Grand Challenge Problems in Digital Imaging*

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*title modified from “Grand Challenge Problems in Digital Image Rendering”

Why should we ask this question?

- The nature of much of our research is highly focused
- It is valuable to take a step back and ask:
  - Where have come from?
  - Where are we going?
- Identifying our long term strategic goals can:
  - Provide a technology roadmap
  - Channel research efforts
  - Enhance investment from industry and government

My Approach

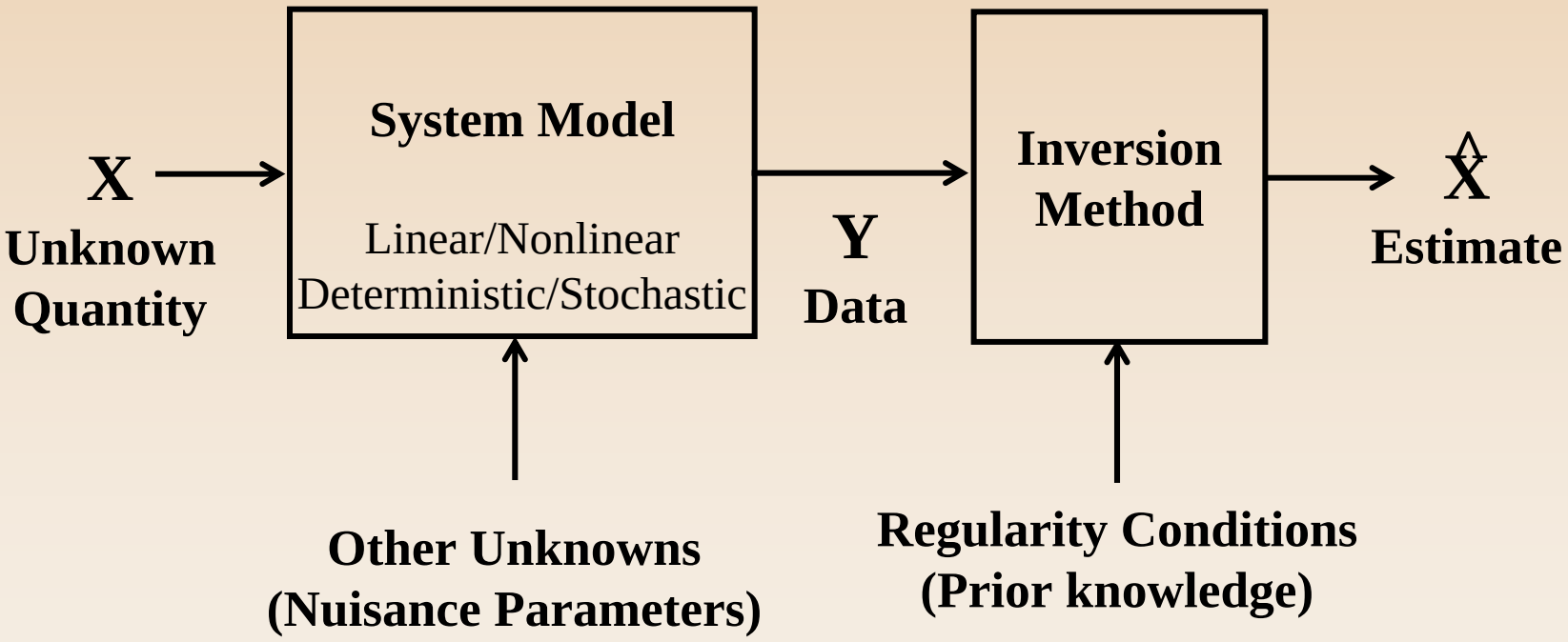
- Step 1
  - Make an irreversible commitment
- Step 2
  - Panic
- Step 3
  - Ask a variety of experts in the field about their views
  - Thank you Zygmunt Pizlo, Jan Allebach, Qian Lin, Ed Delp, Raja Bala, Bernice Rogowitz, Reiner Eschbach, Peter Doerschuk, Guotong Feng, and Yibin Zheng
- Step 4
  - Consolidate input into 7 major GCP's
  - Pull in some illustrative examples of precursor research
- Step 5
  - Go to Step 3

GCP-1: Inversion of Complex Physical Systems

- Many physical systems can be described using a combination of deterministic and probabilistic mathematical models
- Massive computational resources allow for the possibility of inverting these systems
- Depends on:
  - Accurate system models
  - Incorporation of prior information and regularity
- Applications in:
  - Image acquisition and sensing
  - Image rendering
- Two types of inverse problem

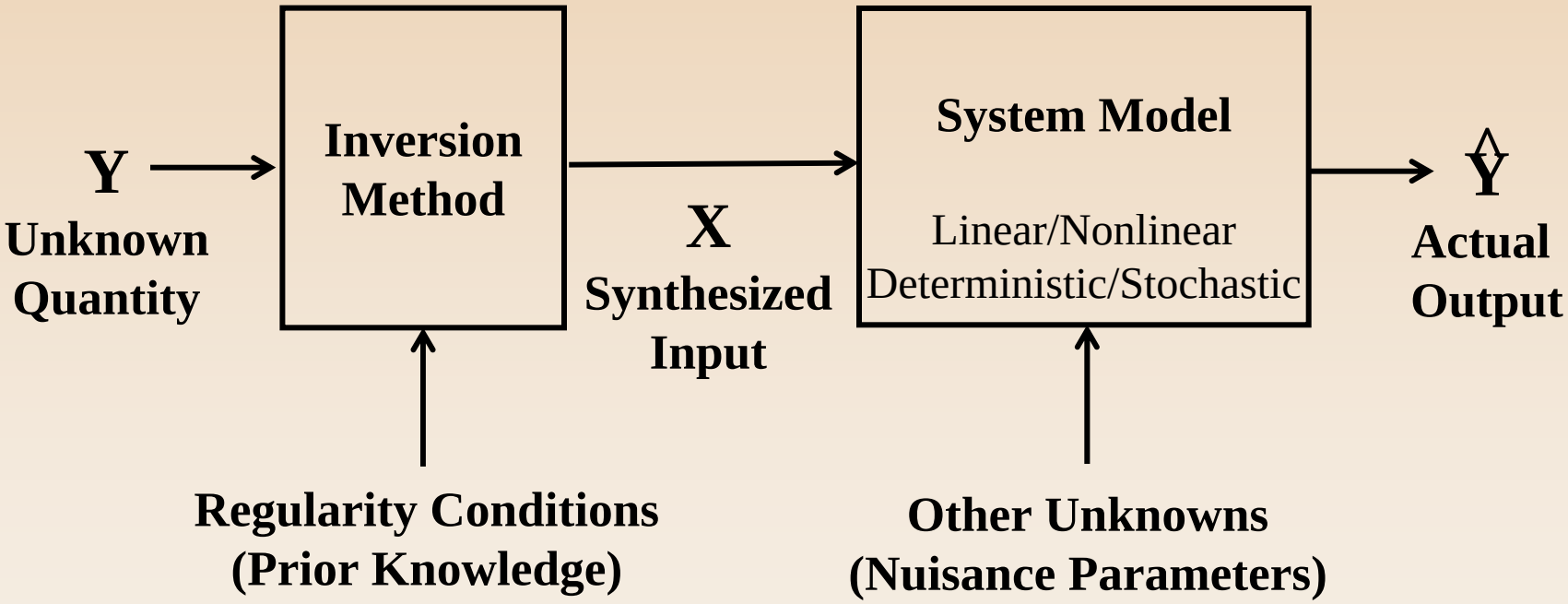
Type I Inverse Problem

- Recover information from indirect measurements



Type II Inverse Problem

- Compute an input that will generate desired result



Type I and II Inverse Problems

- Type I inverse
  - Image deblurring
  - Tomography
  - Image mosaicing
  - 3D scene recovery
  - Human vision
- Type II inverse
  - Colormap design
  - Halftone design
  - Photolithograph

Type I Inverse: Example

- Forward model
  - Gravity
  - Fluid dynamics
  - Light propagation
  - Image formation
- Inversion
  - Illumination estimation
  - Shape from X
  - Inverse dynamics
  - Real world knowledge

- Inverse Solution: Something fell in the water

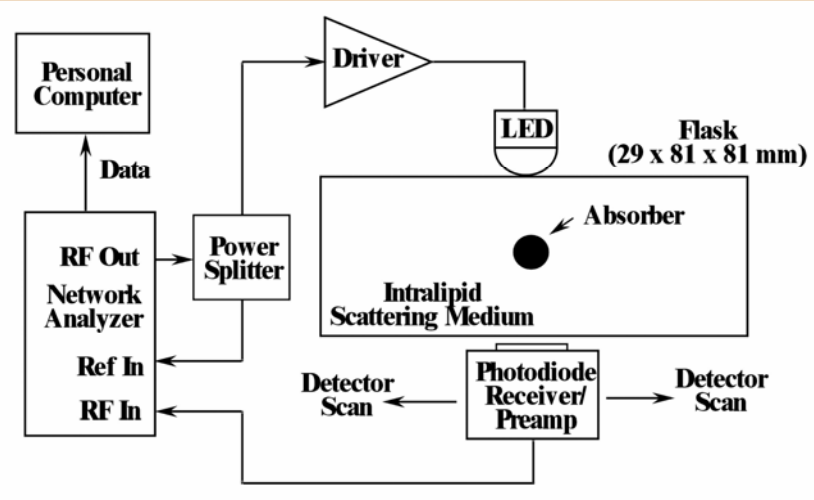
Multigrid Optical Diffusion Tomography (0073357-CCR)

Charles Bouman, Kevin Webb and Rick Millane, Purdue University

Goal: Image in scattering media using light (tumors, blood chemistry, environmental sensing).

