Modified Noise for Evaluation on Graphics Hardware

Marc Olano

Computer Science and Electrical Engineering
University of Maryland, Baltimore County

Graphics Hardware 2005

Outline

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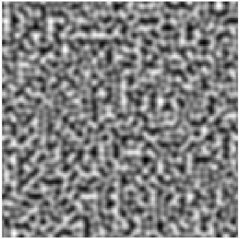
Why Noise?

- Introduced by [Perlin, 1985]
  - Heavily used in production animation
  - Technical Achievement Oscar in 1997
- "Salt," adds spice to shaders



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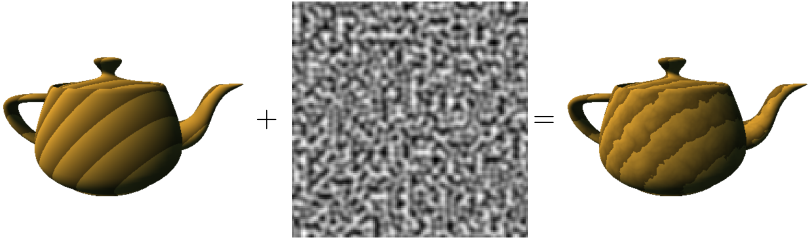
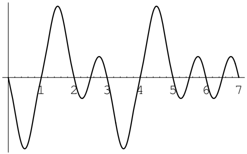


Noise Characteristics

- Random
    - No correlation between distant values
- Repeatable/deterministic
    - Same argument always produces same value
- Band-limited
    - Most energy in one octave (e.g. between f & 2f)



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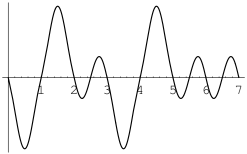

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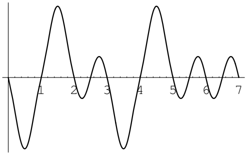
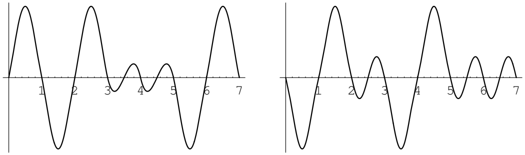


Gradient Noise

- Original Perlin noise [Perlin, 1985]
- Perlin Improved noise [Perlin, 2002]
- *Lattice* based
    - Value=0 at integer lattice points
    - Gradient defined at integer lattice
    - Interpolate between
- 1/2 to 1 cycle each unit



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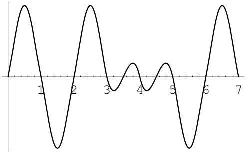

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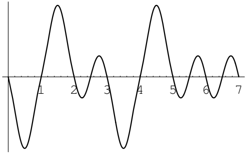

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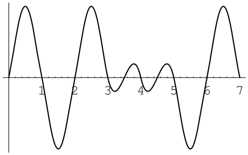

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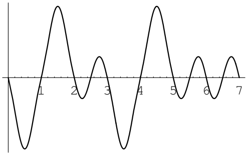

Improved

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- Lattice based
  - Value defined at integer lattice points
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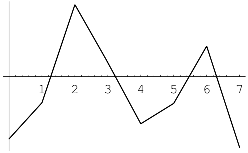
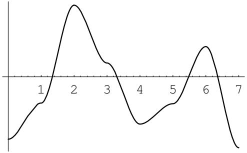
  - Significant low-frequency content
- Easy hardware implementation with lower quality



Linear Interp



Cubic Interp

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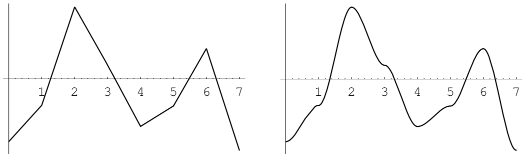

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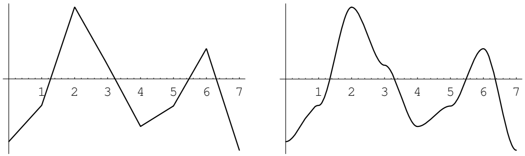

