Appearance Engineering:
Getting from virtual models to physical designs

Presented by

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Aerodyne Research, Inc.

at the

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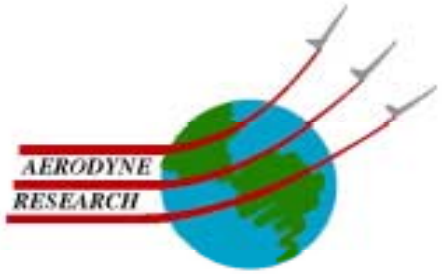


Outline

- **Appearance Engineering vs. Appearance Prediction**
- **3 Basic Application Regimes for Appearance Engineering**
  - **Conspicuity Maximization Example**
  - **Conspicuity Minimization Example**
  - **Notions for Appearance Matching**
- **CMO: Colorant Mapping Optimizer**
  - **Technical Challenges**
  - **How it Works**
- **What next?**

Appearance Engineering vs. Appearance Prediction

- **Prediction: Given the configuration, what is the appearance (under various conditions)?**
  - **Ability to <u>evaluate</u> a given design configuration (i.e. you have radiance, sensor codes), does not equate to ability to <u>generate</u> a worthwhile design.**
- **Engineering: Given the desired appearance (under various conditions), what is the configuration?**
- **"Configuration" means which coatings on which surface elements?**
  - **An "optimal" "paint" scheme is with respect to available coatings (palette), viewing scenarios & design constraints**

"Appearance" couples radiometrics with visual perception

Appearance Engineering Application Regimes

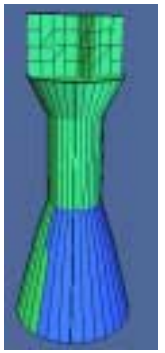
3 Basic Regimes

- 1. Conspicuity Minimization (Camouflage)
- 2. Conspicuity Maximization (Advertising)
  - e.g., for outdoor signage, navigation aids, highway safety
- For conspicuity min/max, the “desired appearance” is defined with respect to the scenario backgrounds
  - “Desired appearance” thus not explicitly pre-conceived
  - Presently, metrics for min. are more evident than for max; 1st-shot maximization metrics are negative-signed minimization metrics
- 3: Appearance Matching
  - Which coatings manifest artistic renderings under varying viewpoint, illumination?
  - e.g., for architectural lighting, product packaging, theatrical set design

Appearance Engineering Design Process - Min/Max Conspicuity

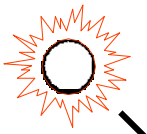
Object 3D Geometry (CAD)

Colorant Mapping Optimizer (CMO)

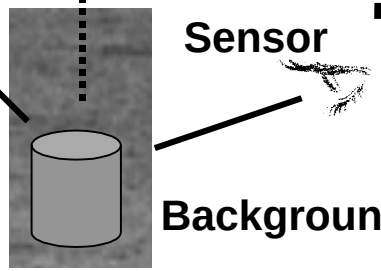


Optimized Colorant Scheme ("Design")