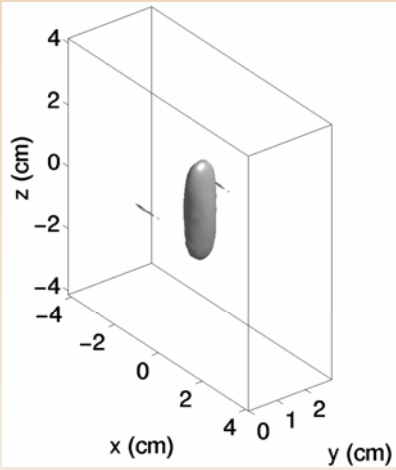
Major Accomplishments: A 3-D image of a cylindrical absorber in a tissue phantom (Intralipid) has been achieved using measured data having multiple modulation frequencies.

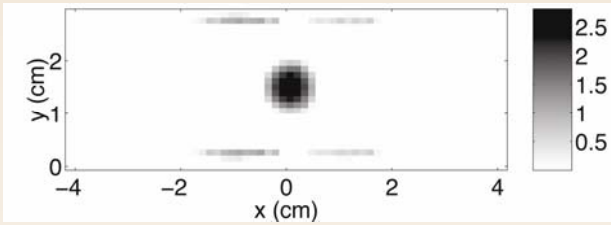
Experimental Apparatus



Tissue Phantom

Reconstruction





[1] A.B. Milstein S. Oh, J.S. Reynolds, K.J. Webb, C.A. Bouman, and R.P. Millane, Optics Letters

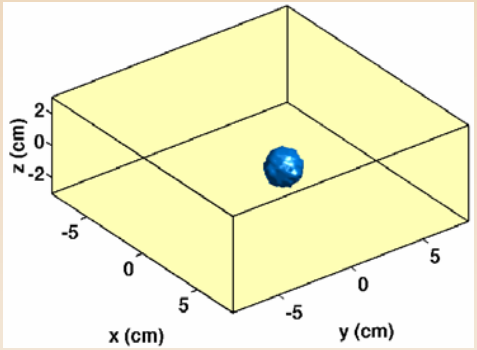
[2] J.C. Ye, C.A. Bouman, K.J. Webb, and R.P. Millane, IEEE Trans. Image Proc., Vol. 10, pp. 909-922, June 2001

Fluorescence Optical Diffusion Tomography (FODT)

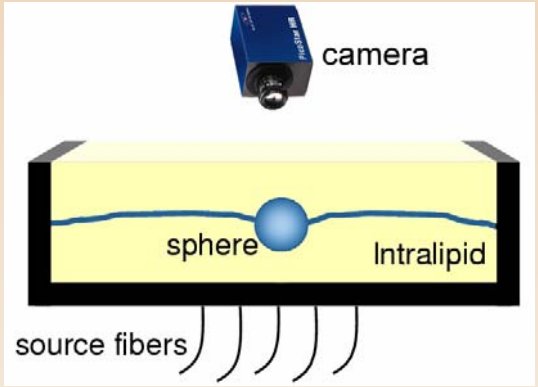
Project: Multigrid Optical Diffusion Tomography (0073357-CCR)
PI's: Charles Bouman, Kevin Webb, ECE, Purdue University
Collaborator: David Boas, MGH, Harvard

Goal: Image fluorescent tumor phantom in scattering media using light.
Applications: Tumor detection, functional imaging, and blood chemistry
Major Accomplishments: A 3-D image of a small sphere containing a fluorophore (ICG) in a tissue phantom (Intralipid) has been achieved using time-resolved measurements