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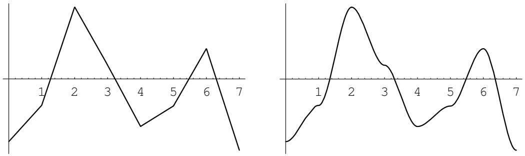


Linear Interp   Cubic Interp

Hardware Noise

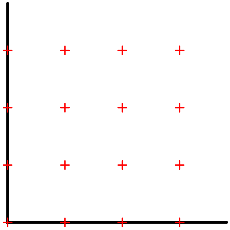
- Value noise
  - PixelFlow [Lastra et al., 1995]
  - *Perlin Noise* Pixel Shaders [Hart, 2001]
  - Noise textures
- Gradient noise
  - Hardware [Perlin, 2001]
  - Complex composition [Perlin, 2004]
  - Shader implementation [Green, 2005]

Noise Details

- Subclass of *gradient noise*
  - Original Perlin
  - Perlin Improved
  - All of our proposed modifications

Find the Lattice

- Lattice-based noise: must find nearest lattice points
- Point $\vec{p} = (\vec{p}^x, \vec{p}^y, \vec{p}^z)$
- has integer lattice location
$\vec{p}_i = (\lfloor \vec{p}^x \rfloor, \lfloor \vec{p}^y \rfloor, \lfloor \vec{p}^z \rfloor) = (X, Y, Z)$
- and fractional location in cell
$\vec{p}_f = \vec{p} - \vec{p}_i = (x, y, z)$



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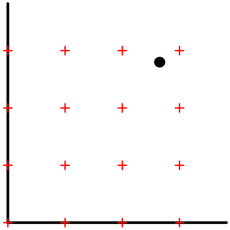

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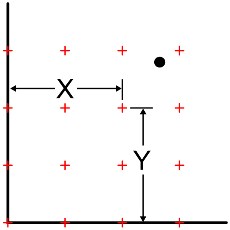

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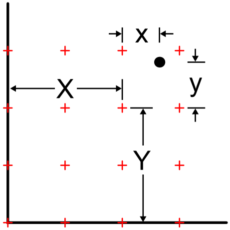

Gradient

- Random vector at each lattice point is a function of $\vec{p}_i$

$$g(\vec{p}_i)$$

- A function with that gradient

$$\begin{aligned} grad(\vec{p}) &= g(\vec{p}_i) \bullet \vec{p}_f \\ &= g^x(\vec{p}_i) * x + g^y(\vec{p}_i) * y + g^z(\vec{p}_i) * z \end{aligned}$$

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- Interpolate nearest 2^n gradient functions
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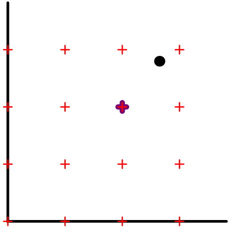

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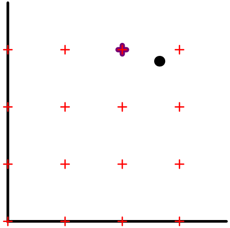

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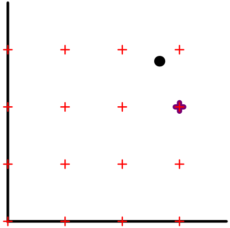

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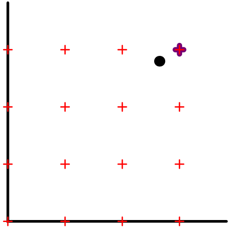

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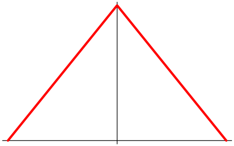

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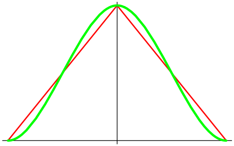

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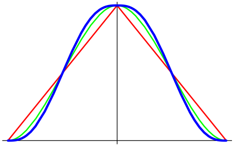

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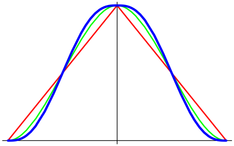

