What Visual Discrimination of Fractal Textures Can Tell Us About Discrimination of Camouflaged Targets

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Combat ID Discrimination Tasks

• Discriminate targets from backgrounds, even when the target is camouflaged.
• Discriminate two or more targets from one another, even if both have similar texture/camouflage.
Julesz Pop Out Conjecture

• Textures that have (sufficiently) different spatial power spectra can be preattentively discriminated – they “pop out” effortlessly.

• Textures that have similar power spectra but different higher order spatial statistics usually require close scrutiny to be discriminated.

• Not always true but a good rule of thumb.
Two Targets on One (L) Background
+-Target Pops Out, T-Target Doesn’t
(from Bergen & Landy, 1991)
Power Spectra of Natural Images
(from Schaaf & Hateren, 1996)
Vast majority of natural images well fit by

\[ A(f_s) = \frac{k}{f_s^\beta} \]
## Statistics of Natural Images

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of images</th>
<th>$\beta\pm1sd$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burton &amp; Morehead</td>
<td>19</td>
<td>$1.05\pm.12$</td>
</tr>
<tr>
<td>Field &amp; Brady</td>
<td>20</td>
<td>$1.10\pm0.14$</td>
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<tr>
<td>Parraga et al.</td>
<td>29</td>
<td>$1.11\pm0.13$</td>
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<td>Ruderman</td>
<td>45</td>
<td>0.905</td>
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<tr>
<td>Webster &amp; Miyahara</td>
<td>48</td>
<td>1.13</td>
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<tr>
<td>Thomson &amp; Foster</td>
<td>82</td>
<td>1.19</td>
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<tr>
<td>Field</td>
<td>85</td>
<td>1.10</td>
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<tr>
<td>van Hateren</td>
<td>117</td>
<td>$1.065\pm.18$</td>
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<tr>
<td>Tolhurst et al.</td>
<td>135</td>
<td>$1.20\pm.13$</td>
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<tr>
<td>Schaaf &amp; Hateren**</td>
<td>276</td>
<td>$0.94\pm0.21$</td>
</tr>
<tr>
<td>Dong &amp; Atick</td>
<td>320</td>
<td>1.15</td>
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<tr>
<td><strong>Weighted average</strong></td>
<td><strong>1176</strong></td>
<td><strong>1.08</strong></td>
</tr>
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Interestingly, fractals, like natural images, also have $1/f$ amplitude spectra.

Not surprisingly, fractal-like textures are starting to show up in camouflage.
Digital Military Camouflage

CADEPAT

U.S. Marines
MARPAT Forest
2-Scale Fractal-like Camouflage

• Courtesy of the Marine Corps Systems Command and the United States Marine Corps, Quantico, VA.
Examples of Fractal-like Camouflage (from hyperstealth.com)
Camouflage Pop Out
(from hyperstealth.com)
Fractals and Pseudo-fractals

- True fractals have something going on at every spatial scale.
- Content at each spatial scale is lawfully related to content at the other scales – called self-similarity. In the Fourier domain they are power laws.
- Even the best realizable fractals are approximations because extreme scales are truncated.
Truncated $k/f_s^\beta$ fractal textures
There are some questions that come up when discussing perception of textures.
Questions: Should Viewing Distance Matter Much?

• One nice thing about perfect fractals is that changing viewing distance has little effect on Fourier spectra. Spatial frequencies that become invisible are cleanly replaced by adjacent scales.

• But, our fractals are truncated.
Questions: Should Psychophysical Method Matter?

• Simultaneous (side-by-side) viewing seems best, but means that the two images must be presented to different patches of parafovea, rather than the optimal fovea.

• Sequential viewing (one after the other) uses the optimal foveal area, but first image must be held in memory to compare to second.

• Nice to compare both in same observers and same stimuli.
Methods

- 64X64 pixels for consistency with another study
- 10 values of spatial exponent (0.4 – 2.2)
- RMS contrast of 11%; 8.6 lumens average
- Near (40 cm; 2.58 deg. VA) and Far (100 cm; 1.03 deg VA) viewing conditions
- Simultaneous and Sequential methodologies with adaptive staircases
METHODS

• 4 subjects, 20/20 corrected vision.
• Each subject made 3 adaptive staircase threshold determinations for the 10 exponents, for each distance and methodology (randomized). Task was to determine which texture had the lowest exponent.
• Took about 20 hours per subject, completed in 2 1 hour experiments each day over several weeks.
Average of 4 Observers

[Graph showing the average of 4 observers with data points for Simultaneous Near, Sequential Near, Simultaneous Far, and Sequential Far.]
Spatial Fractals –
Take Home Messages

• Discrimination thresholds are smaller for moderate values of beta than for extreme values of beta, with a minima around 1.4-1.6. This is not an exponent typical of natural images. Small difference, but may be significant for IFF under sequential viewing.

• Discrimination is better for simultaneous rather than sequential comparisons. Same functional shape.

• Discrimination is slightly better for near, but not a lot better, given the factor of 2.5 in distances. However…
• The effect of increasing distance is to slide the spatial frequency content to higher spatial frequencies.
• Our experiment was designed so that the highest spatial frequency content would still be visible to all observers. But check out the individual data…
Individual Data

- $\frac{3}{4}$ subjects have similar data for near and far for both viewing conditions.
- For VB, far thresholds are greatly elevated. This is expected for a sampling problem, which VB has (mild optic nerve hypoplasia).
So, What Can Discrimination of Fractal Textures Tell Us About Discrimination of Camouflaged Targets?

- Camouflage should have many scales, so its perception is almost independent of distance.
- Camouflage should have $1/f^\beta$ spectra to match typical natural images ($0.9<\beta<1.2$).
- For IFF, probably better if $\beta$ on high side.
- Operators should use side-by-side displays, instead of switching between views.
- Operators with “normal vision” may have hidden problems with this kind of image.
Can We Generalize to Spatiotemporal (Dynamic) Fractal Textures?

And why should we?
Sometimes the Camouflage Moves
Also

• With active camouflage, the camouflage may change to compensate for changes in the background.
• Studying dynamic fractals brings up the possibility of taking advantage of stochastic resonance, which can enhance detection and perhaps discrimination. SR is often more efficient for 1/f stimuli.
Temporal Amplitude Spectra of Dynamic Natural Scenes (from Billock et al., 2001)
So we study dynamic textures of the form

$$A(f_s, f_t) = k/f_s^\beta f_t^\alpha$$
Time For A Demo!

Dynamic Fractal Textures
Spatiotemporal Discrimination
Spatiotemporal Notes

• The interior region of the discrimination space is surprisingly uniform. Usually you have to manipulate the space to achieve this.

• Going to dynamic noise introduces the possibility of nonlinear dynamic effects like stochastic resonance. 1/f noise is often more efficient than white.
Time For A Demo!

Stochastic Resonance of the Third Kind (Hallucinatory Pattern Formation)
THANK YOU!
EXTRA SLIDES
Comparison of “Above” and “Below” Thresholds

VB has more trouble with “below” discriminations (lower exponent=more spatial frequency content; VB has optic nerve hypoplasia consistent with sampling hypothesis).