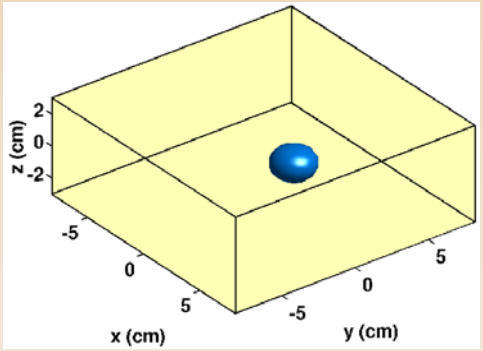
Tissue Phantom

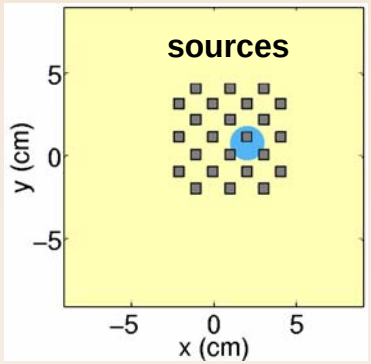


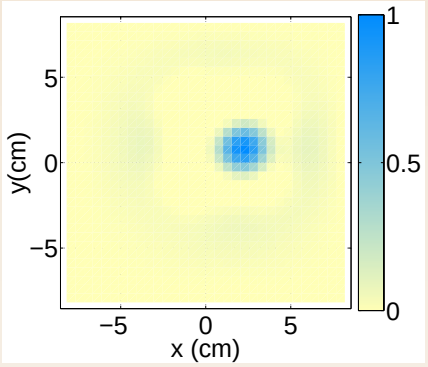
Measurement



Reconstruction







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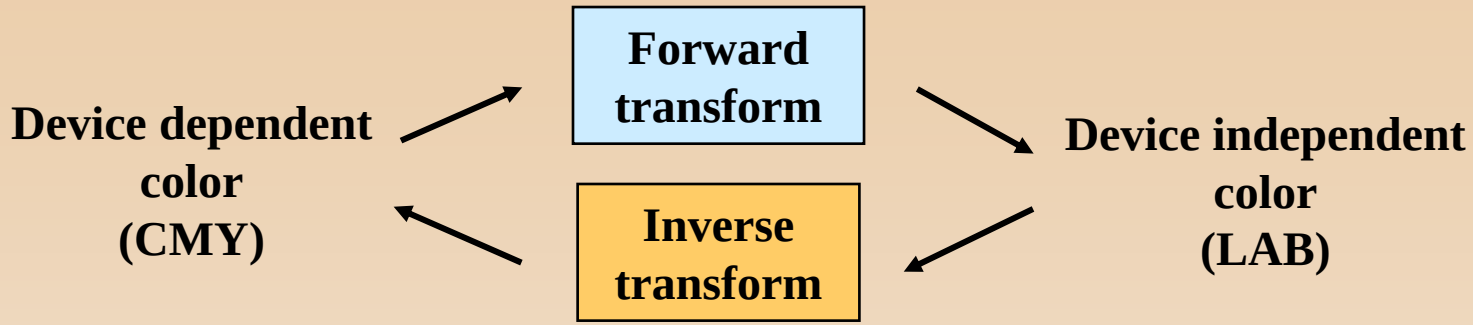
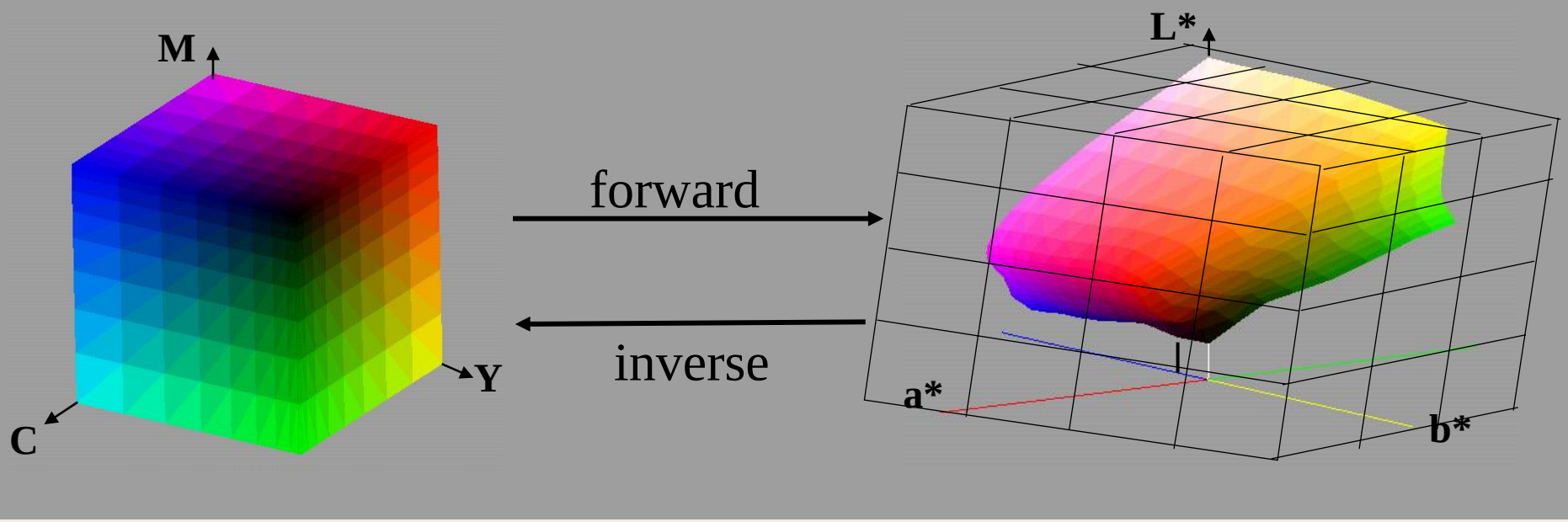
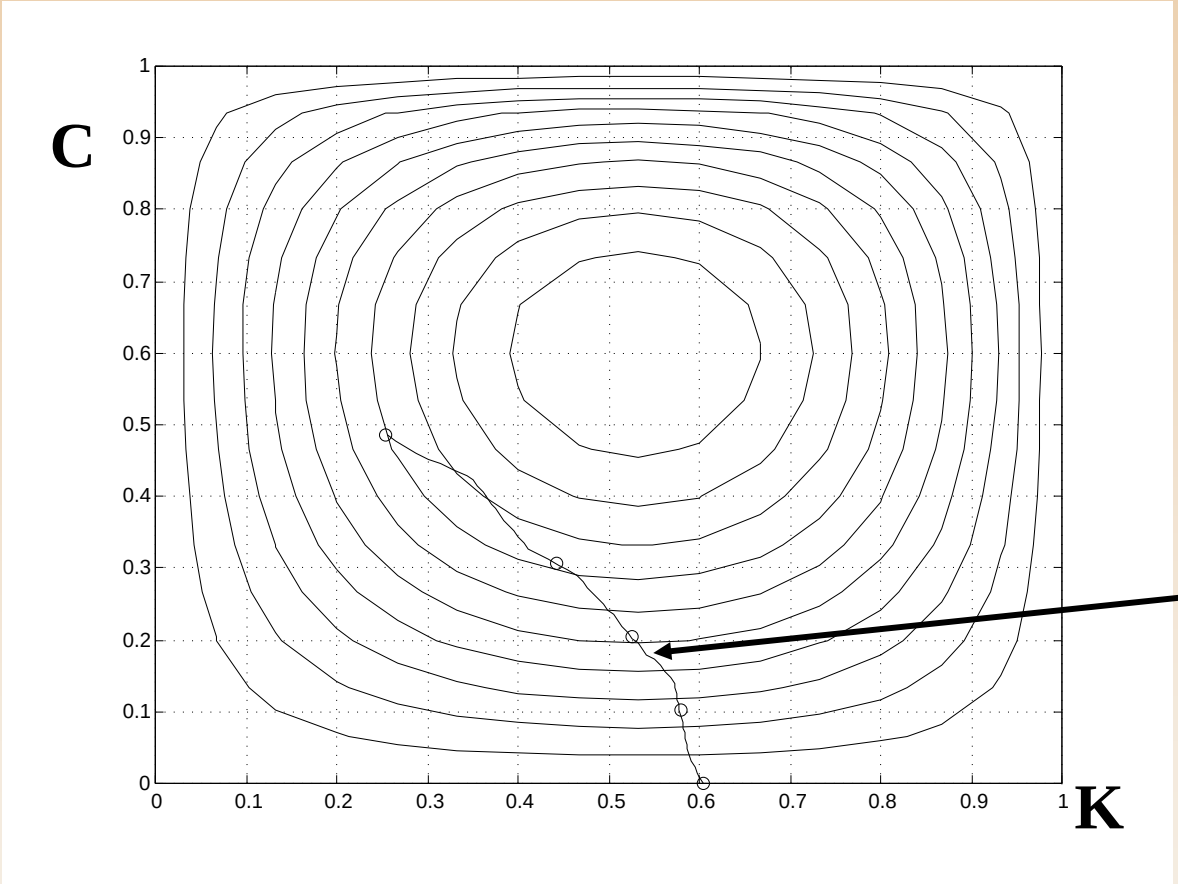
Printer characterization*





*Raja Bala, EI 2003

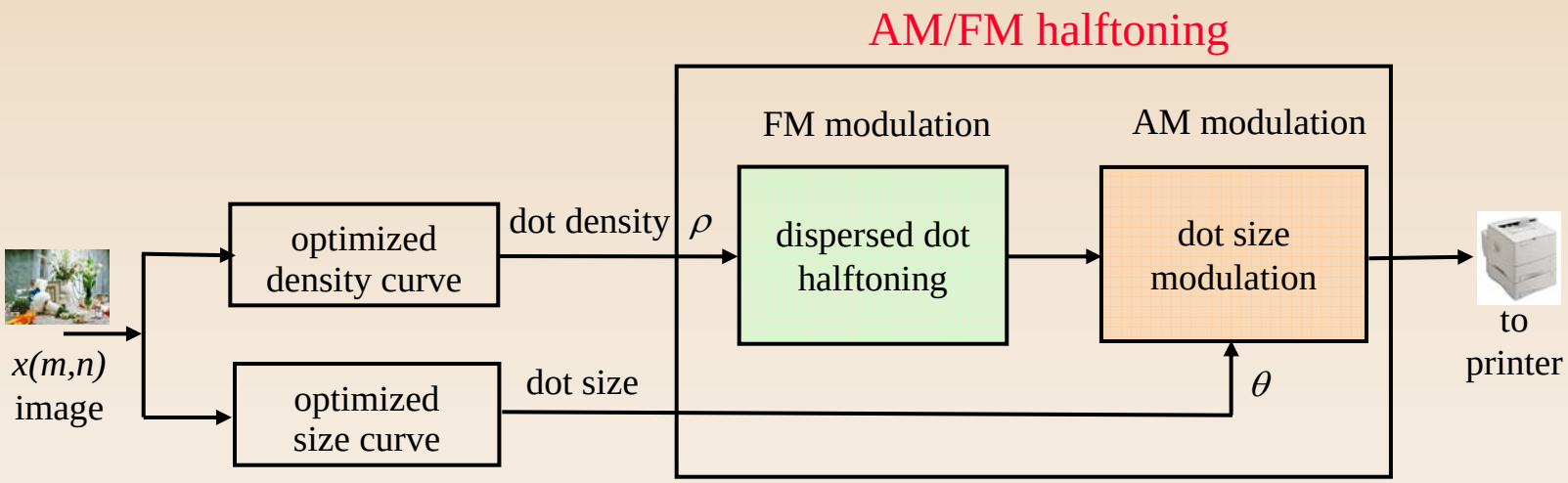
Same color, different moiré*



*R. Bala and R. Eschbach, PICS 1999

AM/FM Halftoning

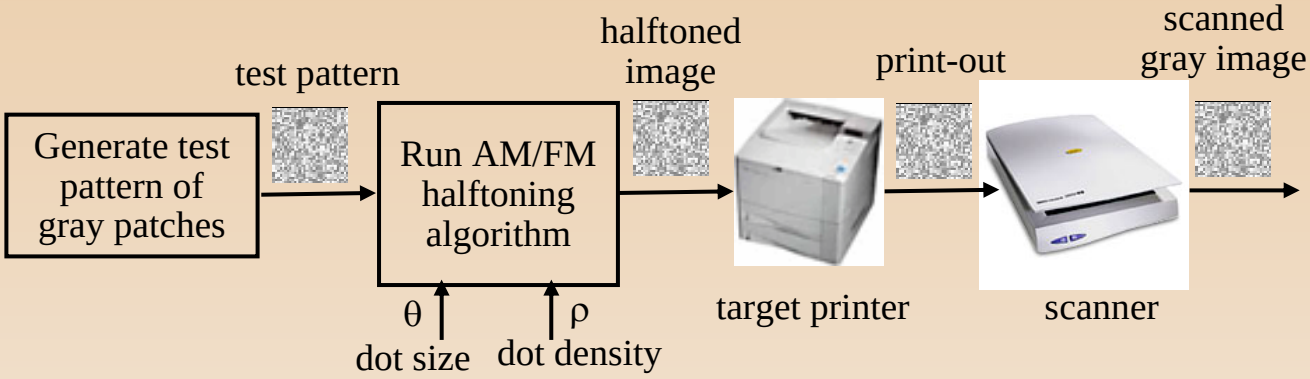
- Each input gray level g is rendered with the optimal combination of dot size, $\theta_{g,}$ and dot density, ρ_g