Illumination



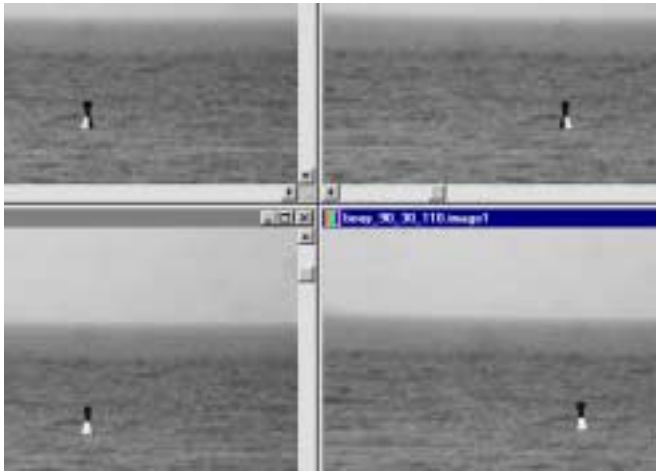
Viewpoint; Sensor



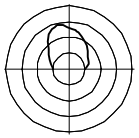
Background

Appearance Prediction Code

Conspicuity Maximized Over Scenarios

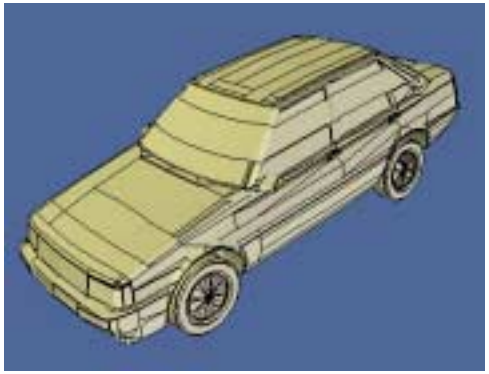


Viewing Scenarios; Backgrounds

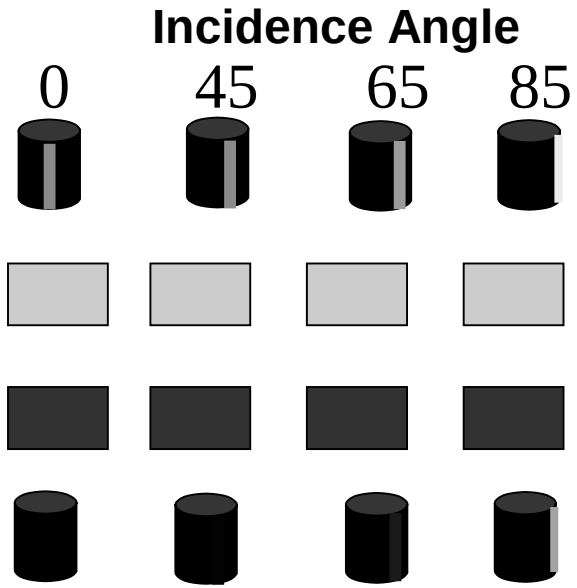


"Palette" of Optical Coatings (BRDF Models)

Camouflage Design & Tradeoffs - Explanation of Example



- 3D Signatures computed using the GSL physics-based code
- 3D Object ("target") is a Fiat automobile (~5K facets)
- Visual luminance (CIE "Y") band
- Clear day, deciduous terrain
- Materials (Coatings) Palette:
  - (1) Specular high-reflect. ("chrome")
  - (2) Diffuse high-reflectance ("white")
  - (3) Diffuse low-reflectance ("black")
  - (4) Specular low-reflectance ("flint")
- Reflectance treatments applied over entire object (for purposes of example)



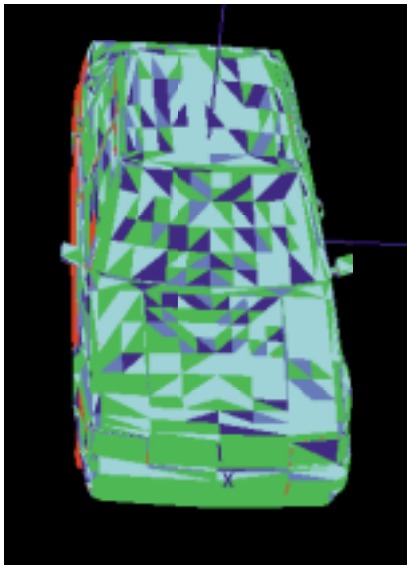
Single-Scenario Design

1.

2.

3.

