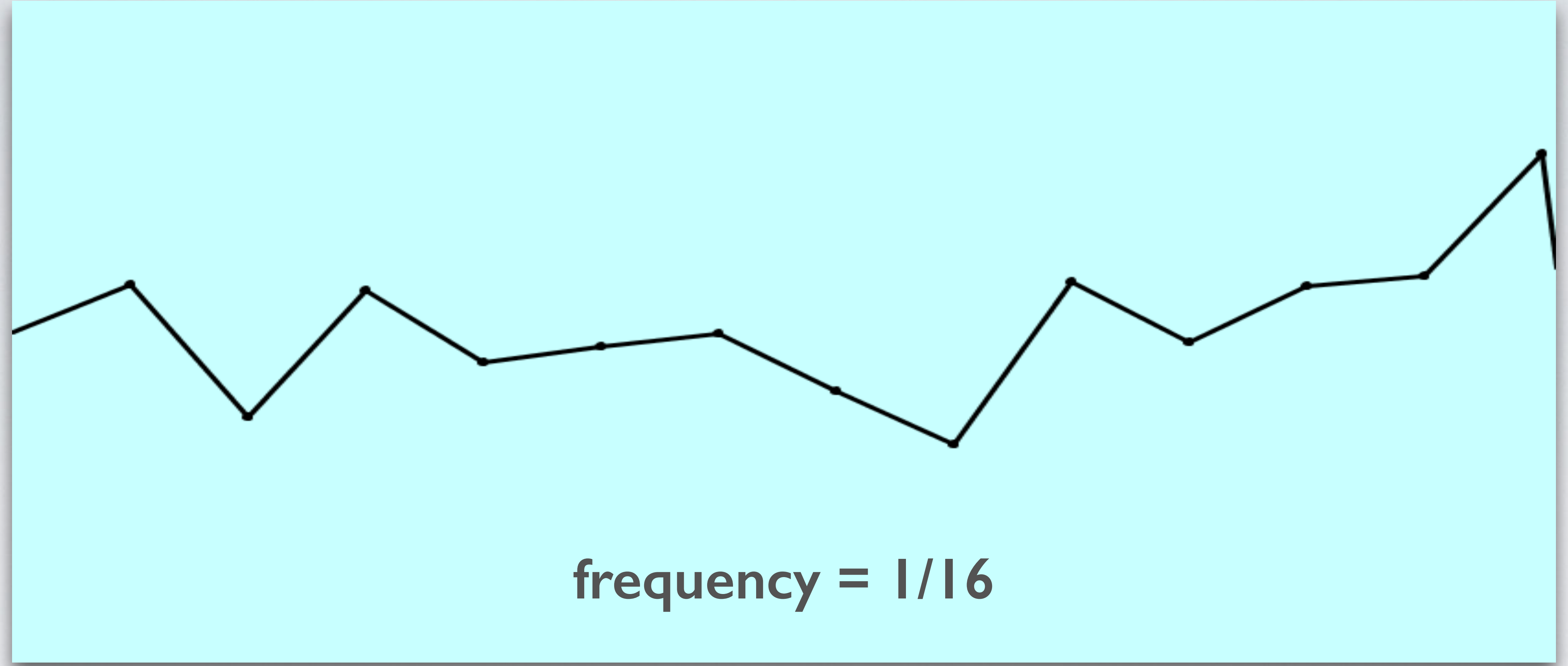

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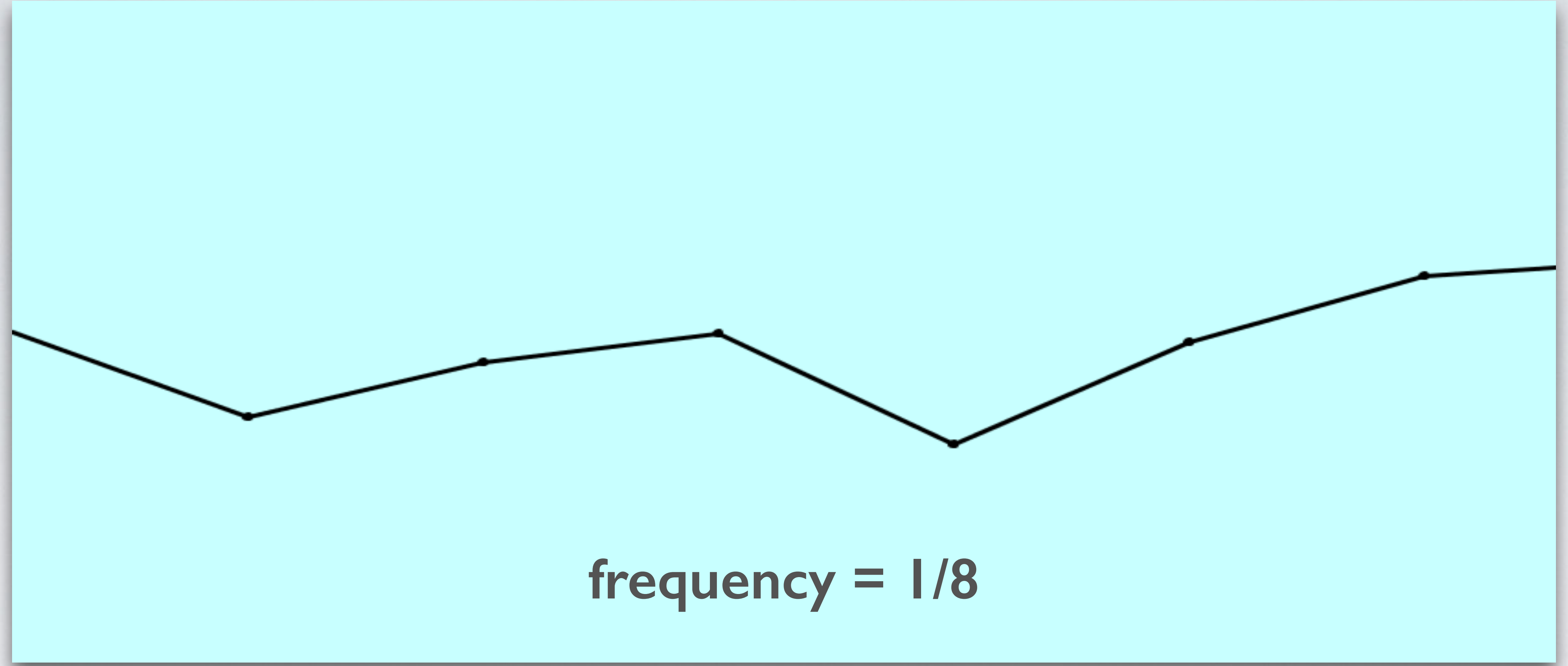

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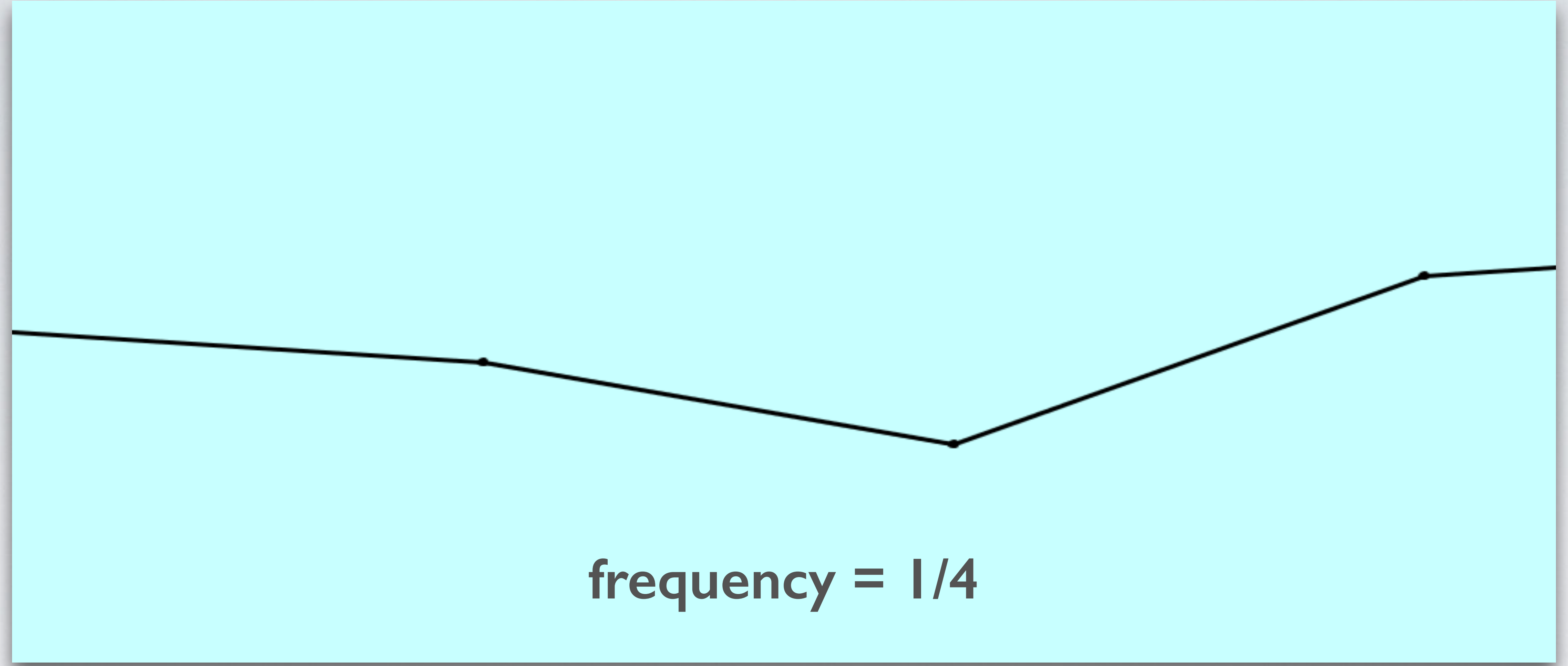