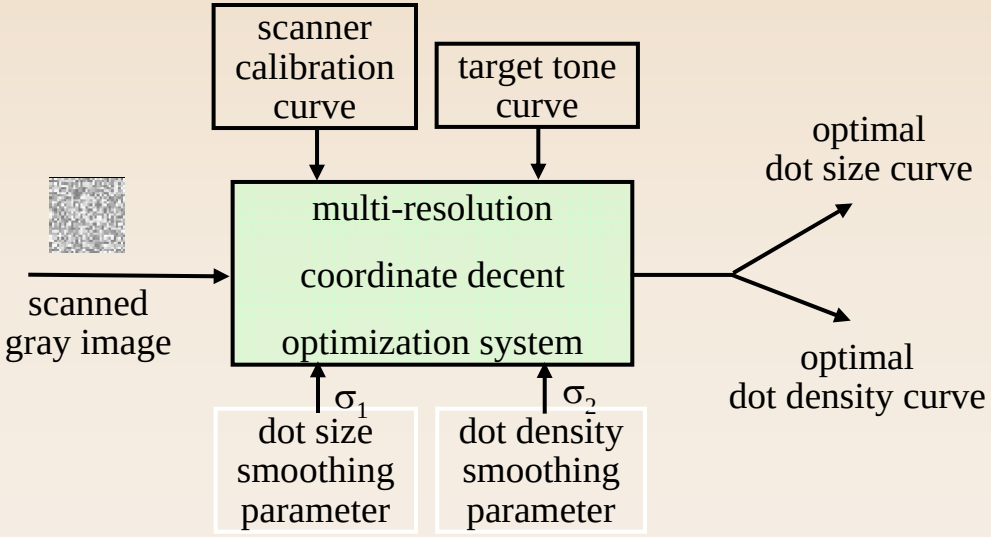
*with Zhen He

AM/FM Parameter Design System*

- Measurement step



- Optimization step

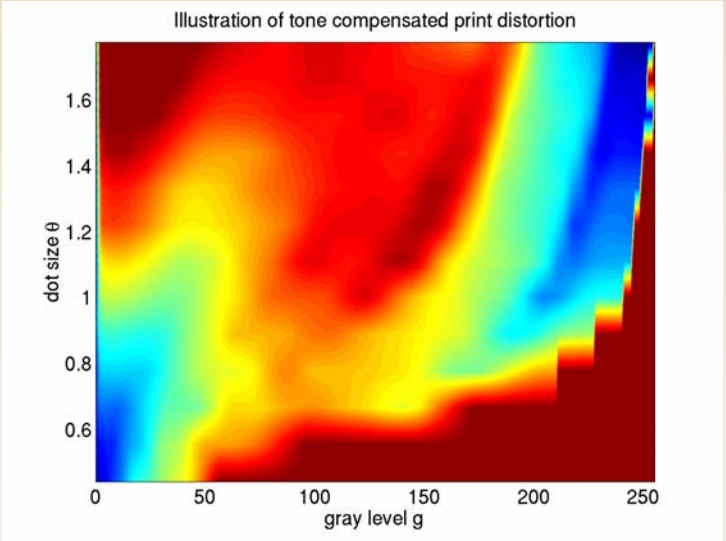


Finding the Best Inverse

- Optimal dot size curve is obtained by minimizing the cost function:

$$\vec{\theta}^* = \underset{\vec{\theta} \in [\theta_{\min}, \theta_{\max}]^{254}}{\arg} \min C(\theta_0, \vec{\theta}, \theta_{255})$$

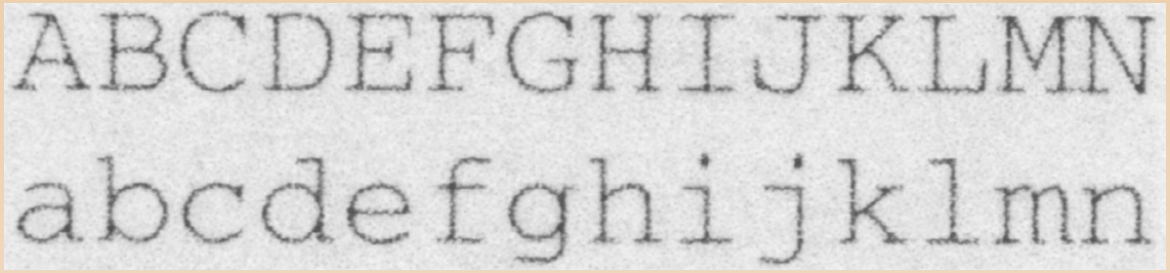
- Requires non-convex optimization
- Results in best path from highlights (small dots) to shadows (large dots)



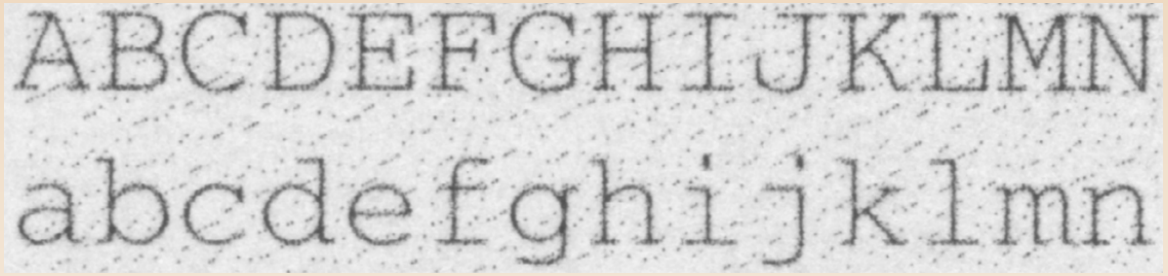
High lights Shadows

Rendering of Scanned Text

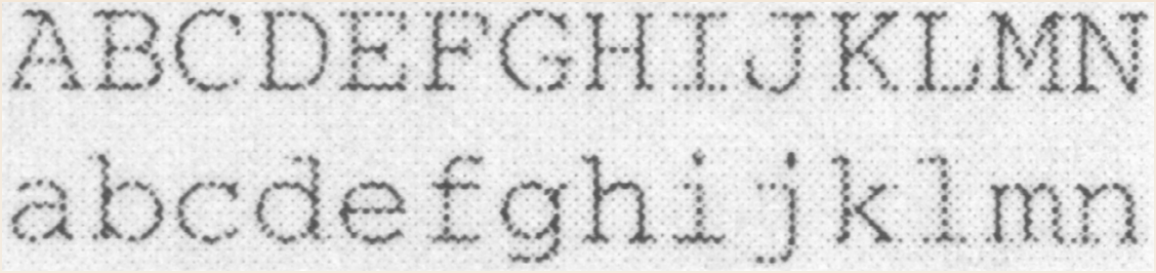
AM/FM halftoning



Floyd-Steinberg error diffusion



PhotoTone

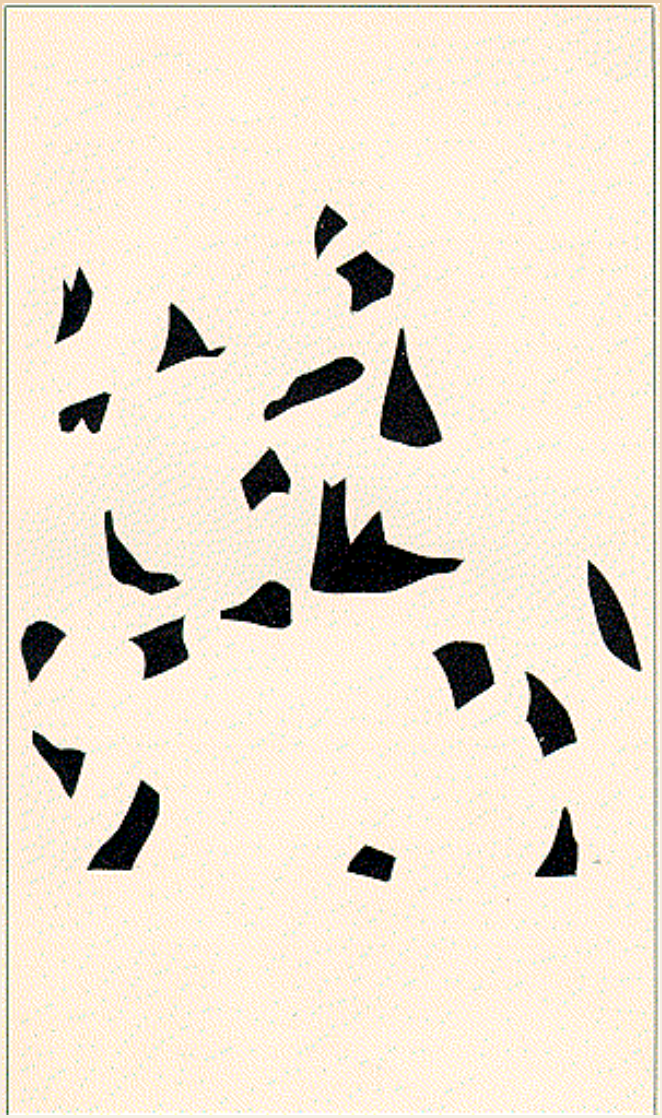


GCP-2: Automated Extraction of Perceptual Organization

- Segregation of figure/ground
  - Essential in many imaging problems
  - An unsolved problem
- Association of component hierarchies
  - Natural scenes
  - Objects
  - Documents

Familiarity (Experience) in Perception

(Courtesy of Zygmunt Pizlo)