Hash

- n-D gradient function built from 1D components

$$g(\vec{p}_i)$$

- Both original and improved use a permutation table *hash*
- Original: g is a table of unit vectors
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- Original: on the surface of a n-sphere
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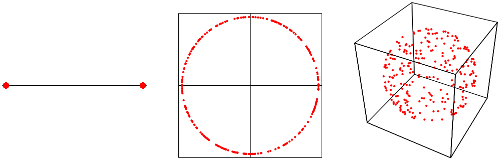
  - Found by decoding bits of hash of $\vec{p}_i$



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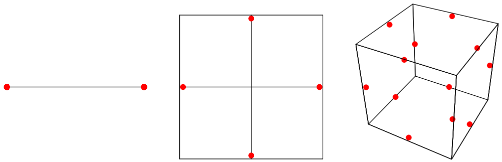

Gradients of noise(x,y,0) or noise(x,0)

- Why?
  - Cheaper low-D noise matches slice of higher-D
  - Reuse textures (for full noise or partial computation)
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  - Possibly including 0 gradient vector!

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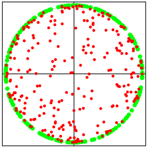

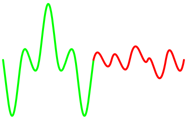

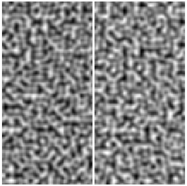

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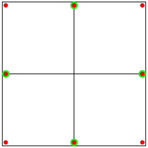

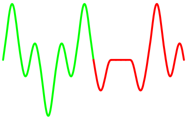

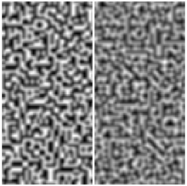

Solution?

- Observe: use gradient function, not vector alone

$$grad = g^x\ x + g^y\ y + g^z\ z$$

- In any integer plane, fractional $z = 0$

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- Any choice keeping projection of vectors the same will work
  - Improved noise uses cube edge centers

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  - Instead use cube corners!

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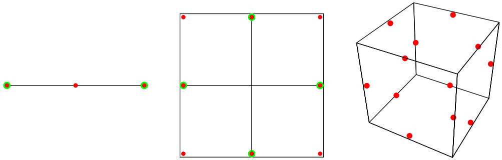

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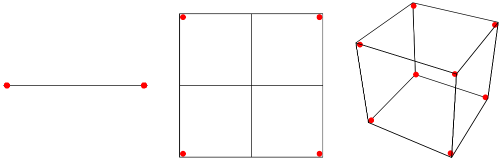

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- Simple binary selection from hash bits
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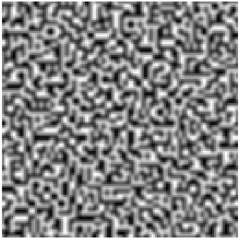
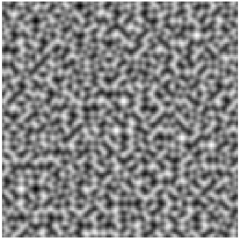


Edge Centers



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  - Texture sampling 3-4x highest frequency
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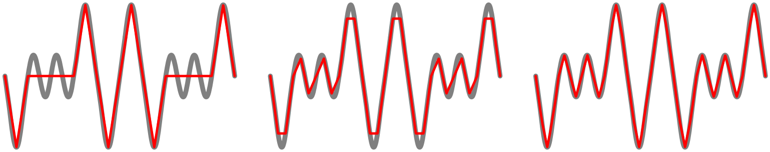

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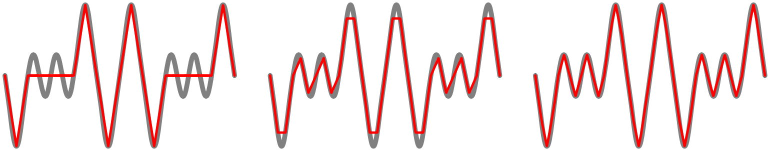

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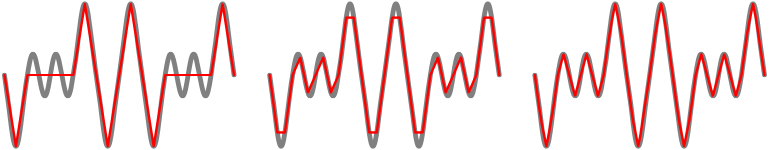