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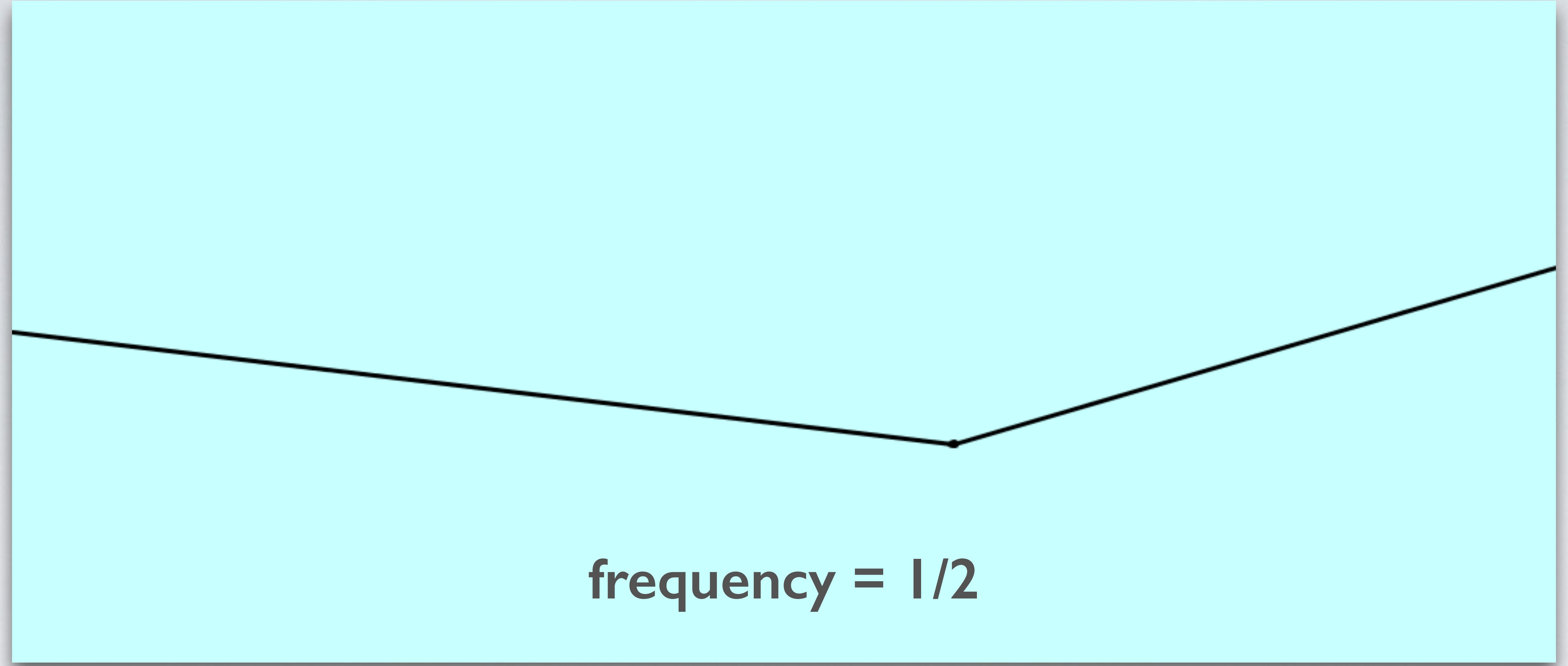

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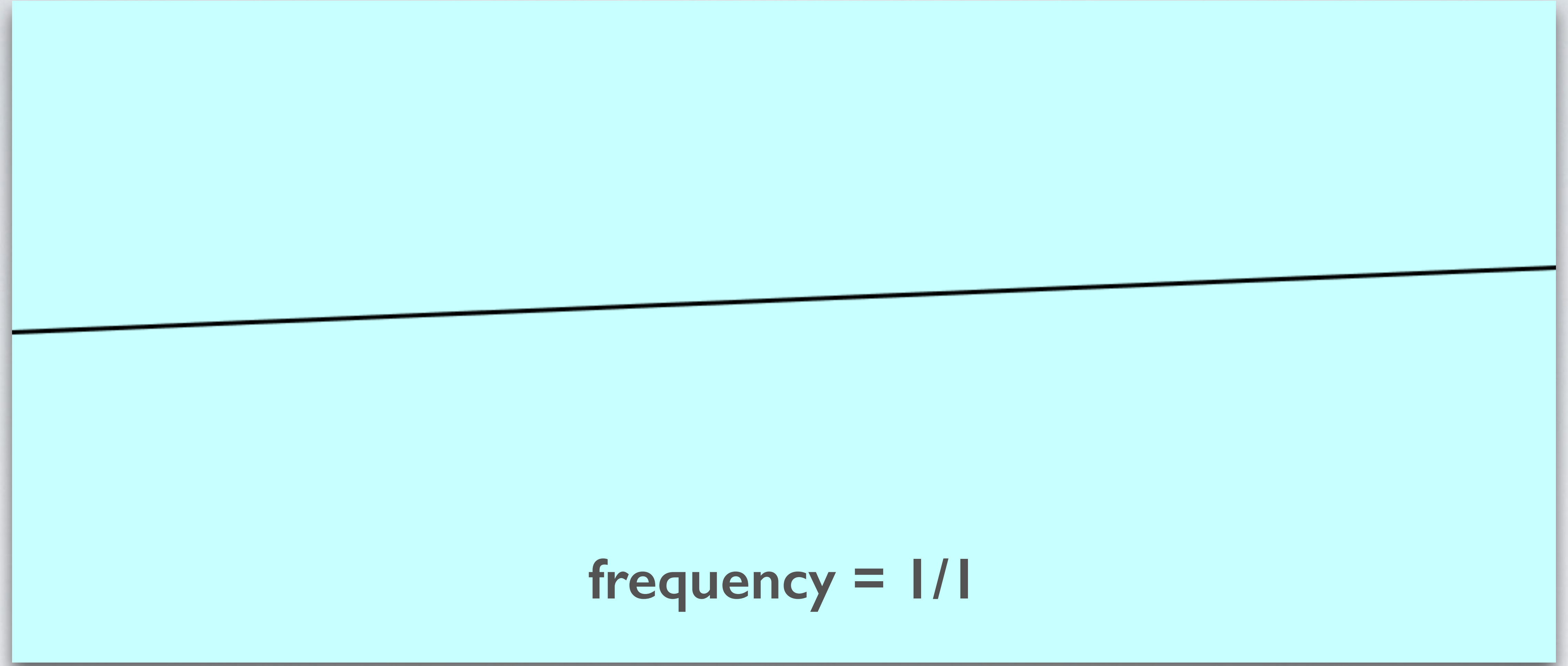

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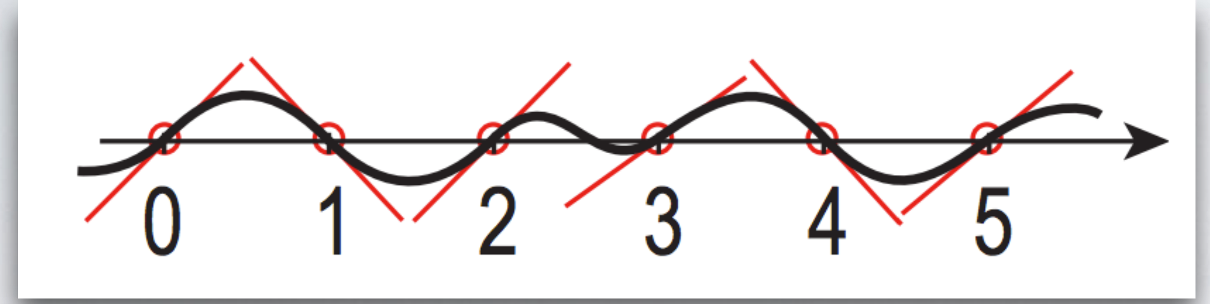
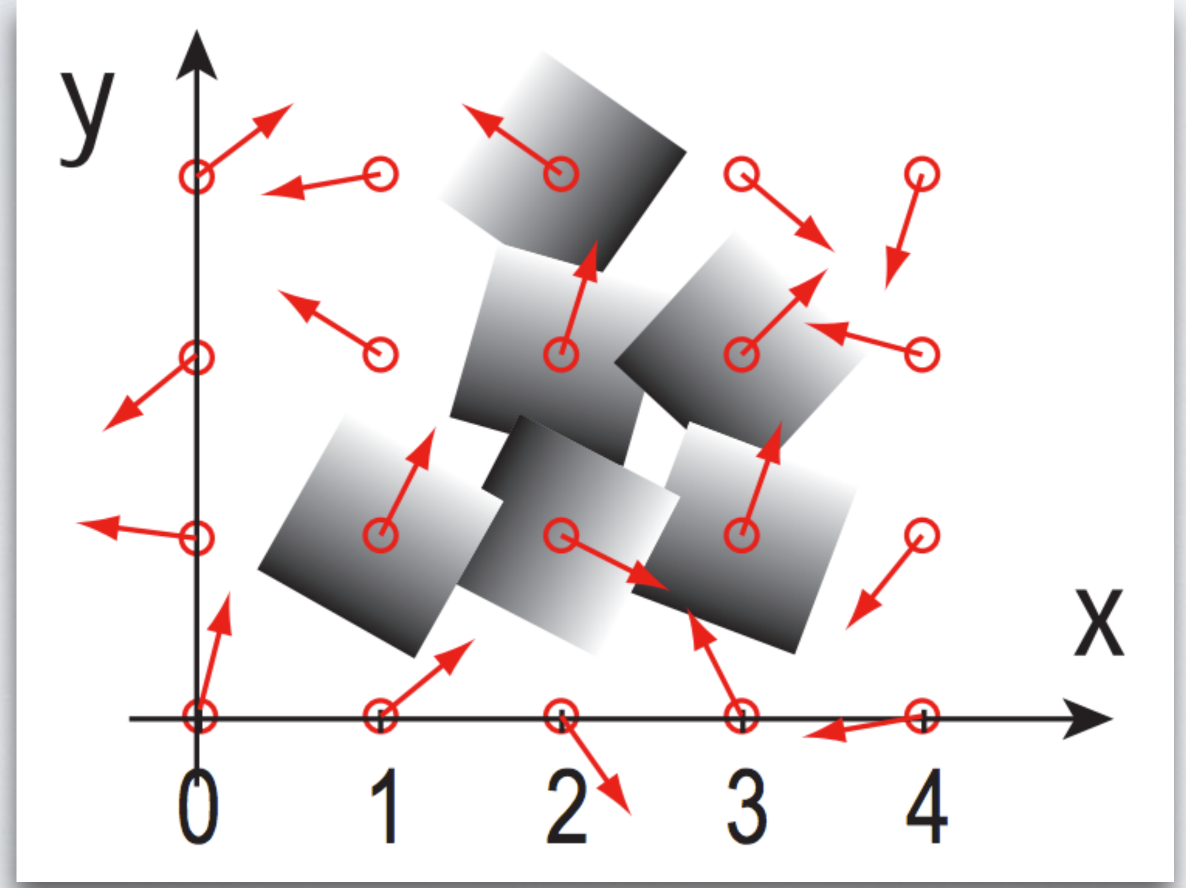
PERLIN NOISE

Ken Perlin (source)

- Can we do better than value noise?
- Rather than defining a value at each sample point, we can define a gradient.
- Invented by Ken Perlin (1983), frustrated with the "machine-like" look of computer graphics
- Won an academy award for technical achievement!