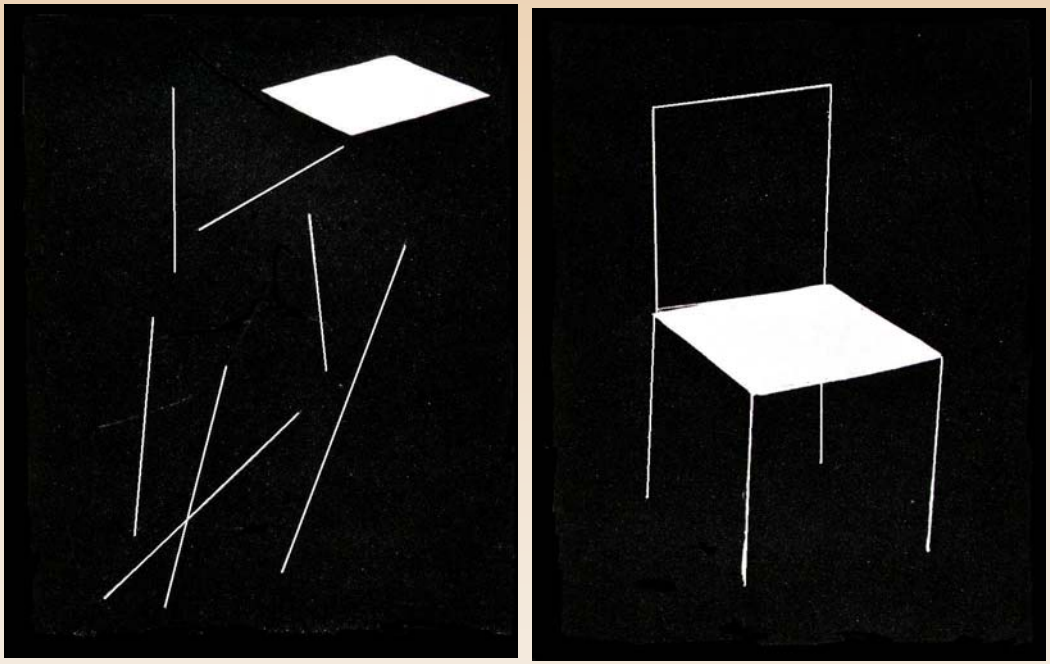


Street (1931)

Familiarity as a Constraint:
Transactional Psychology

(Courtesy of Zygmunt Pizlo)

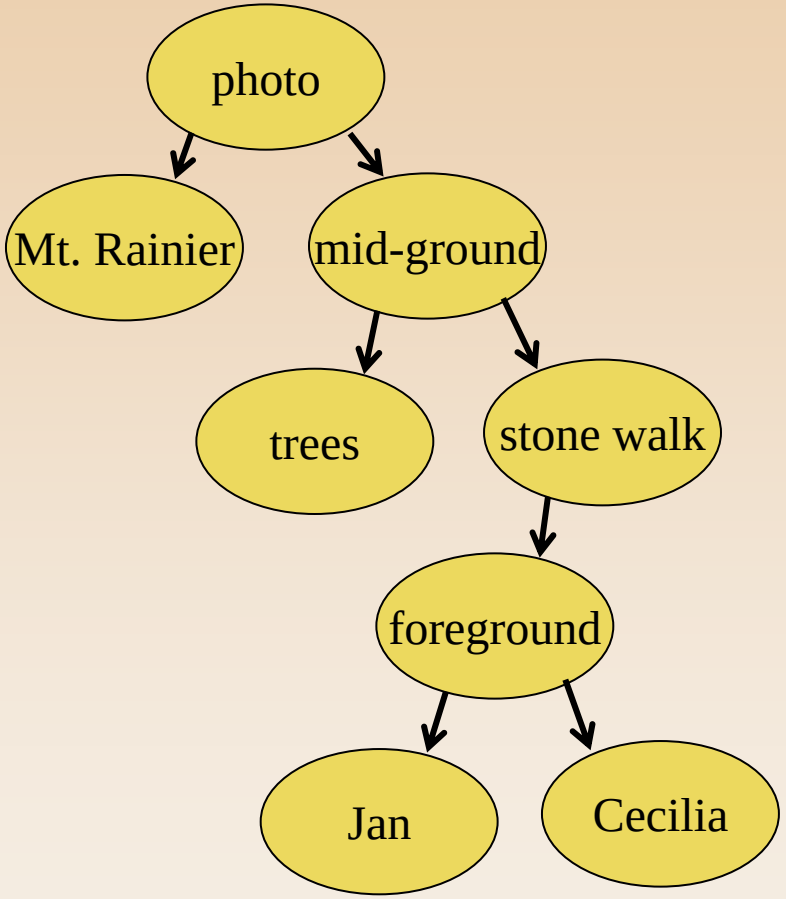
Two views of the same set of rods and a planar figure.



Ames (1950)

We usually operate in a familiar environment. Perhaps we just learned how the objects look. Constraints are then provided by the prior probability.

Perceptual Organization*

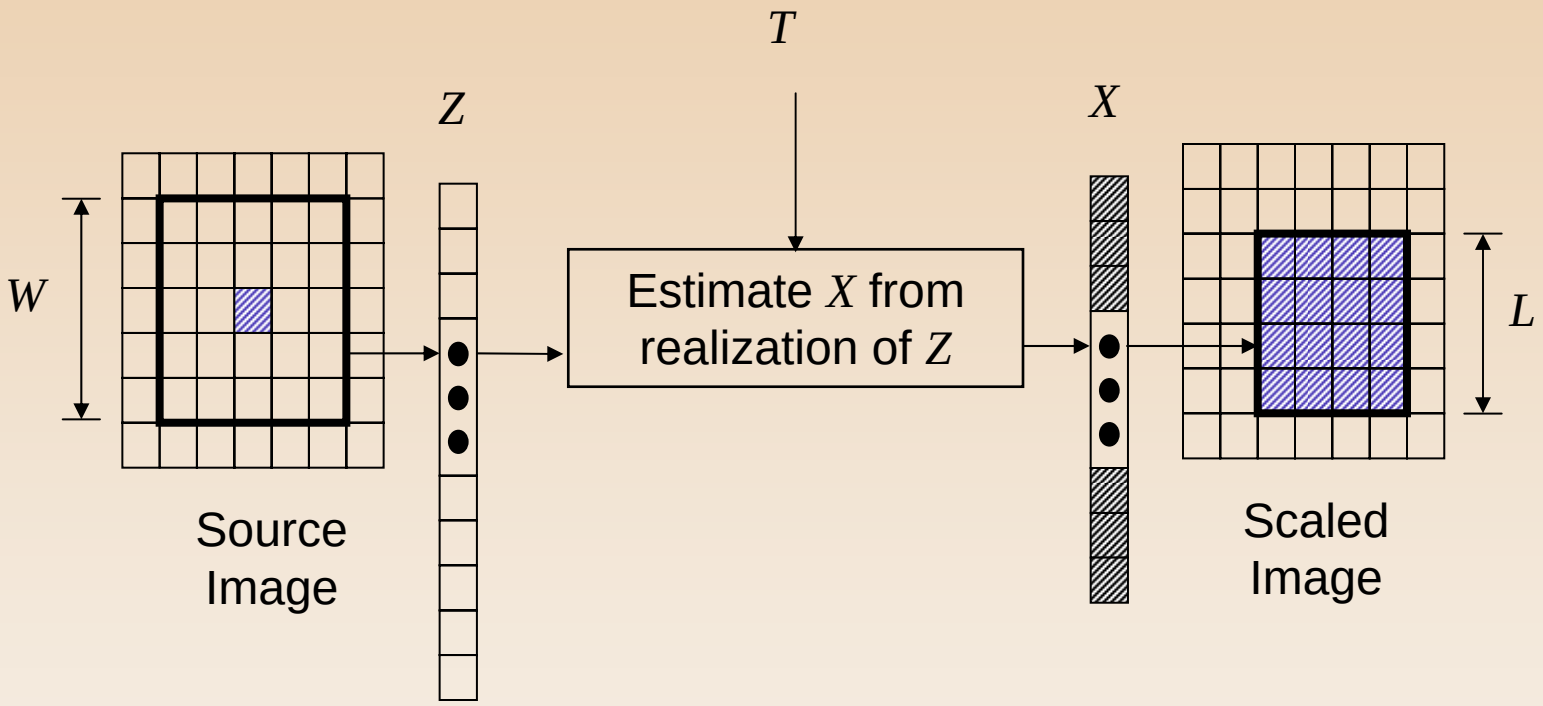


*courtesy of Jan Allebach and Cecilia Weber

GCP-3: High Level Interpretation for Image Processing and Render

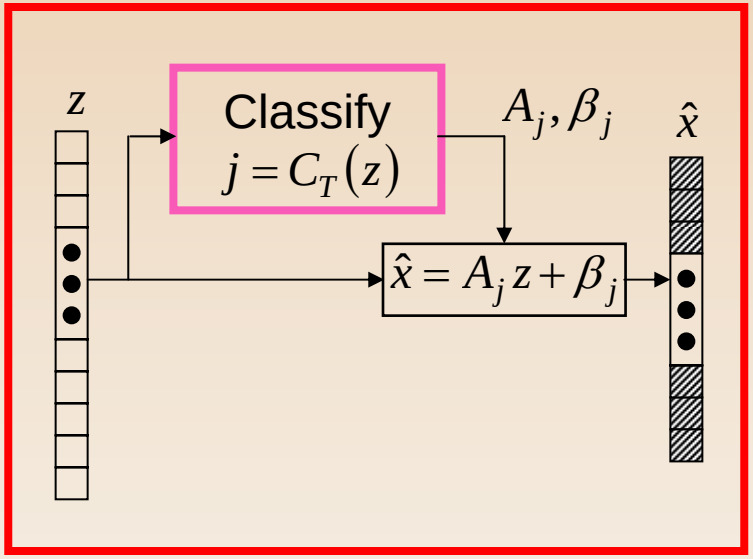
- Context provides information that can be used to:
  - Enhance image quality
  - Improve rendering
  - Increase compression
  - Re-render image
- Contextual information can range from:
  - Low level
    - Local pixel
    - Pixel window
  - Midlevel
    - Wavelet coefficients
    - Pyramid representations
    - Feature vector extraction
  - High level
    - Figure/ground segregation
    - Object recognition
    - Face recognition
    - Image interpretation