1. White Paint Uniformly Applied
2. Optimized, but <u>NOT</u> considering texture (mean, variance only)
3. Optimized, this time including texture consideration
4. Color-coded facet paint scheme

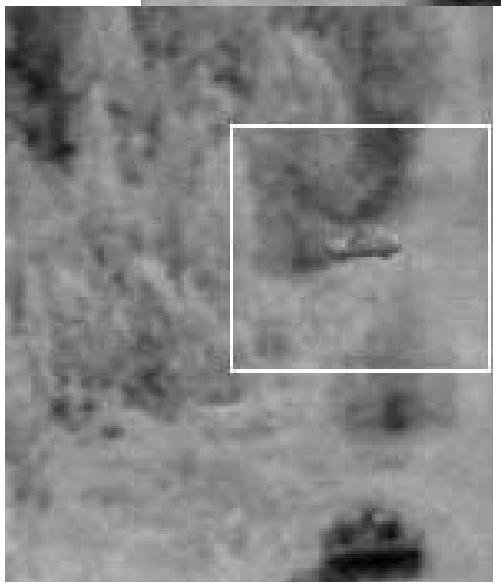


4.

Joint Two-Scenario Design

BEFORE

AFTER



Scheme Complexity & Palette Tradeoffs

No Constraints.

<u>Paint Proportions:</u>
5 units “white”
1.8 units “black”
1.5 units “flint”
0.5 units “chrome”

Constrained “Parts” Count

Constrained Palette (“white” & “chrome” only)

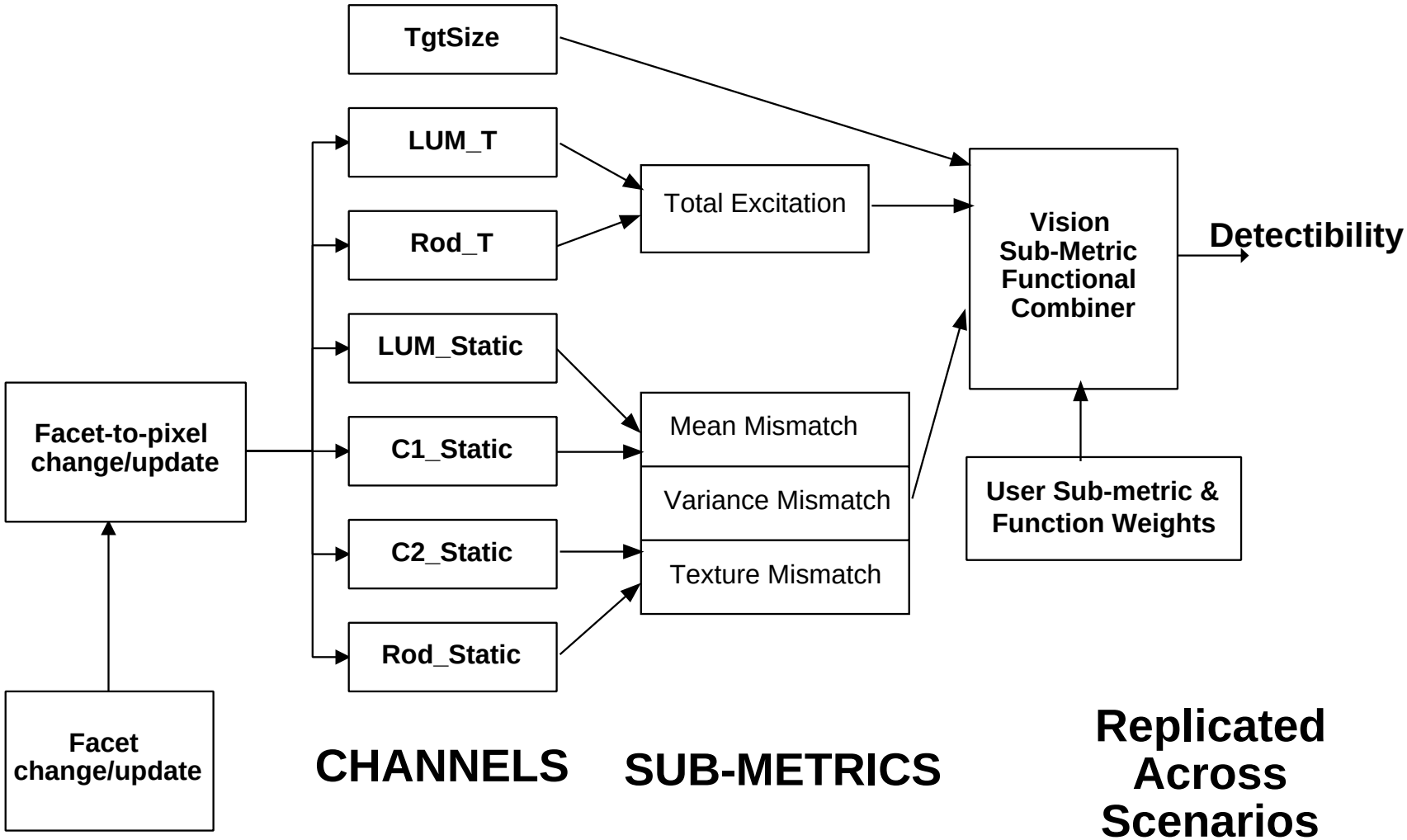
Notions for Appearance Matching Application Regime