PERLIN NOISE

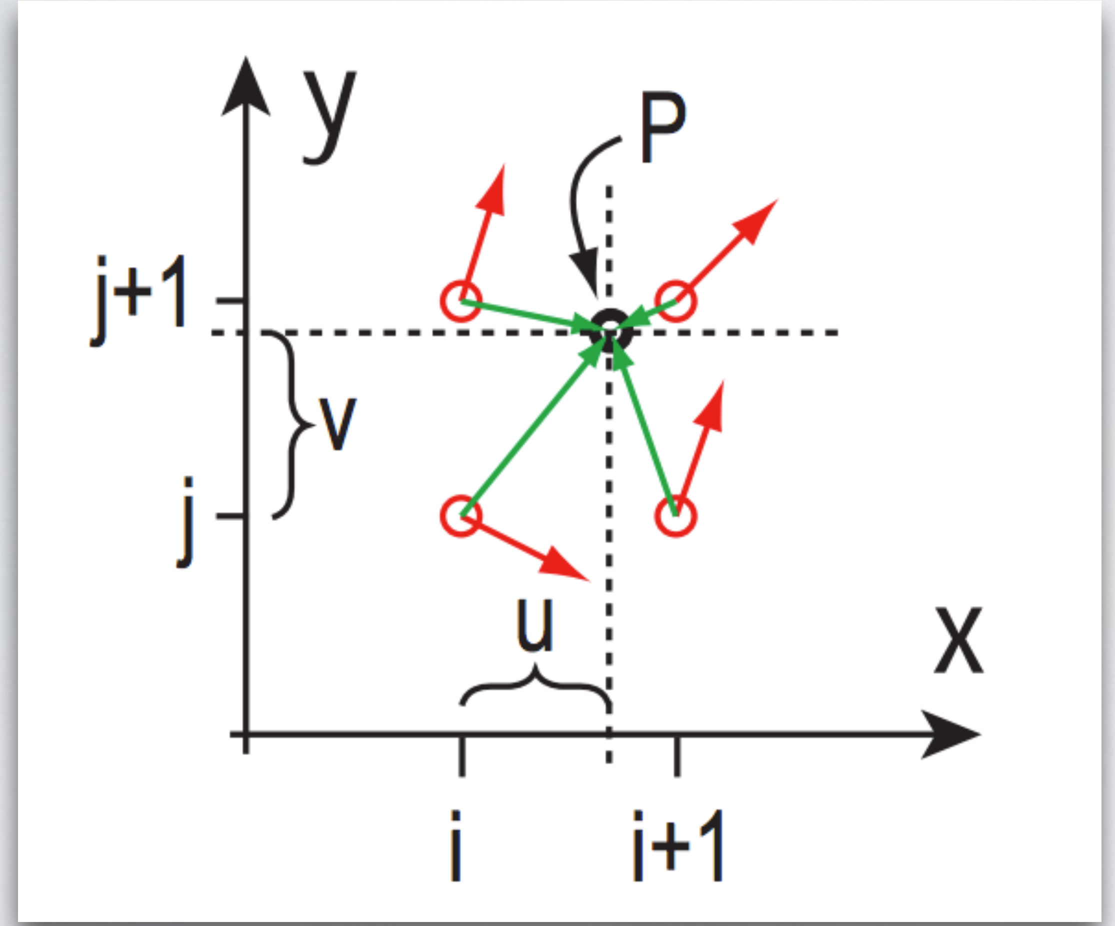




Stephan Gustavson (source)

- Begin by defining a gradient, rather than a value at each integer point on the lattice.
- Any selection of gradients will do, as long as they are well-distributed.
- Perlin recommends vectors to each of the edges of a unit square / cube.

PERLIN NOISE

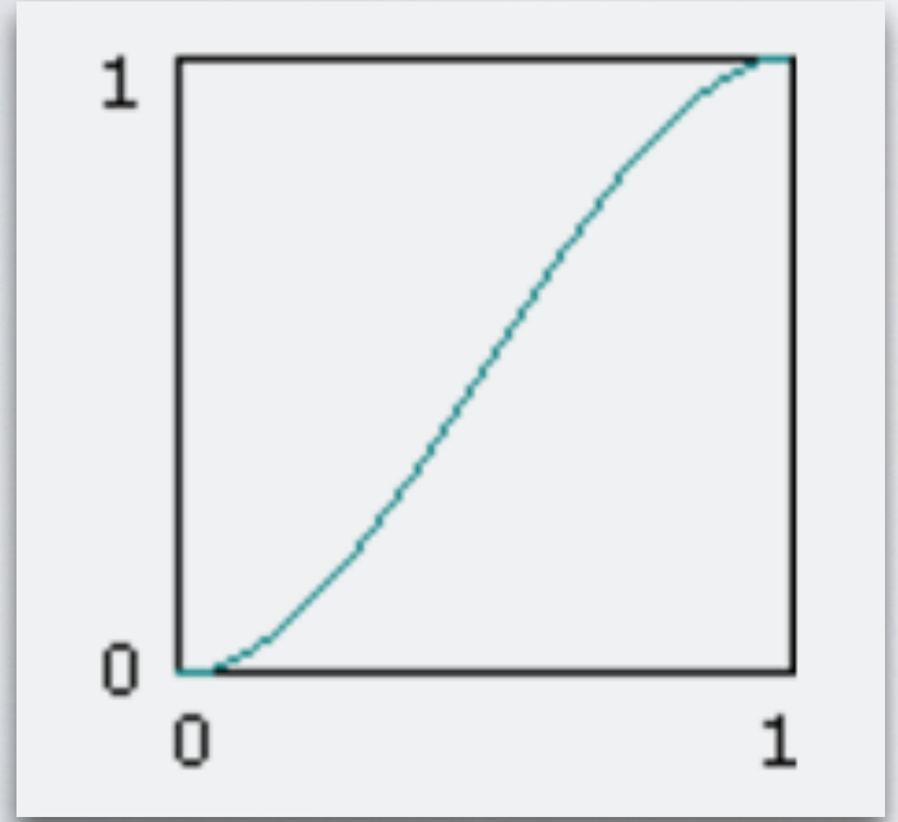


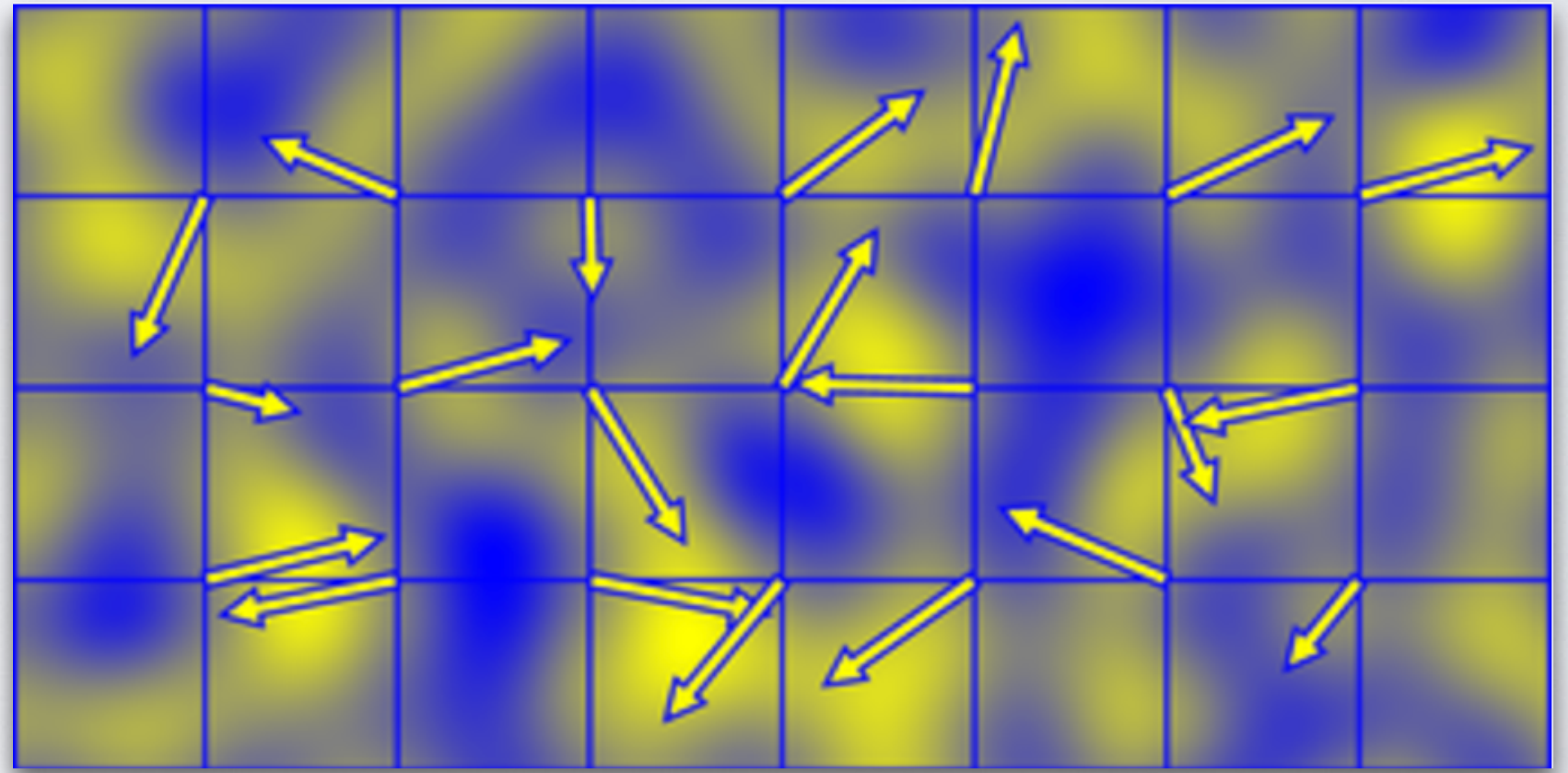
Stephan Gustavson (source)

- Next calculate the **distance vectors:** (P - V) for each surrounding lattice point V.
- For each surrounding lattice point, **influence_vector = dot(gradient_vector, distance_vector)**
- Interpolate between all the influence vectors to get your final value.