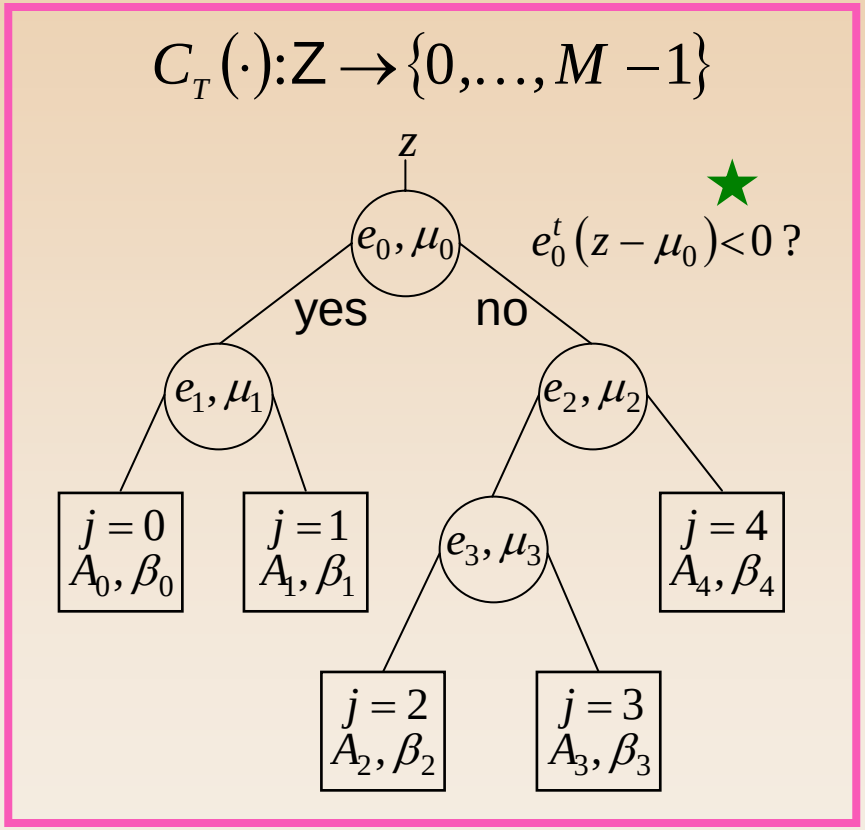
Example 1: image scaling by tree-based resolution synthesis*



*with Brian Atkins and Jan Allebach

Structure of estimator*





*with Brian Atkins and Jan Allebach

4X scaling results*

Photoshop Bicubic Interpolation

Tree-Based Resolution Synthesis

*with Brian Atkins and Jan Allebach

Mixed Raster Content (MRC) Document Compression*

Scanned Document

Synthetic Document

*with Guotong Feng and Hui Cheng

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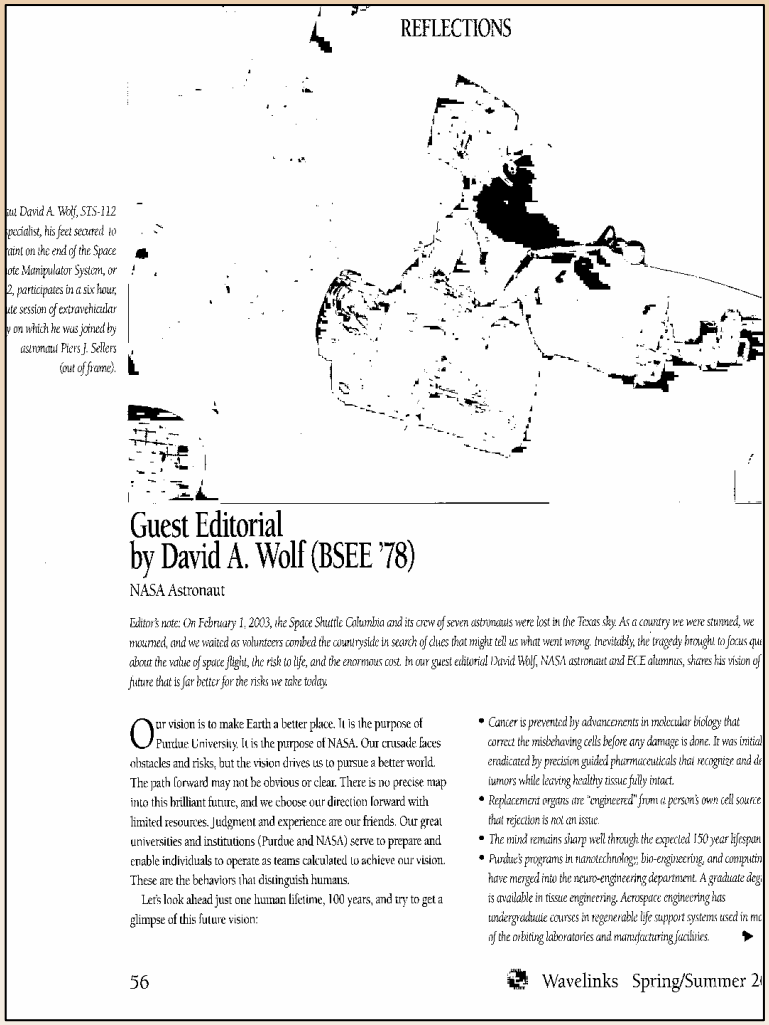
Binary Mask of Scanned Test Image*



REFLECTIONS

...ut David A. Wolf, STS-112 ...pecialist, his feet secured to ...aint on the end of the Space ...ote Manipulator System, or ...2, participates in a six hour, ...ute session of extravehicular ...y on which he was joined by ... astronaut Piers J. Sellers (out of frame).

Guest Editorial
by David A. Wolf (BSEE '78)

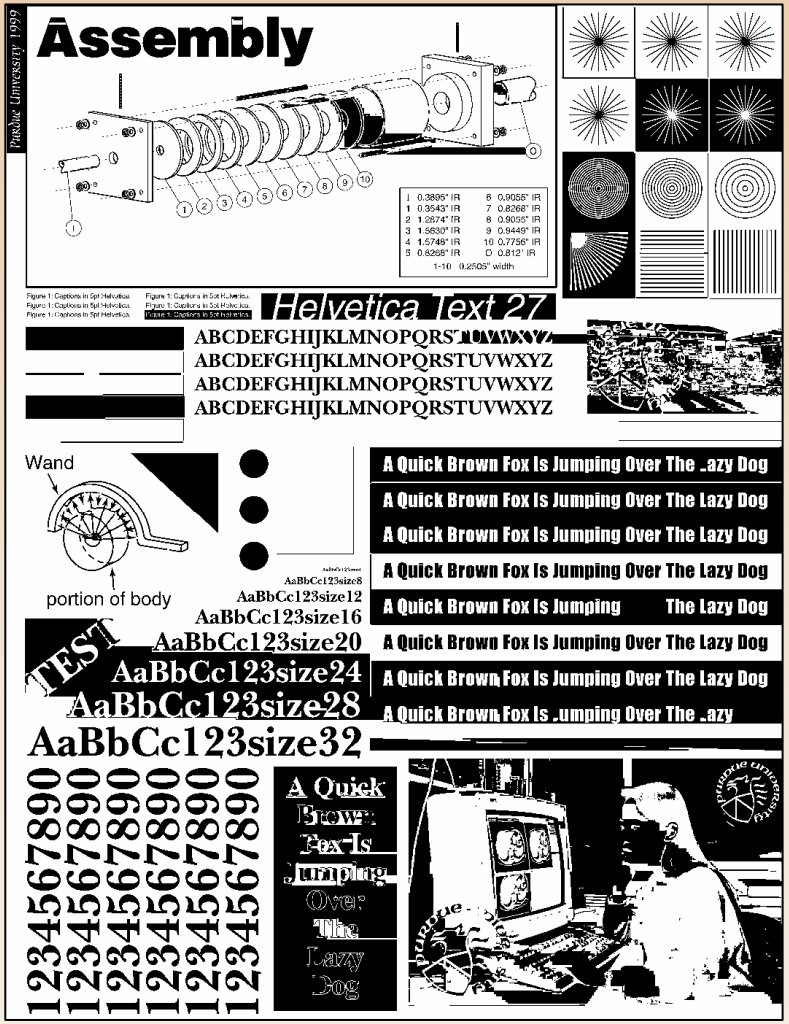
NASA Astronaut

Editor's note: On February 1, 2003, the Space Shuttle Columbia and its crew of seven astronauts were lost in the Texas sky. As a country we were stunned, we mourned, and we waited as volunteers combed the countryside in search of clues that might tell us what went wrong. Inevitably, the tragedy brought to focus qu... about the value of space flight, the risk to life, and the enormous cost. In our guest editorial David Wolf, NASA astronaut and ECE alumnus, shares his vision of future that is far better for the risks we take today.

