Spatiotemporal discrimination thresholds for dynamic random fractal (1/f) textures

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1 Introduction

- Fractals are mathematical entities that are self−similar over many spatial or temporal scales.
- The $1/f^b$ spectra of random fractal textures simulates the spectra of natural images without being confounded by phase information.
- Similarly, temporal sequences of natural images have $1/f^a$ temporal spectra.
- So, a reasonable model for spatiotemporal texture sequences is:

$$A(f) = K fs^{b} * ft^{a}$$

where fs and ft are the spatial and temporal frequencies, respectively.

Thus, data on sensitivity to perturbations in a dynamic fractal's coordinates should provide useful insights into the perception of natural scenes

2 Methods

2a Participants

- Four experienced psychophysical observers.
- SF was naïve to the purpose of the experiment.

2b Apparatus

- All stimuli were generated and presented on a Silicon Graphics O2 at 30 HZ.
- Viewing distance was 40 cm.

2c Procedure

- Just Noticeable Differences (JNDs) were measured separately for spatial and temporal exponents using an adaptive staircase.
- A reference and a comparison image sequence were presented side by side (1.1 mm apart) for 2.133 seconds or until the observer responded, whichever came first.

2d Stimuli

- 80 spatiotemporal, grey−scale, random−phase fractals:
  - 10 spatial exponents (0.4 to 2.2 in steps of 0.2)
  - 8 temporal exponents (static, and 0.2 to 1.4 in steps of 0.2).
- The average luminance was constant at 8.57 cd/m^2.
- The Mean Square Contrast was constrained to be 10.98%.
- Each fractal was limited to 64x64 pixels (18x18 mm) in size, and 64 frames long (2.133 s).

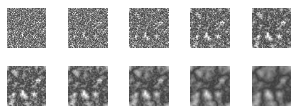

Figure 1: A representative frame from the dynamic fractal sequence. Here, the snapshots are presented at the size used in the experiment. In the top row, from left to right, the spatial exponents are 0.4, 0.6, 0.8, 1.0, and 1.2. In the bottom row, the exponents are 1.4, 1.6,1.8, 2.0, and 2.2.

Fractal Construction details: Each 64 frame stimulus sequence was created by:

1. First producing a series of random white noise images (256 grey−scale).
2. Each image in the series was Fourier−transformed and the amplitudes of all spatial frequencies were equalized to ensure that the noise was uniformly white.
3. The resulting amplitude spectra were then filtered so that:
   a. the amplitude spectrum varied over time following the power law relationship $1/f^a$
   b. the amplitude spectrum varied over space following the power law relationship $1/f^b$
4. The resulting filtered spectra were inverse−Fourier transformed to produce the stimulus image sequence.