- **Optimize coating assignments upon 3D CAD model to best match pre-conceived desired appearance(s)**
  - **Desired appearances crafted within paint programs and artistic rendering packages**
  - **Challenge addressed by a CMO approach is that real coatings vary in appearance under varying viewpoint, illumination**
- **Optimization is to 1st-order a multiple template-matching problem**
  - **Provision of a parametric (versus discrete) coatings palette facility is likely more important than existing spatial patterning capability**
- **Still a need for spatial patterning in situations where coating scheme granularity can be finer than visual "pixel" resolution (e.g., for standoff distance viewing)**
  - **Essentially the synthesis of "macro" BRDFs from elemental BRDFs**

Why Appearance Engineering is Hard

- **“Correspondence” Problem: Need to “paint” a 3D object with materials**
  - **Complex, indirect relationship between materials placements and their manifested “brightness”**
- **Robustness Problem: Multi-scenario variability**
  - **Object appearance varies strongly with viewpoint, pose, & illumination conditions**
- **Non-Obvious Appearance (Photons-to-Percepts) Metrics**
  - **Consider both Static and Moving Objects**
- **Non-Analytic Discrete Combinatoric Search**
  - **Potential number of “paint” schemes is staggering --> (Number_of_“coatings”) [raised to the Power of Number_of_Surface_Elements]**
  - **e.g., 10^1000 -- more combinations than # atoms in the Universe!!**
  - **Often constrained to discrete, non-analytic evaluation**