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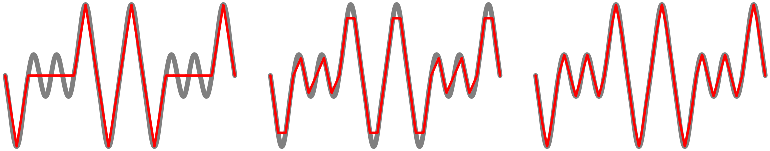

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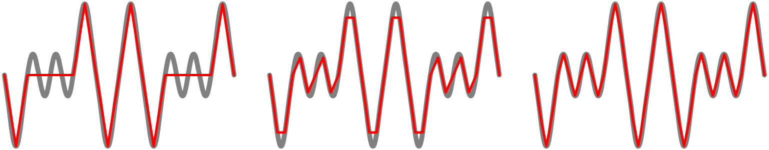

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Factorization Details

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- 256-element *permutation array*
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  - Low correlation of hash output for nearby inputs
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- Use a random number generator?
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- Hash argument is seed
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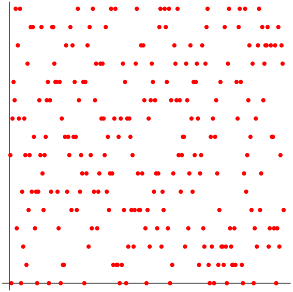
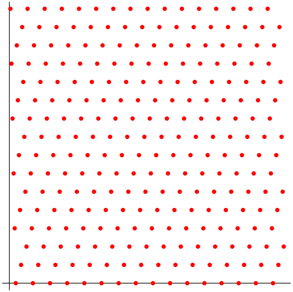


permute table



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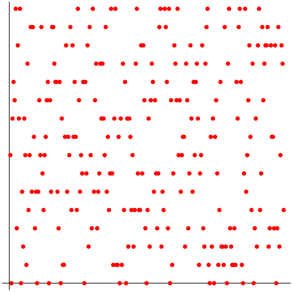

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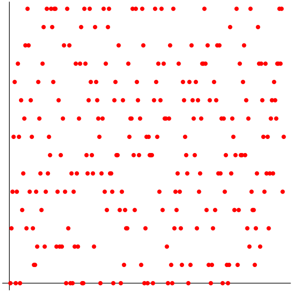

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Blum-Blum Shub

$$x_{n+1} = x_i^2 \text{ mod } M$$
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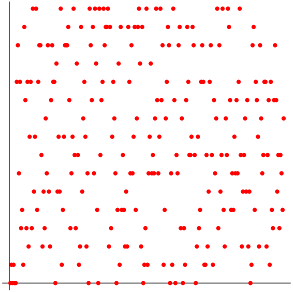

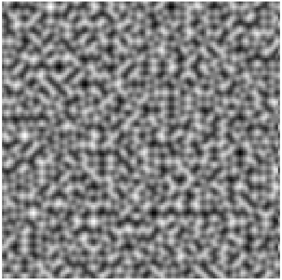

523*527

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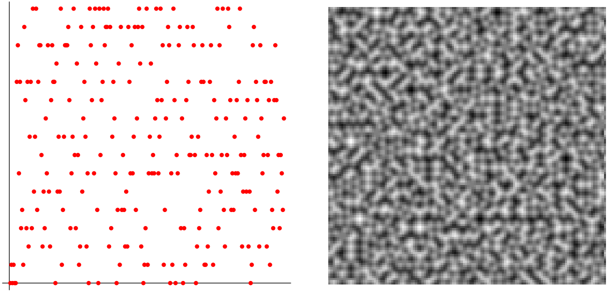

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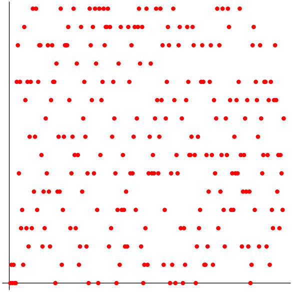
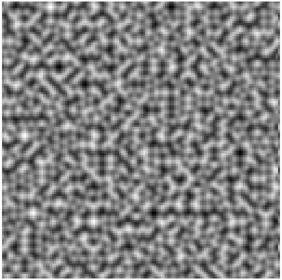