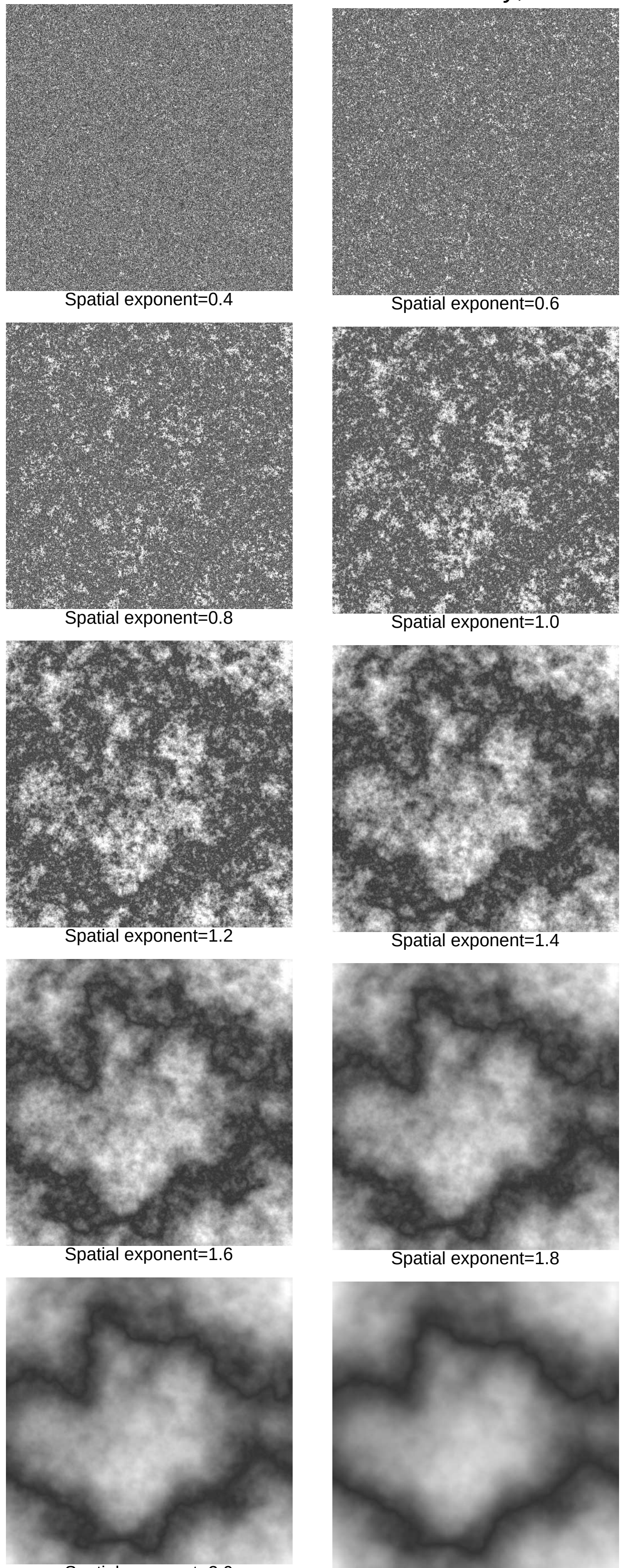

Figure 2: A representative frame from the dynamic fractal sequence. Here, for presentation purposes, the snapshots were generated covering an area 8 times larger than their original size.

3 Spatial JND's

3a Task

- The reference and comparison image sequences had identical **temporal** exponents.
- The temporal exponent was held constant while the **spatial** exponent was adaptively varied.
- The observers were asked to identify the reference image:
  - Above JND's: Find the more "fine−grained" texture
  - Below JND's: Find the less "fine−grained" texture

3b Results

- Spatial JND's are plotted in Figure 3 as a function of the spatial exponent.
- Discriminations were easiest when the spatial exponent was between 1.4 and 1.8, which is consistent with previous research (1−3).
- The data for both above and below JND's are remarkably similar across 3 of the 4 subjects.
  - The 4th subject, VB, has higher thresholds and variances.
  - This might be due to sampling problems induced by a mild, congenital paucity of retinal ganglion cells (optic nerve hypoplasia).

4 Temporal JND's

4a Task

- The reference and comparison image sequences had identical **spatial** exponents.
- The temporal exponent was held constant while the **temporal** exponent was adaptively varied.
- The observers were asked to identify the reference image:
  - Above JND's: Find the faster and "more jittery" sequence
  - Below JND's: Find the slower and "less jittery" sequence

4b Results

- Temporal JND's are plotted in Figure 5 as a function of the temporal exponent.
- Discriminations were easiest when the temporal exponent was between 0.8 and 1.0, which is the range of exponents for natural stimuli.
- The anti−persistent fractals (temporal exponent < 0.5) were extremely difficult to discriminate.
- The Below JND's tended to be larger for smaller temporal exponents.
  - Specifically, the size of the JND often produced comparison stimuli with negative temporal exponents (i.e., the amplitude spectra were not A=1/f, but A=f).
  - Note that this shift can only occur for the Below discriminations, and is the most likely explanation for the Above/Below threshold asymmetry.

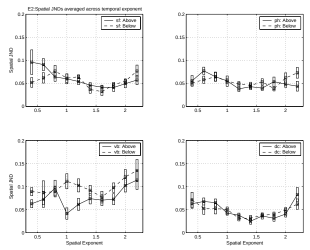

Figure 3: Spatial JND's collapsed across temporal exponents. Here the spatial discriminations are plotted as a function of spatial exponent.

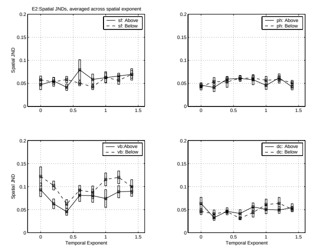

Figure 4: Spatial JND's collapsed across spatial exponents. Here the spatial discriminations are plotted as a function of temporal exponent.

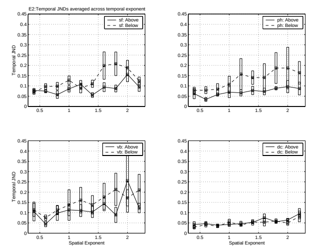

Figure 5: Temporal JND's collapsed across spatial exponents. Here the temporal discriminations are plotted as a function of temporal exponent.

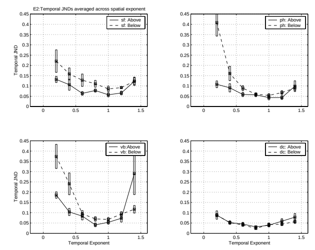

Figure 6: Temporal JND's collapsed across temporal exponents. Here the temporal discriminations are plotted as a function of spatial exponent.

Spatial JND's did not vary much with changes in the temporal exponent (Figure 4)

Temporal discriminations became more difficult as the texture became coarser (Figure 6).

5 Conclusions

- Figure 7 plots the discrimination thresholds in Spatiotemporal fractal space
- Spatial discriminations appear to be independent of the speed or persistence of motion
- Temporal discriminations are dependent on the coarseness of the stimuli. This makes intuitive sense, as it would be easier to see a 1mm object move 2mm (200% of its size) than it would be to see a 100 m object move the same distance (0.002% of its size).
- The use of a common mathematical framework for characterizing both dynamic noise and dynamic images may facilitate the study of masking of images by noise.

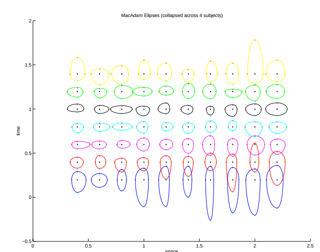

Figure 7: MacAdam Ellipses Here the Above and Below JND's are plotted together.

References

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