CMO's Visual Pattern Conspicuity Computation



Visual Pattern Conspicuity - Channels

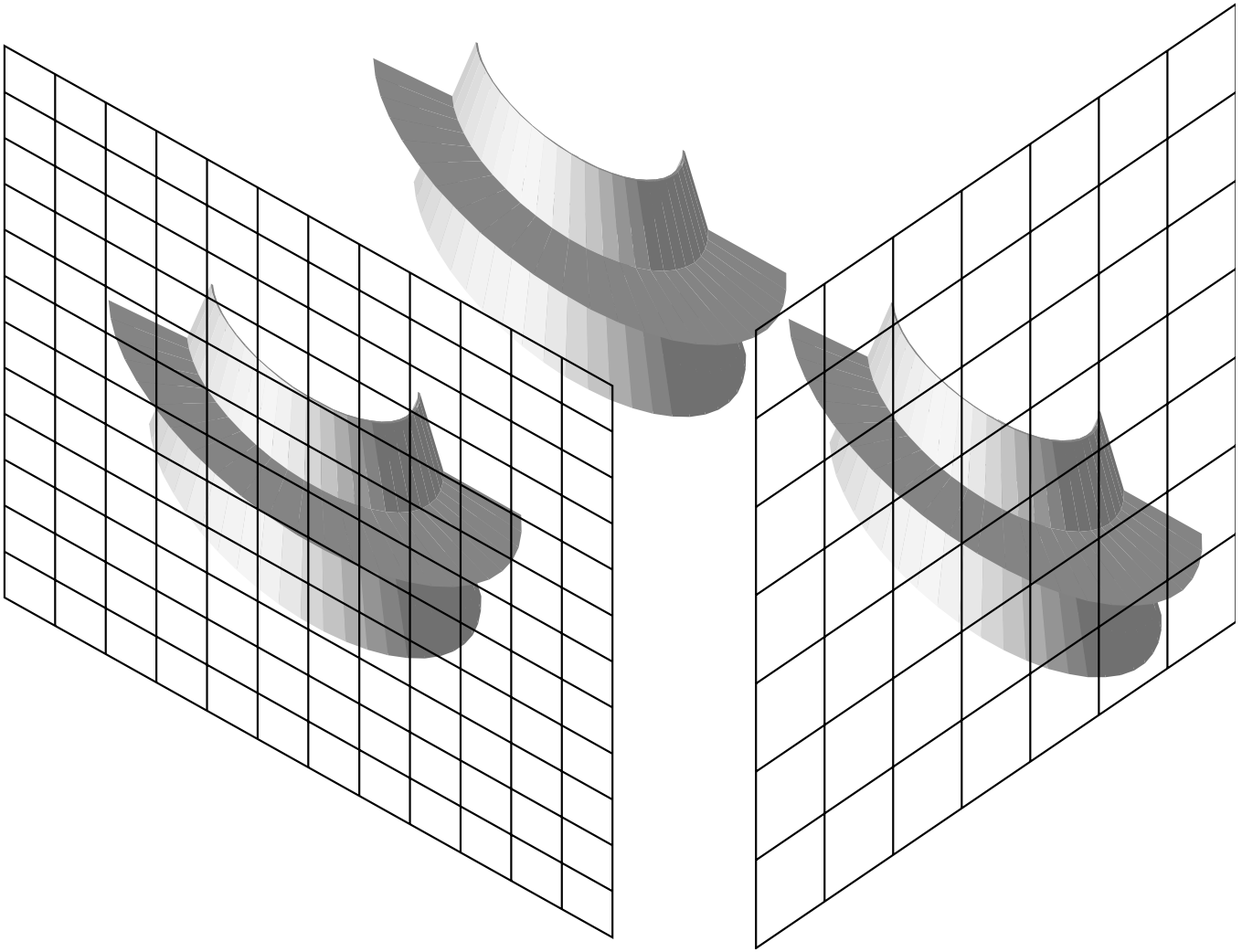
- **Conspicuity based on multi-channel measures of mismatch between target & its local background**
- **Channel structure is motivated by knowledge of the "early" components of the early (pre-attentive) human visual system (HVS)**
  - **Color Opponency**
  - **Temporal (Motion) Filtering**
- **Channels are "glimpse" image planes**
  - **Temporally weighted and accumulated over frames comprising glimpse**
  - **Chromatic combinations of retinal Cone (S,M,L) and Rod fundamentals**