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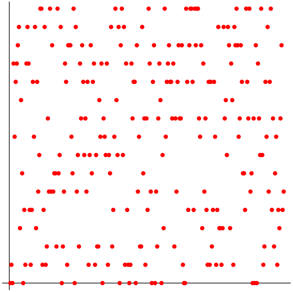

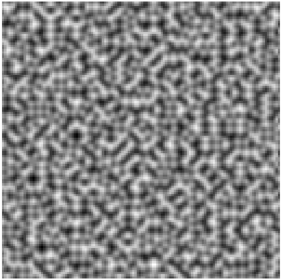

29*31

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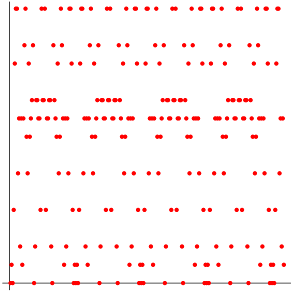
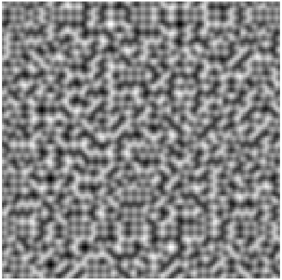
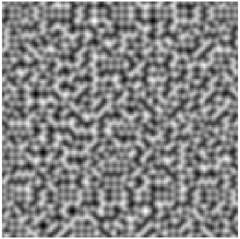


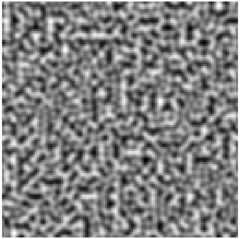


Modified Noise

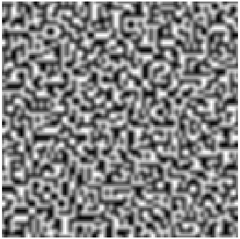
- Square and mod hash
  - $M = 61$
- Corner gradient selection
  - One 2D texture for both 1D and 2D
- Factor
  - Construct 3D and 4D from 2 or 4 2D texture lookups



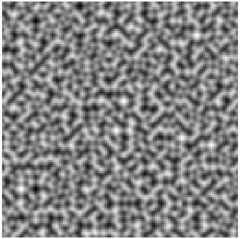
Comparison



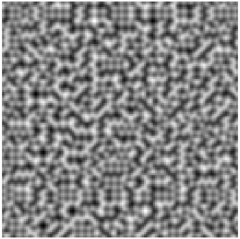
Perlin original



Perlin improved



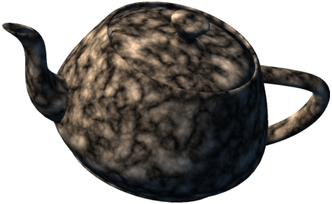
Corner gradients



Corner+Hash

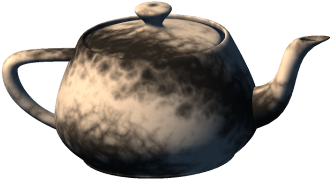
Using Noise

3D noise



3D turbulence

Wood



Marble

Outline

Introduction & Background

Modifications

Conclusion

Conclusions

- Three (mostly) independent modifications to Perlin noise
  - Corner gradient: can subset noise
    - noise(x) = noise(x,0)
    - noise(x,y) = noise(x,y,0)
  - Factorization: can superset noise
    - build 3D noise out of 2D
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  - Computed hash
    - lookup-free noise
    - avoid potentially costly chained lookups
- Admit a range of choices for texture vs. compute

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Future Work

- Other computed hash functions?
- Extend to simplex noise
- Extend to other hash-based primitives
  - Tiled texture
  - Worley cellular textures
- Further explore turbulence & fBm
  - Can we pre-bake the octaves together?

Questions?

www.umbc.edu/~olano/noise

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