Our vision is to make Earth a better place. It is the purpose of Purdue University. It is the purpose of NASA. Our crusade faces obstacles and risks, but the vision drives us to pursue a better world. The path forward may not be obvious or clear. There is no precise map into this brilliant future, and we choose our direction forward with limited resources. Judgment and experience are our friends. Our great universities and institutions (Purdue and NASA) serve to prepare and enable individuals to operate as teams calculated to achieve our vision. These are the behaviors that distinguish humans.

Let's look ahead just one human lifetime, 100 years, and try to get a glimpse of this future vision:

- *Cancer is prevented by advancements in molecular biology that correct the misbehaving cells before any damage is done. It was initial... eradicated by precision guided pharmaceuticals that recognize and de... tumors while leaving healthy tissue fully intact.*
- *Replacement organs are "engineered" from a person's own cell source ... that rejection is not an issue.*
- *The mind remains sharp well through the expected 150 year lifespan.*
- *Purdue's programs in nanotechnology, bio-engineering, and computin... have merged into the neuro-engineering department. A graduate deg... is available in tissue engineering. Aerospace engineering has undergraduate courses in regenerable life support systems used in m... of the orbiting laboratories and manufacturing facilities.*



Generated from **RDOS-MRC**, 400 dpi

*with Guotong Feng and Hui Cheng

Generated from **RDOS-MRC**, 400 dpi

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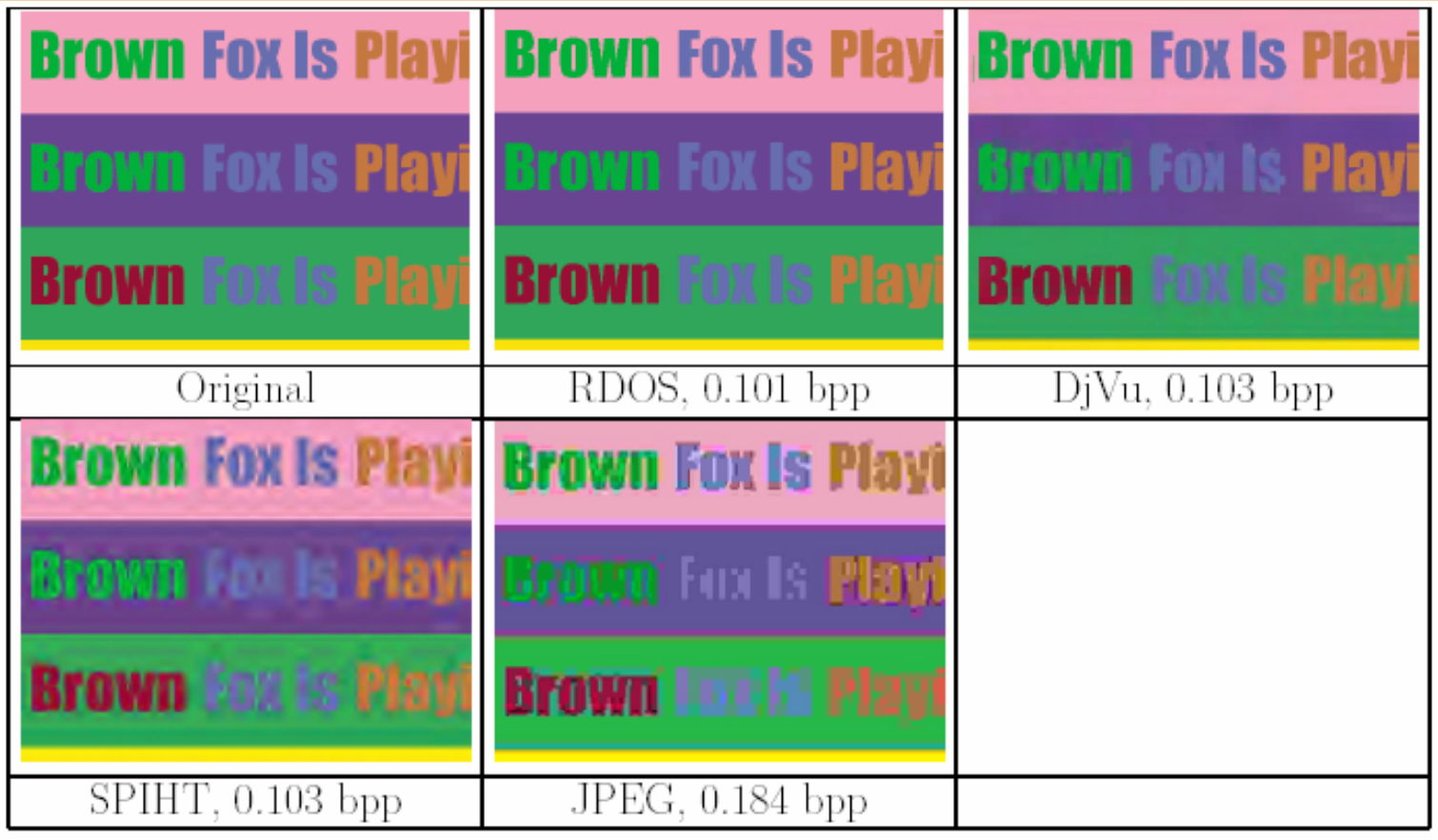
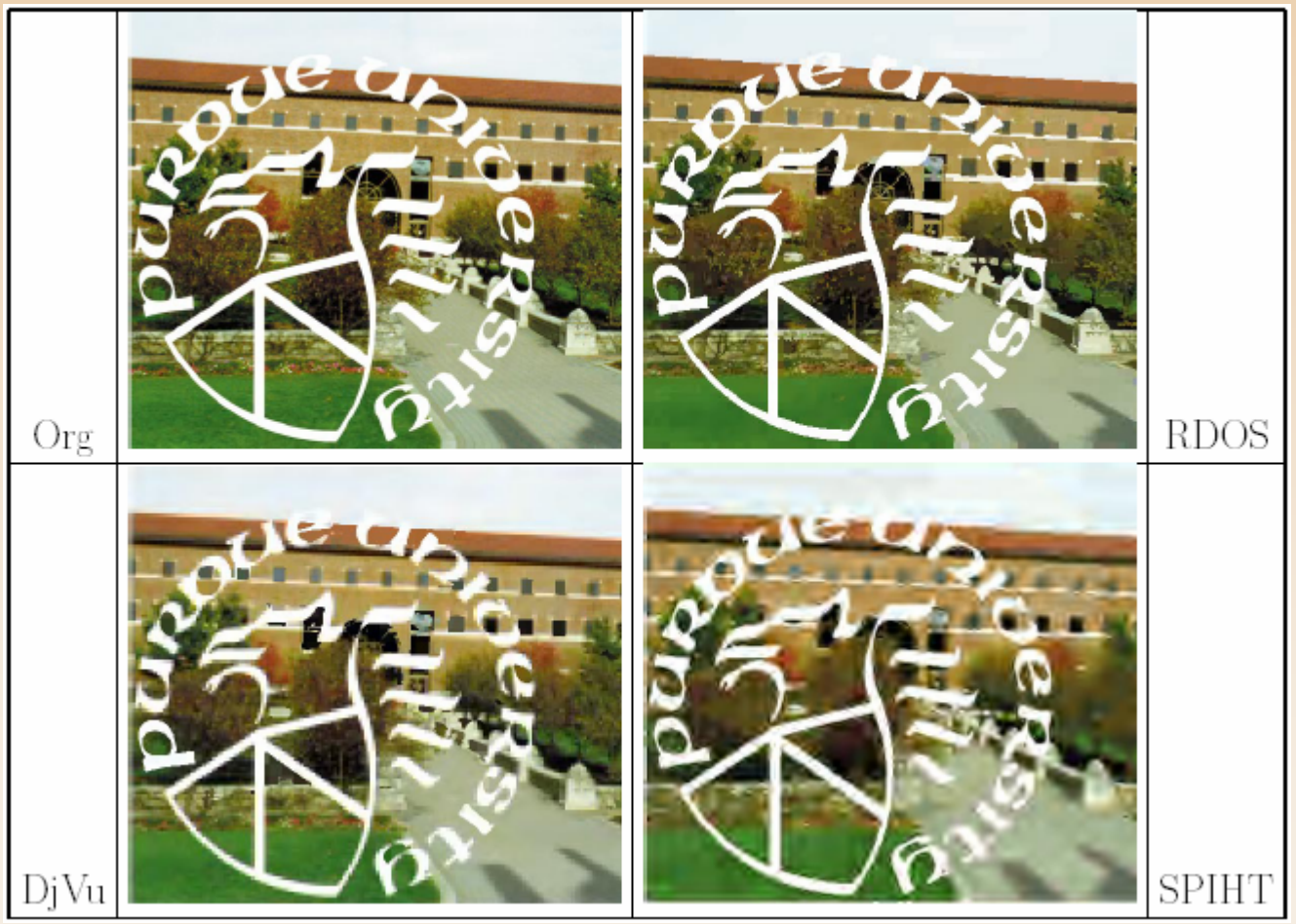
Comparison of RDOS, DjVu, SPHIT, and JPEG*