PERLIN NOISE

- Rather than just using linear interpolation, we can use a fade function.
- new_t = $6t^5 - 15t^4 + 10t^3$





Boojum (source)

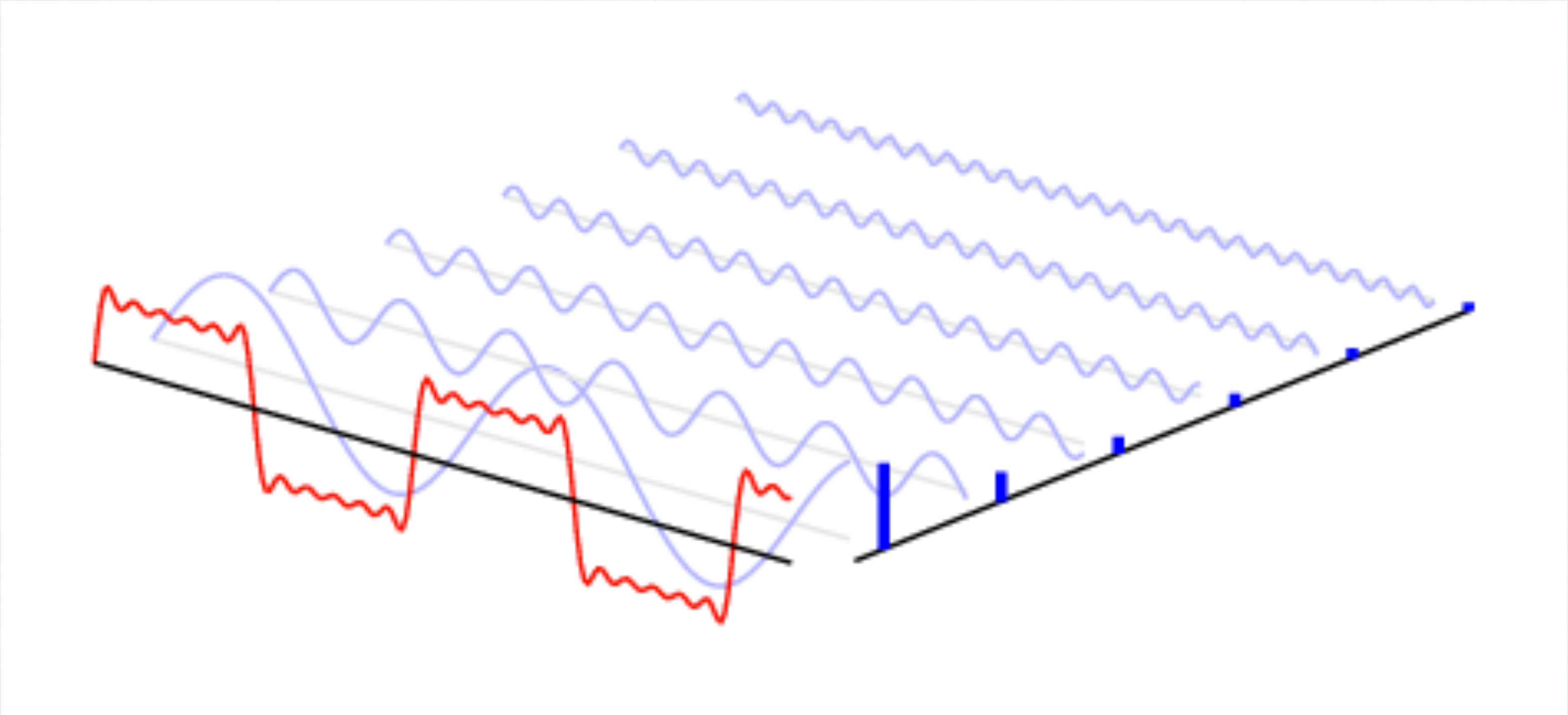
MANY, MANY METHODS

- Main types of noise generation approaches
  - Lattice noise (value or gradient)
    - Interpolates or convolutes values and/or gradients defined on an integer lattice
  - Explicit noise
    - Generate values in a preprocess step and store it. (Not strictly procedural)
  - Sparse convolution noise
    - Sum contributions from randomly positioned and weighted kernel functions.

DESCRIBING NOISE

COMPONENT FREQUENCIES

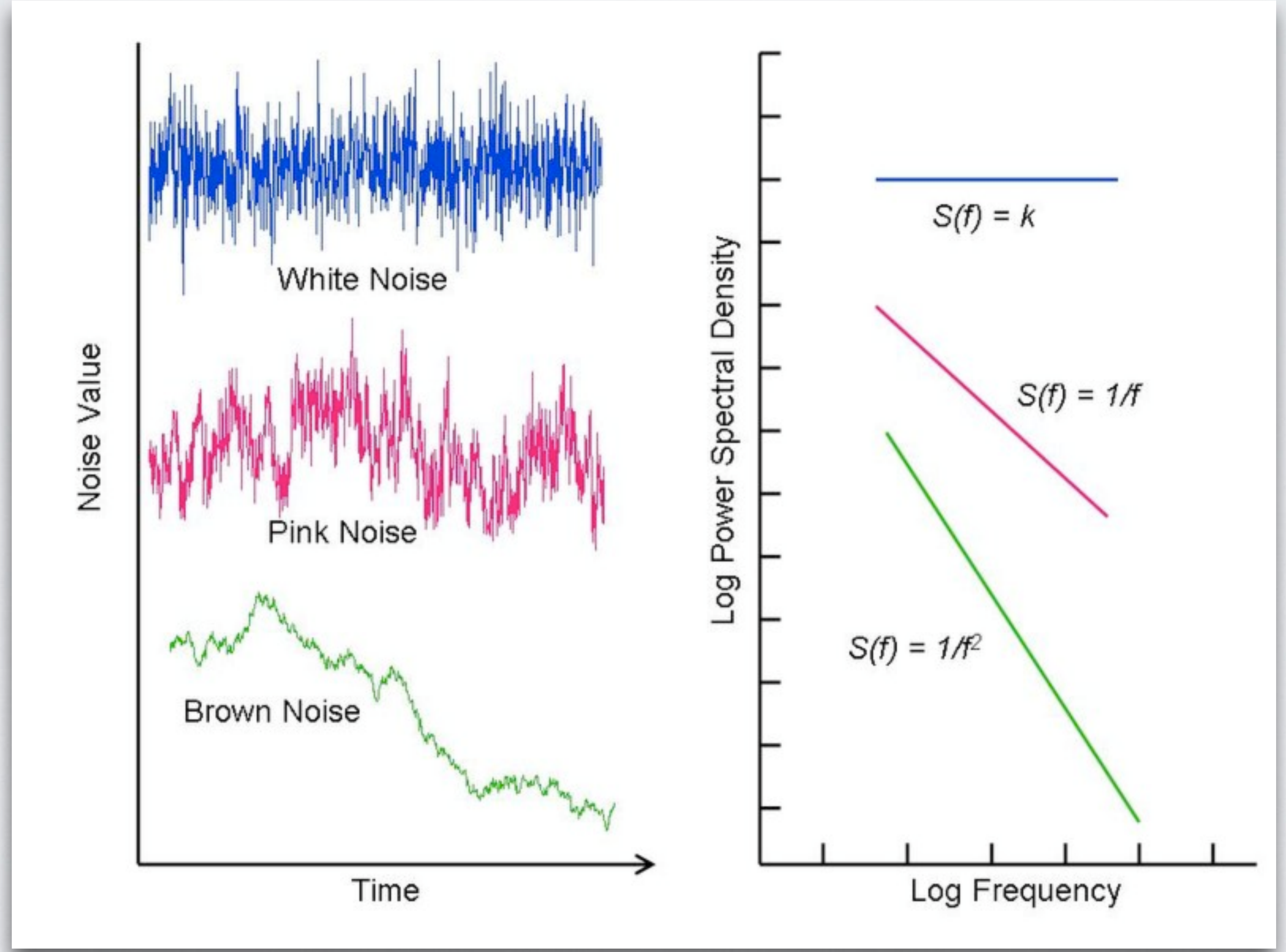
- Brief signal processing aside…
- Fourier transform insight: any function, or signal, can be decomposed simple component signals at different frequencies.
- Formally, noise functions are described by their *power spectrum*, the distribution of its energy among its different frequency components.



PFGPlots.net (source)

THE COLORS OF NOISE

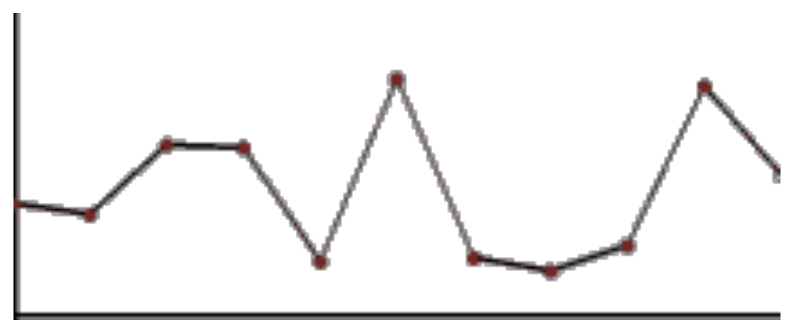
- Color describes component frequencies



inspirehep.net (source)

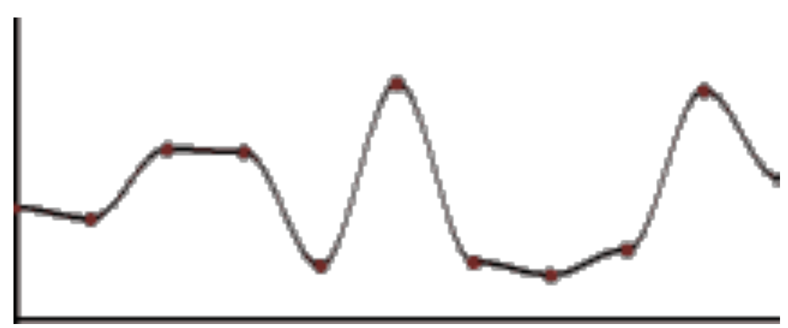
MODIFICATIONS

INTERPOLATION METHODS



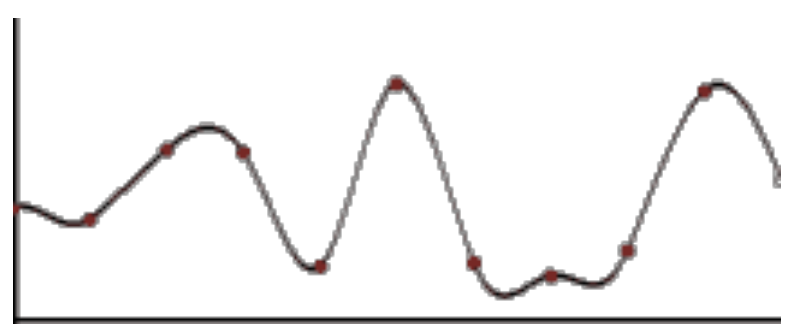
linear

```
float linear_interpolate(float a, float b, float t) {
  return a * (1 - t) + b * t;
}
```