Visual Pattern Conspicuity - Mismatch Sub-Metrics

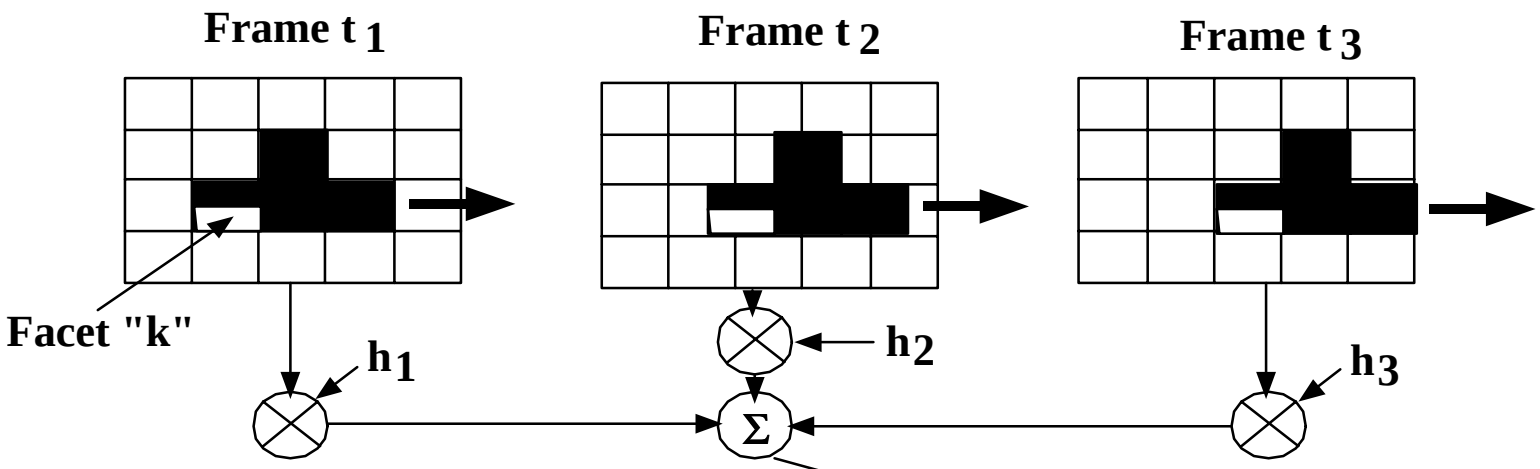
- **Measure for temporal bandpass (motion) channels is summed absolute excitation.**
- **Measures for temporal lowpass (static) channels:**
  - **Mean mismatch- $|MeanTgt^2 - MeanBkg^2|$**
  - **Variance mismatch - |VarTgt - VarBkg|**
  - **Texture mismatch, based on hybrid deterministic pattern / indeterministic Gaussian Markov random field (GMRF) form**
- **GMRF mismatch considers the local background at the silhouette boundary**
  - **Enables "phase-matching" at silhouette**
  - **"Edges" thus minimized (or maximized) implicitly**
- **GMRF texture mismatch term essential to good results**

Facet-to-Pixel Mappings

for 2 different views and sensor pixel IFOVs



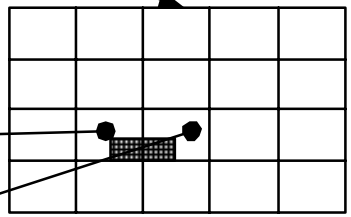
Spatio-temporal Facet-to-Pixel Mapping



Facet k's Impact:

Pixel (3,2):
$\Delta L_k \{0.5\ h_1 + 0.25\ h_2 + 0\ h_3\}$

Pixel(3,3):
$\Delta L_k \{0\ h_1 + 0.25\ h_2 + 0.5\ h_3\}$



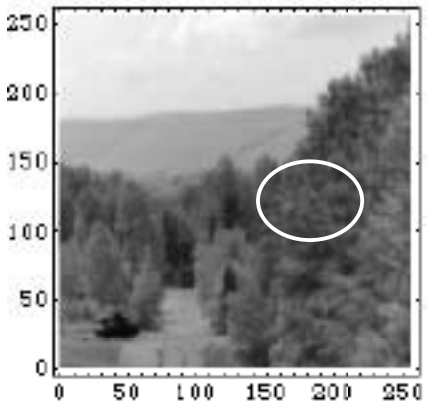
LUM_T Channel (glimpse)