cosine

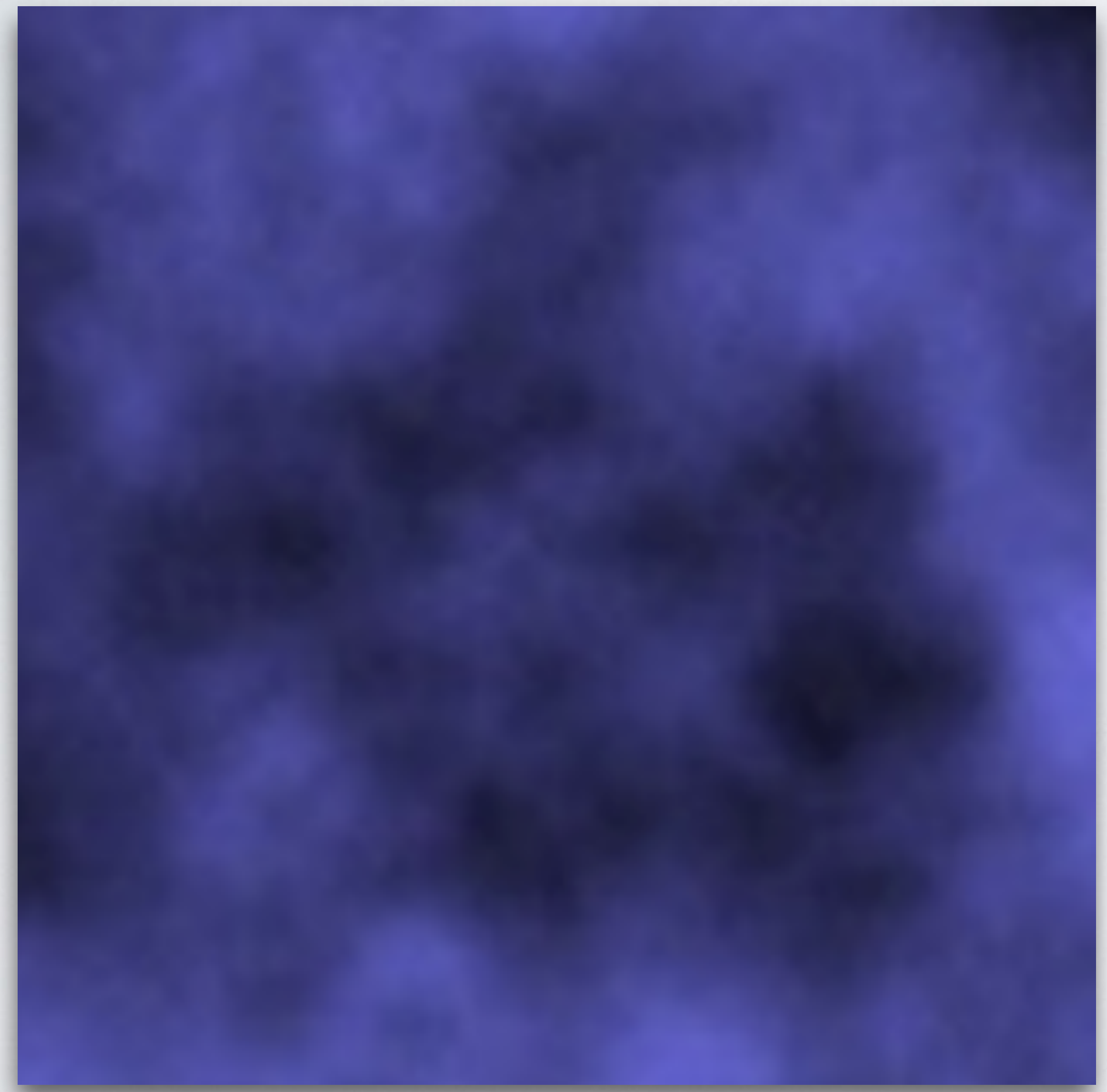
```
float cosine_interpolate(float a, float b, float t) {
  float cos_t = (1 - cos(t * M_PI)) * 0.5f;
  return linear_interpolate(a, b, cos_t);
}
```



cubic

```
float cubic_interpolate(float v0, float v1, float v2, float v3, float t) {
  float A = (v3 - v2) - (v0 - v1);
  float B = (v0 - v1) - P;
  float C = v2 - v0;
  float D = v1;
  return A * pow(t, 3) + B * pow(t, 2) + C * t + D;
}
```

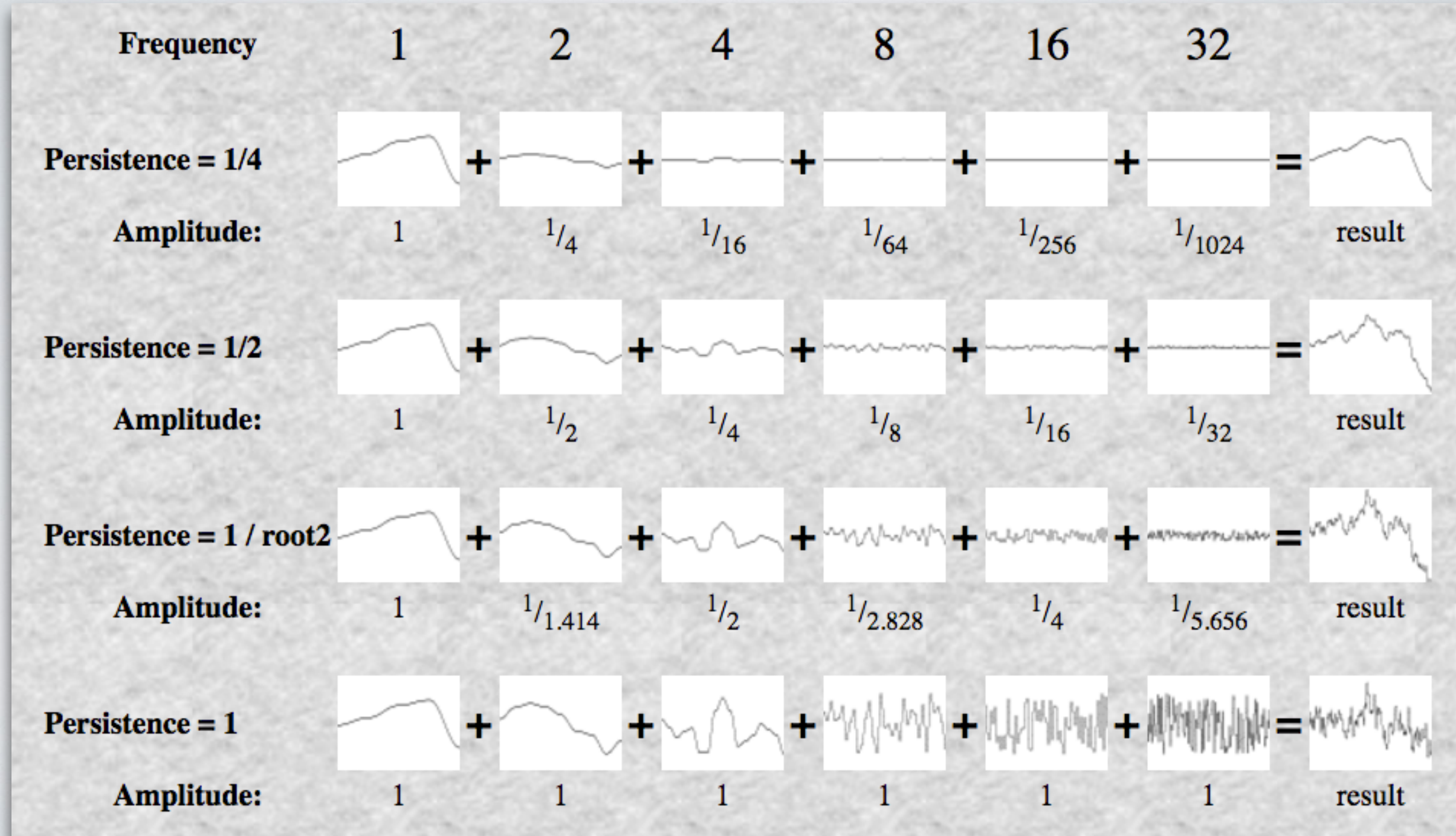
MULTI-OCTAVE NOISE (FBM)



Hugo Elias (source)

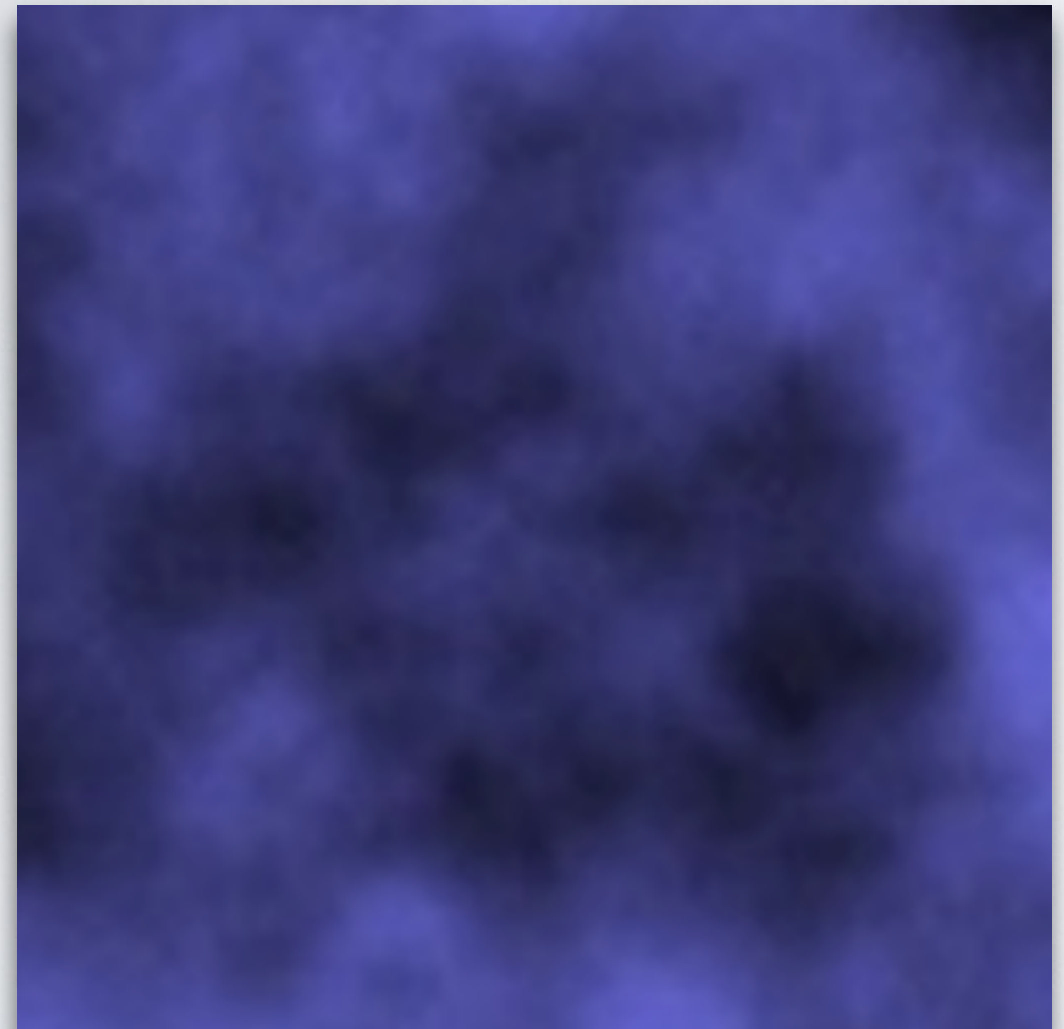
- Observation: organic patterns have multiple levels of detail
- Idea: sum multiple noise functions ("*octaves*") at different frequencies and amplitudes.
- AKA "fractional brownian motion"
- Octave contributions are modulated using
  - **frequency**: sample rate
  - **persistance:** decay of amplitude as frequency increases.

MULTI-OCTAVE NOISE (FBM)



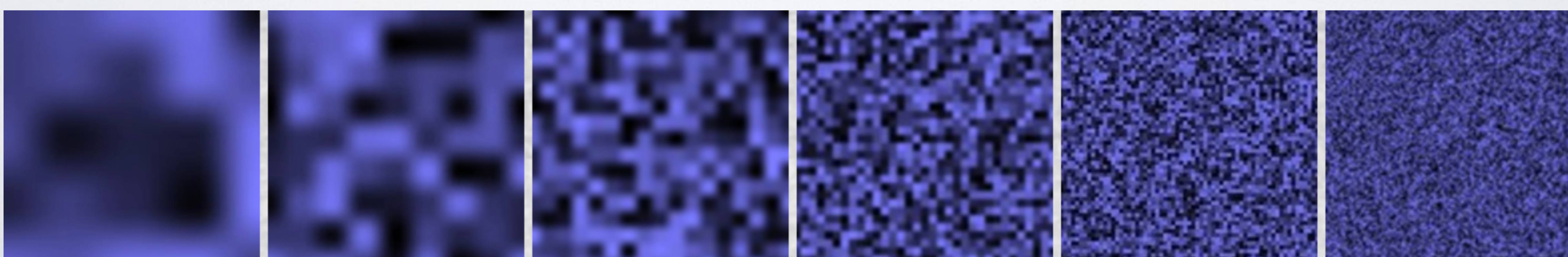
Hugo Elias (source)

MULTI-OCTAVE NOISE (FBM)



Applicable in n dimensions!

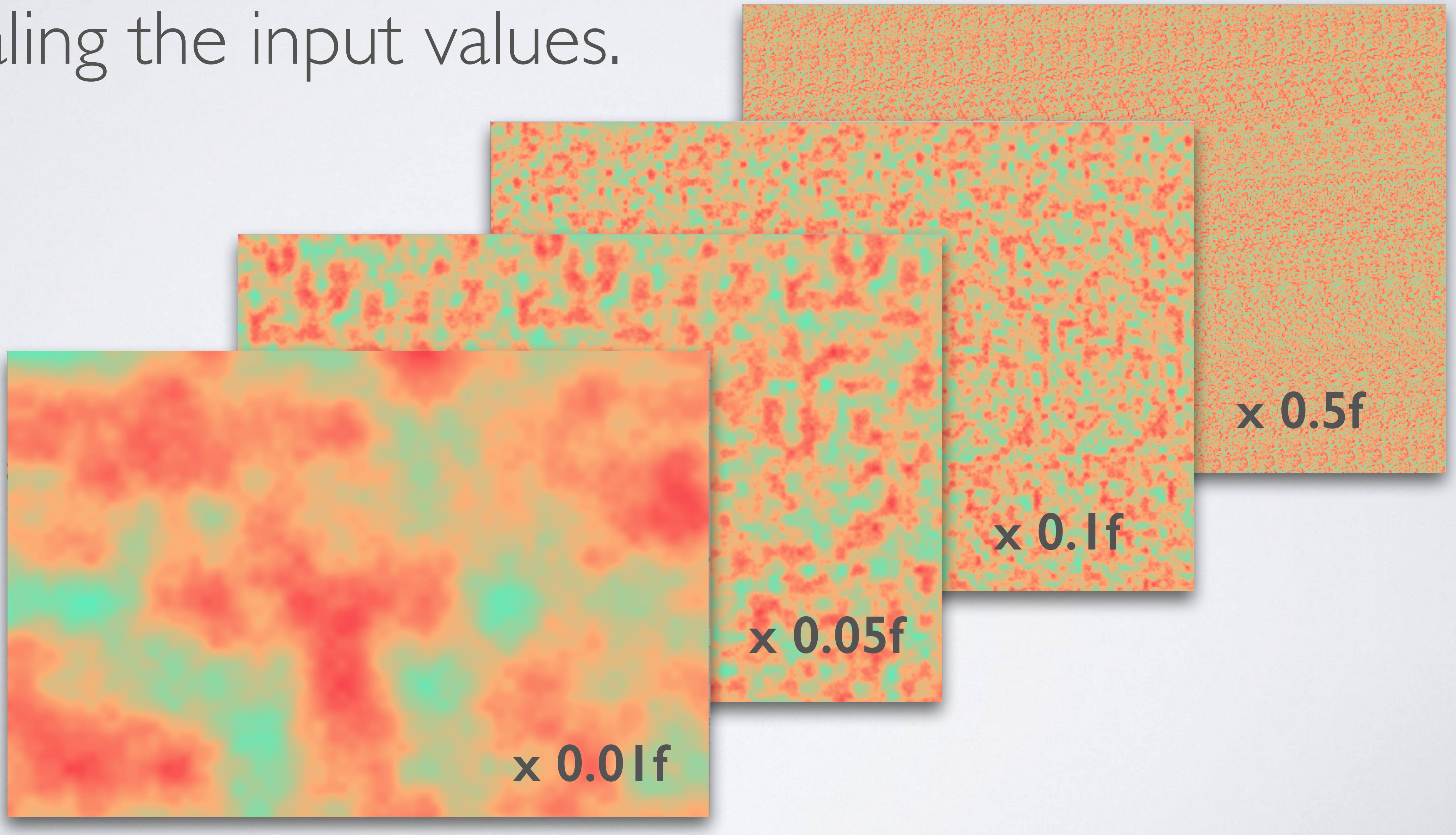
```
PerlinNoise2d(float x, float y) {
  float total = 0;
  float persistence = 1 / 2.0f;

  // Loop for some number of octaves
  for (int i = 0; i < N_OCTAVES; ++i) {
    float frequency = pow(2, i);
    float amplitude = pow(persistence, i);

    // Accumulate contributions in total
    total += sampleNoisei(x, y, frequency);
  }
  return total;
}
```



Hugo Elias (source)

"ZOOMING IN"

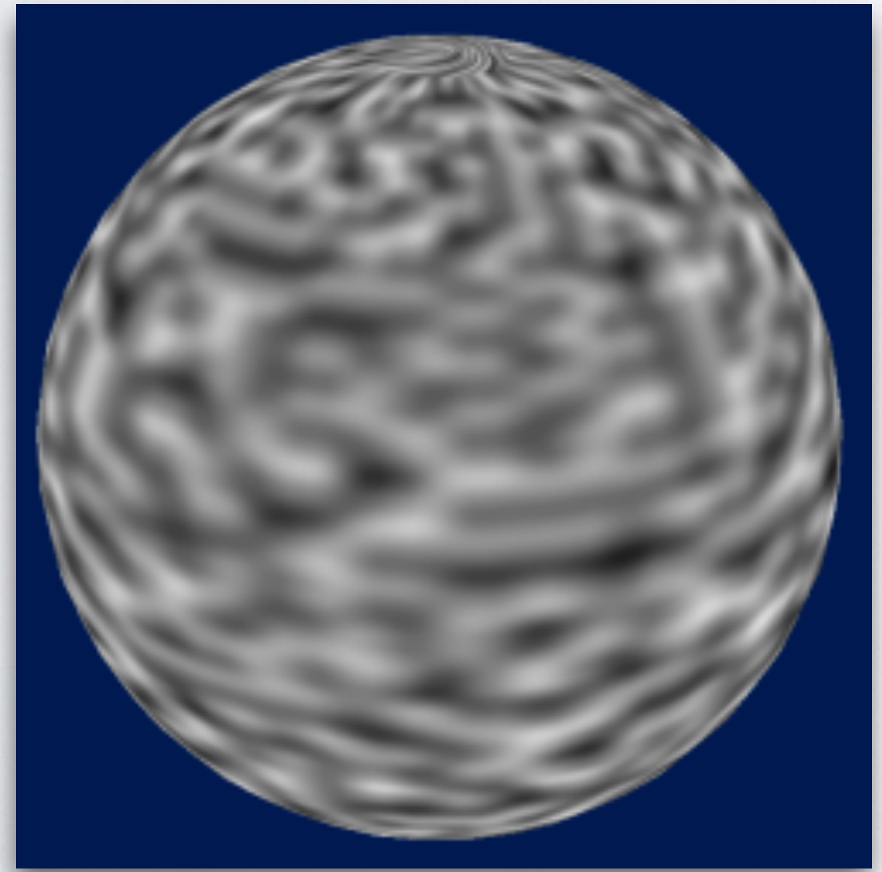
You can adjust the feature size of your noise output by scaling the input values.