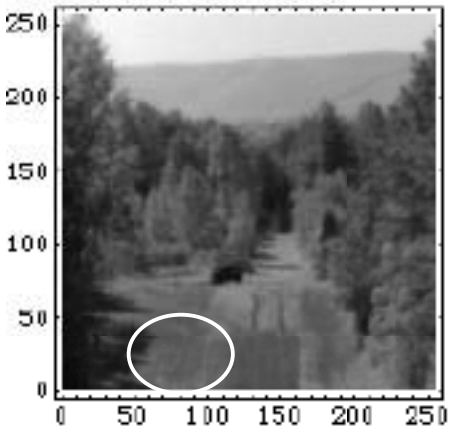
$\Delta LUM\_T(i,j) = \Delta L_k \Sigma_t\ a_{i,j,k,t}\ h_t$

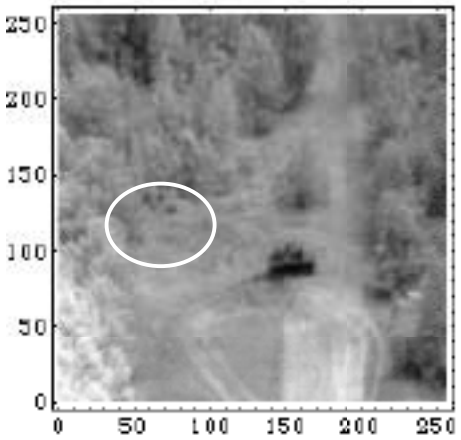
---> $a_{i,j,k,t}$ are the maps!

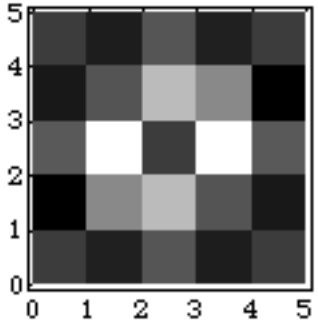
$$\mathbf{LUM\_T(i,j) = \{\Sigma_k\ L_k\ \Sigma_t\ a_{i,j,k,t}\ h_t\} + \{\Sigma_t\ h_t\ L_{bg}(i,j,t)\ \Sigma_k\ (1-a_{i,j,k,t})\}}$$

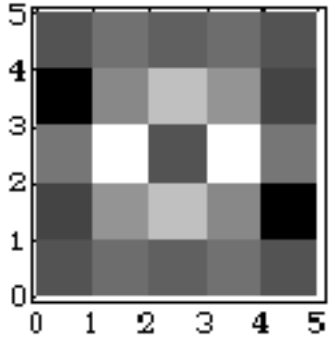
GMRF Parameter Estimates

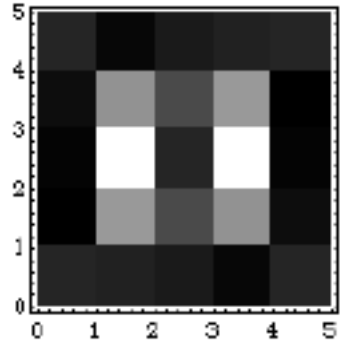












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Development of CMO

- **Originally proposed by Aerodyne in 1990**
- **IR&D funding by Lockheed Aeronautical Sector and Boeing Helicopters**
- **Army Aviation Applied Technology Directorate (AATD)/Ft. Eustis sponsorship enabled expansion to handle spatially resolved patterns, human visual detection**
- **AATD is now the Release Authority for CMO**

What Next with CMO and Appearance Engineering?

- **Does anybody care?**
  - **Determine breadth, depth of markets for Appearance Engineering**
- **Demonstrate payoffs beyond those achievable by “guessing” or manual (intuitive) design efforts**
  - **Easily shown for conspicuity min/max.**
  - **Differential payoffs to Appearance Matching may exist when attempting to apply novel optical materials**
- **Integrate additional vision science into conspicuity maximization, appearance matching**
  - **chromatic/spatial configural effects on percepts**