SOLID TEXTURING

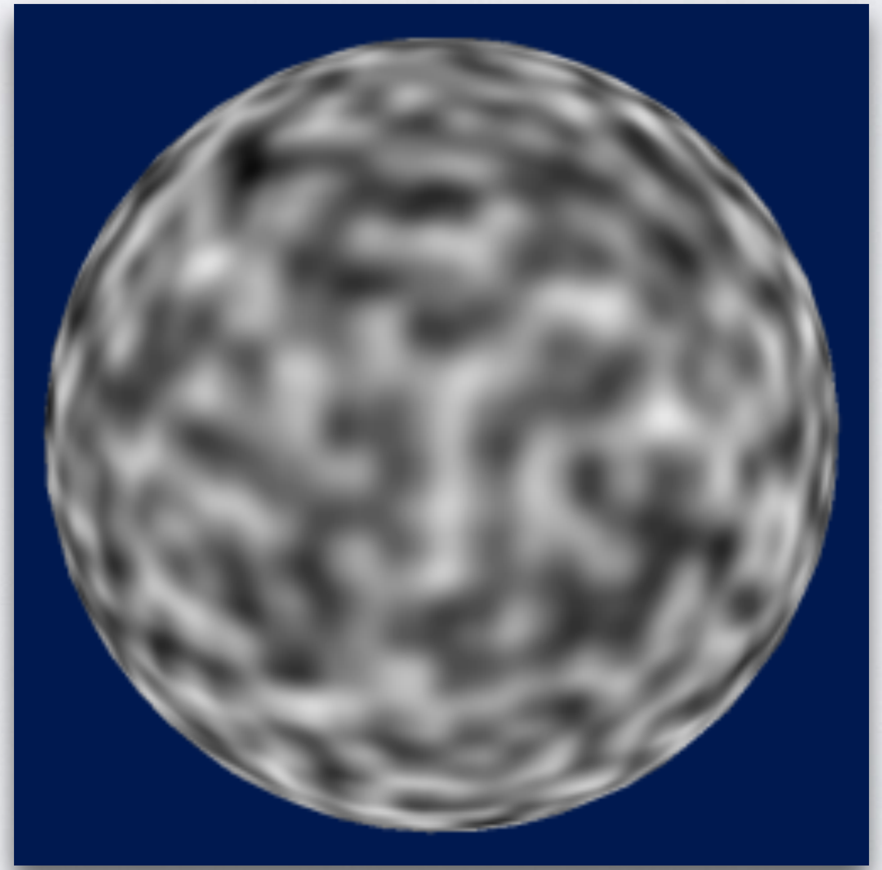
Avoid mapping problems that arise from applying a 2D texture to a 3D surface.

2D



Stephan Gustavson (source)

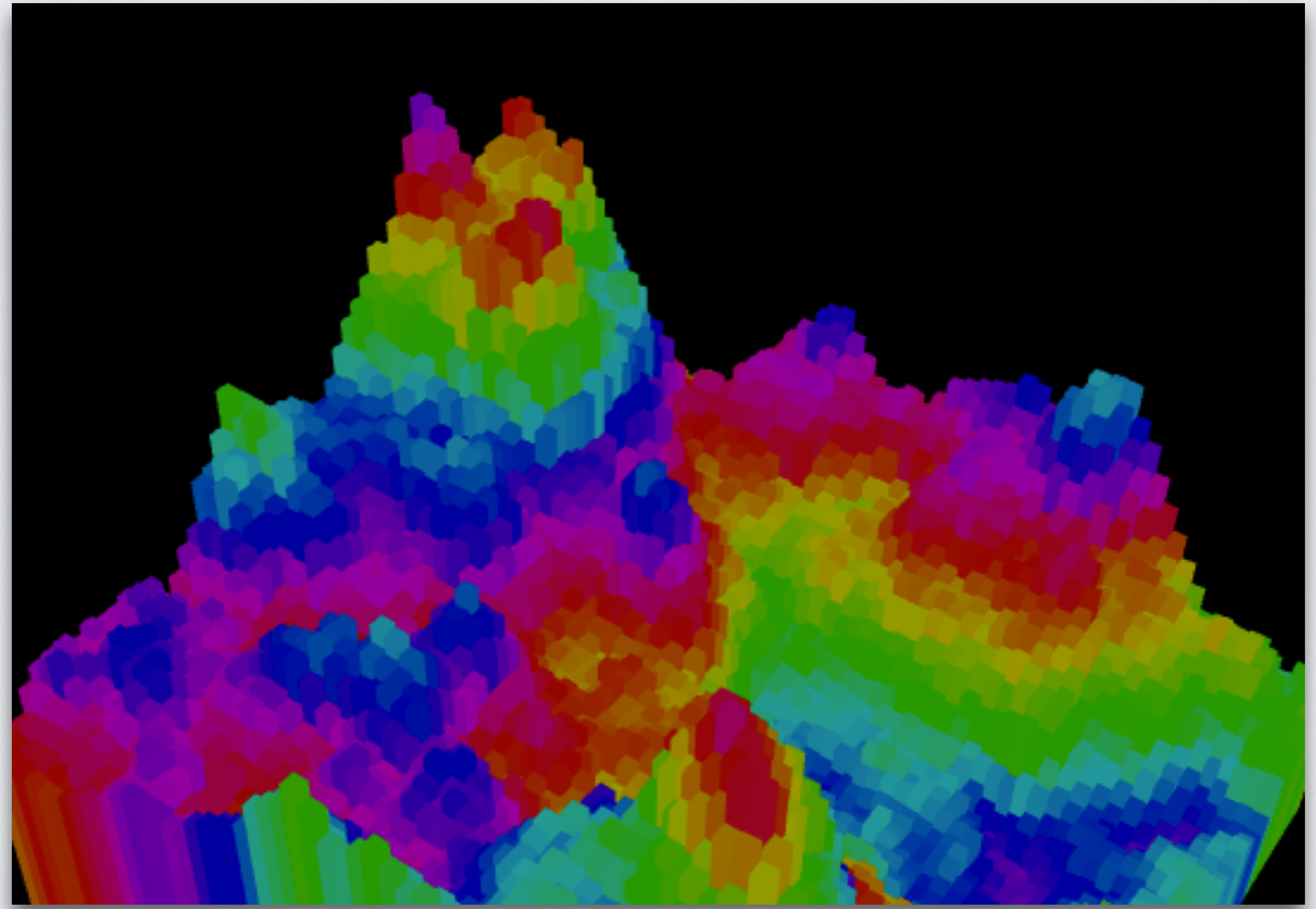
3D



APPLICATIONS

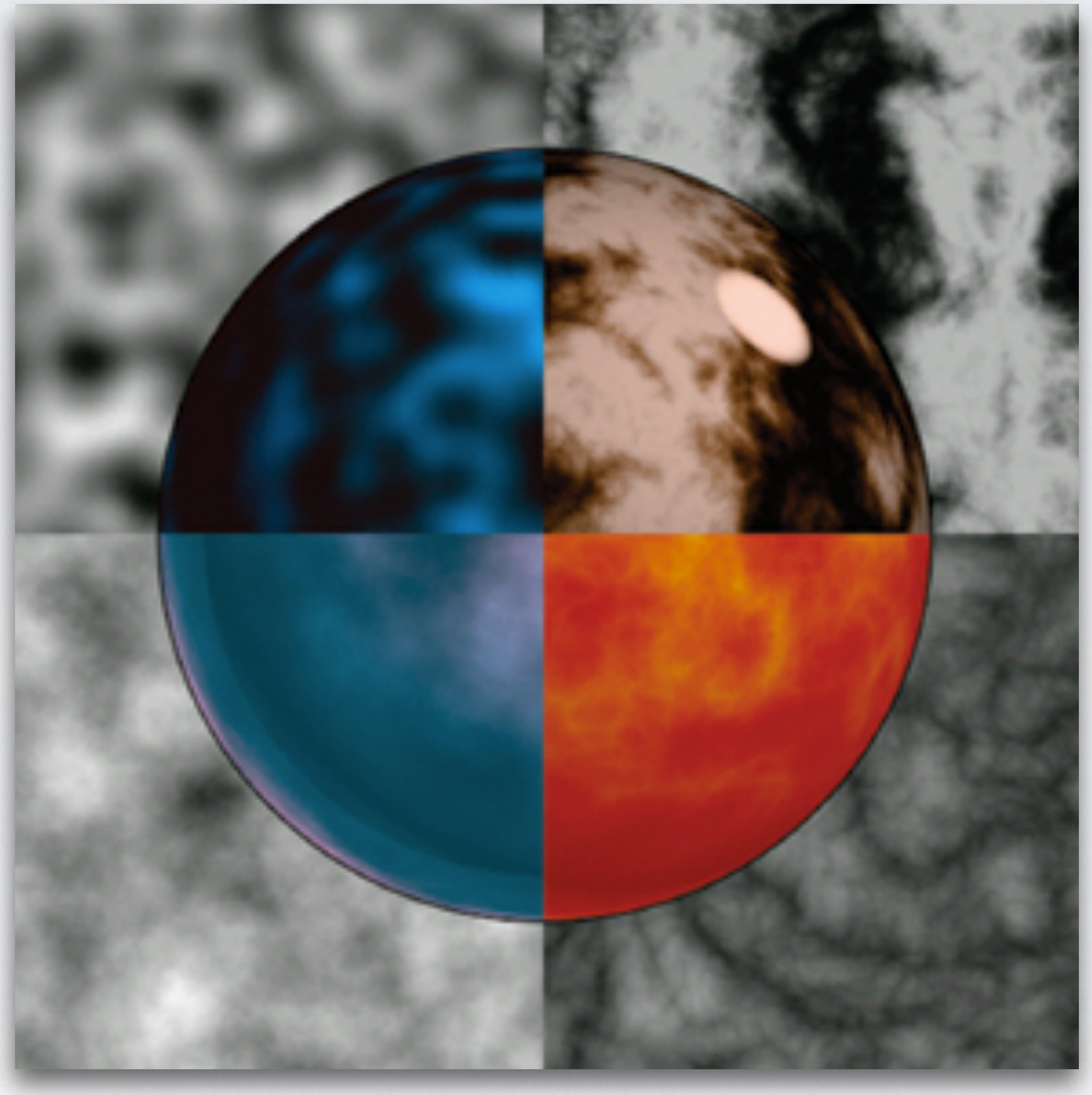
HEIGHT / DISPLACEMENT

- Use noise as a displacement along normals to make terrain.



COLOR

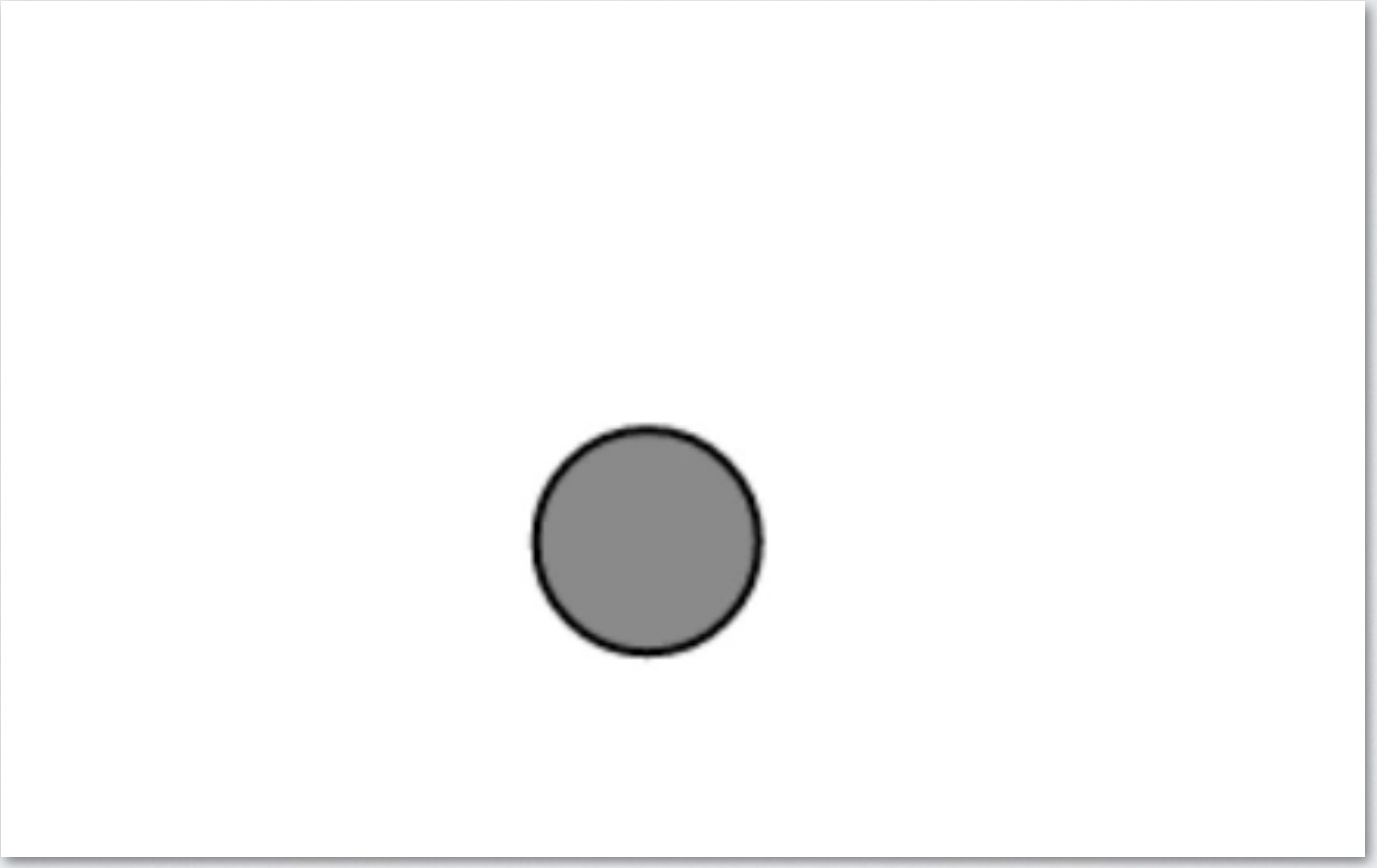
- Map noise output to color, gradient or bins.



Ken Perlin (source)

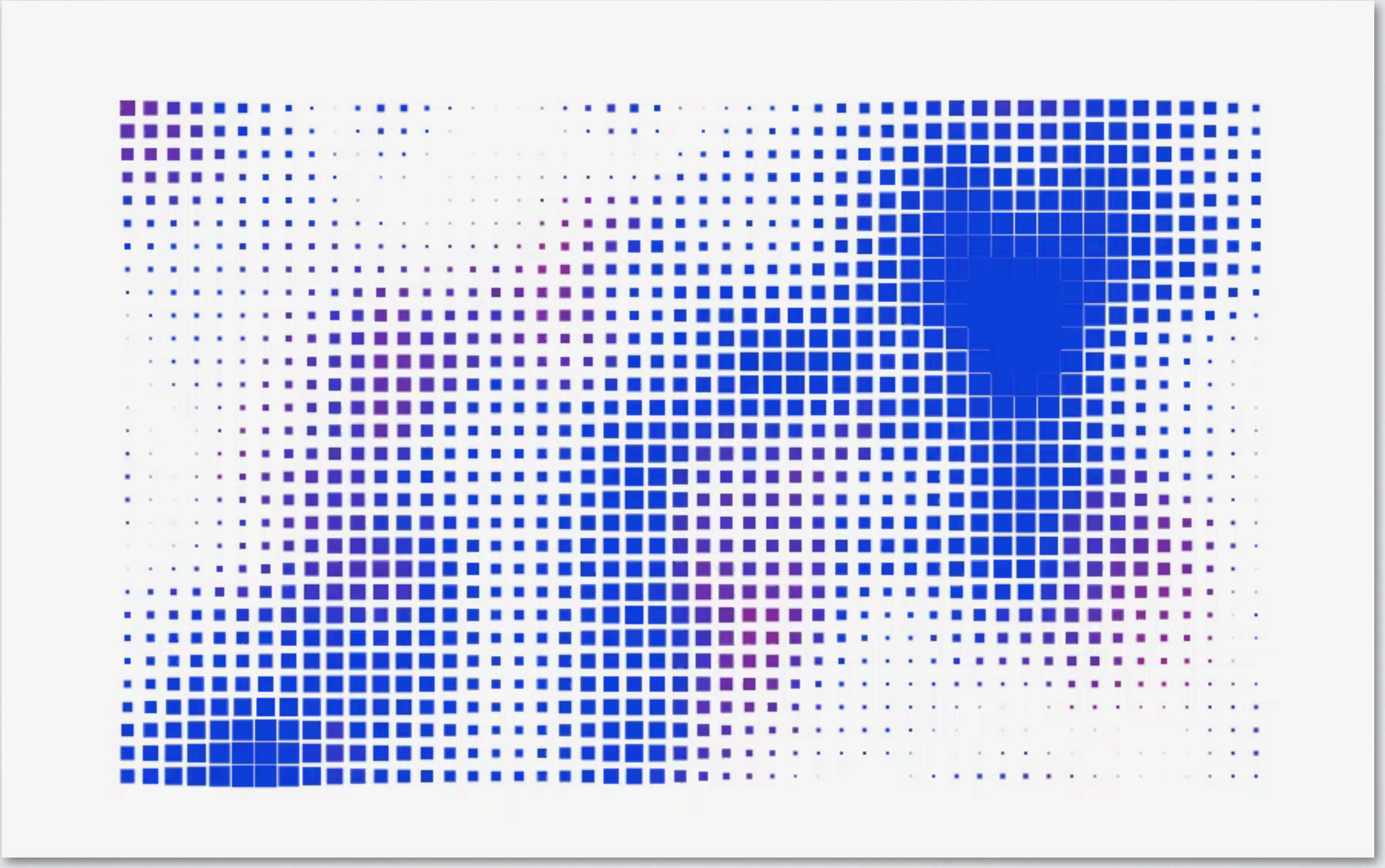
ANIMATION

- Use noise as a velocity or offset for natural movement



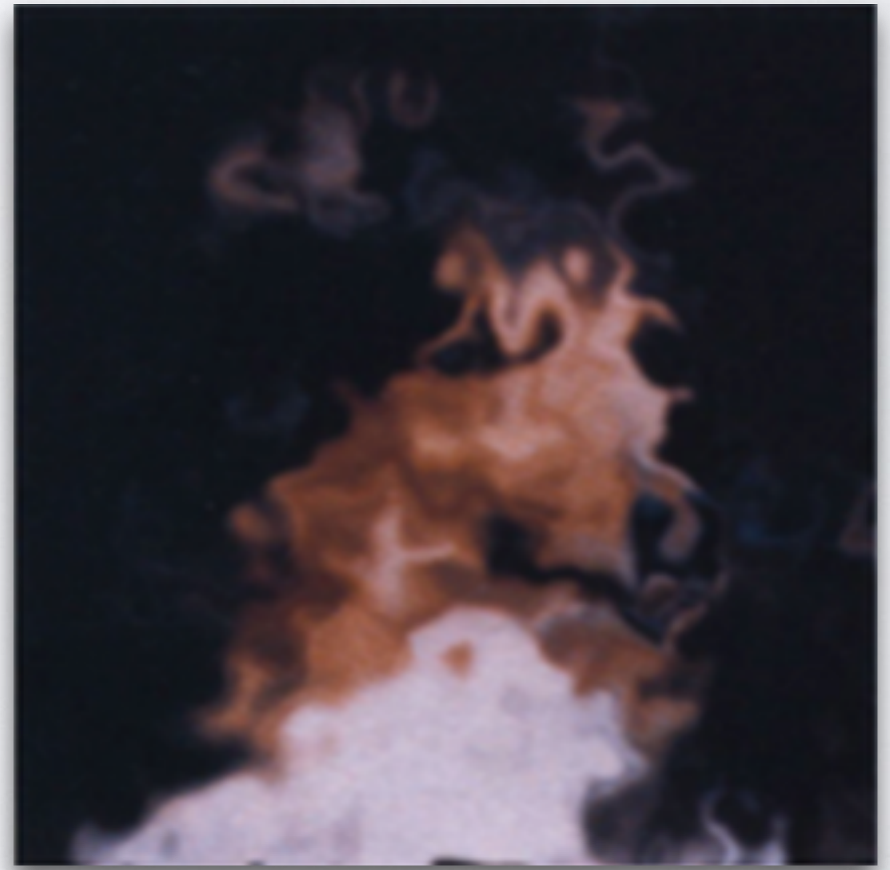
ANIMATION

- Use time as an extra parameter to create ripples



PERTURBATION

- Offset regularly-spaced coordinates (eg. image-texture reads) with noise to create a turbulent effect.



Ken Perlin (source)

IN SUMMARY

- We characterize noise by its power spectrum — component frequencies
- Many generation methods
  - Directly generating pseudo-random noise
  - using a value or gradient lattice
- Ways to modify noise output
  - Sample at different frequencies
  - Add multiple noise functions together
  - Apply a smoothing function, modify interpolation
  - Scale input parameters to “zoom”

REFERENCES

- Papers
  - Original Perlin Noise
  - Improved Noise
  - Survey of Procedural Noise Techniques
- Noise explanations
  - Layman's intro to noise concepts
  - Gentle explanation of Perlin noise with reference code
  - Ken Perlin explains Perlin noise and its usage
  - Good explanations of both Perlin and Simplex noise
- Bonus
  - Some fbm value noise tips from IQ
  - Layman’s introduction to Fourier transformation

ASSIGNMENT

- Create an animated cloud using multi-octave noise.
- Displace a sphere vertices along normals using noise.
- Also apply noise based color patterns.
- All computation should be done in the shader!

Ken Hermann