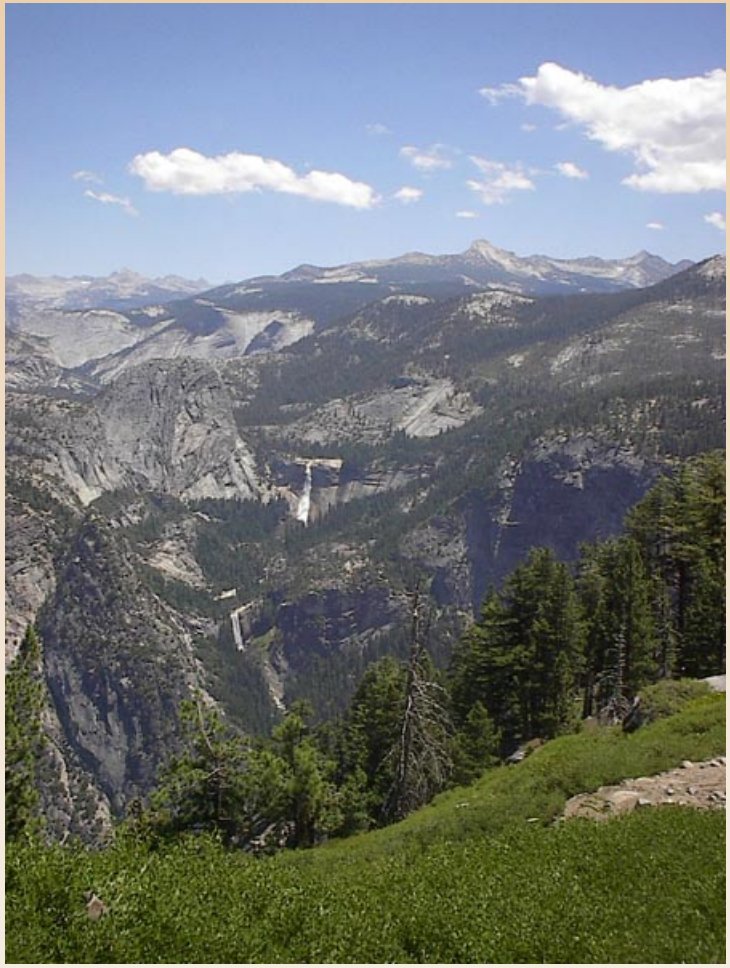
*with Guotong Feng and Hui Cheng

Comparison of RDOS, DjVu, and SPHIT*



*with Guotong Feng and Hui Cheng

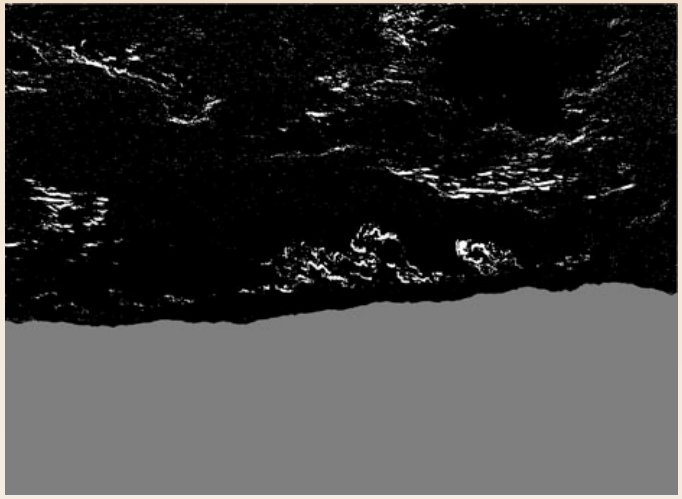
Higher level means more semantic: haze removal in outdoor scenes*



Original

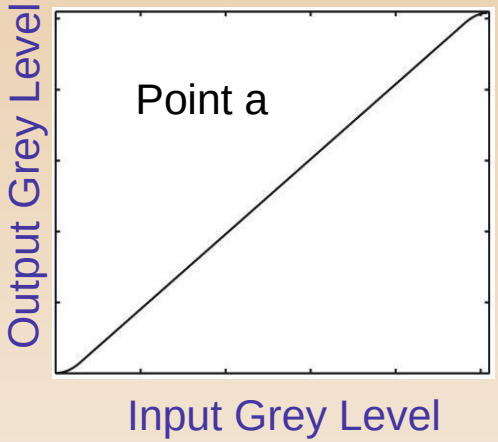
*Maria Groszek, Jan Allebach and Zygmunt Pizlo, EI 2005

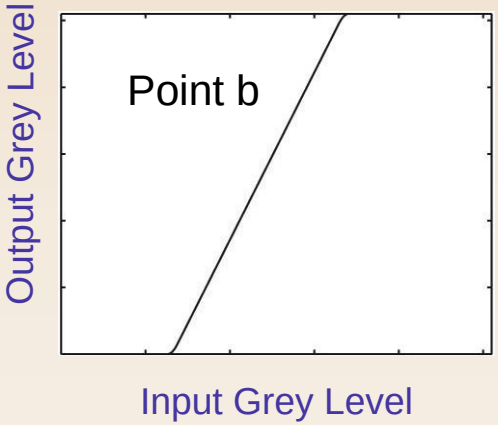
Generate edge map, then find connected components in sky and ground

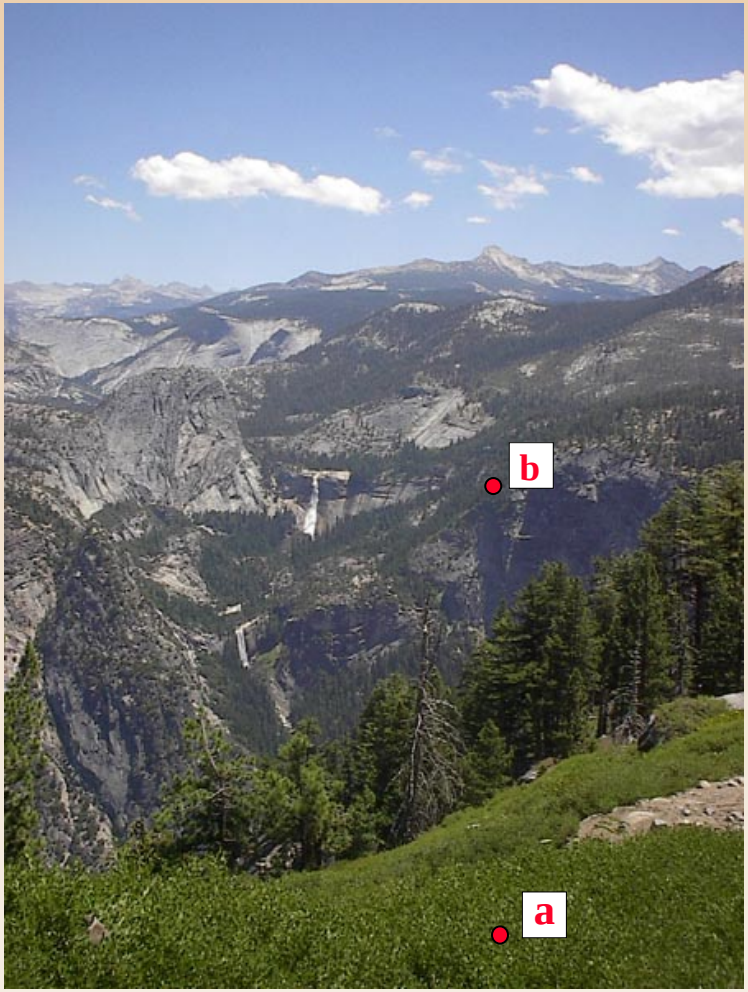


Contrast enhancement steps

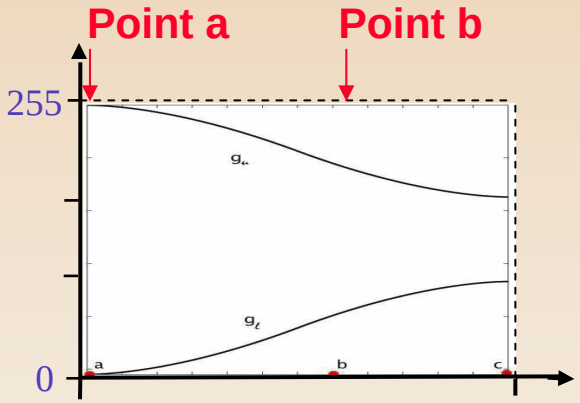
Contrast enhancement curve



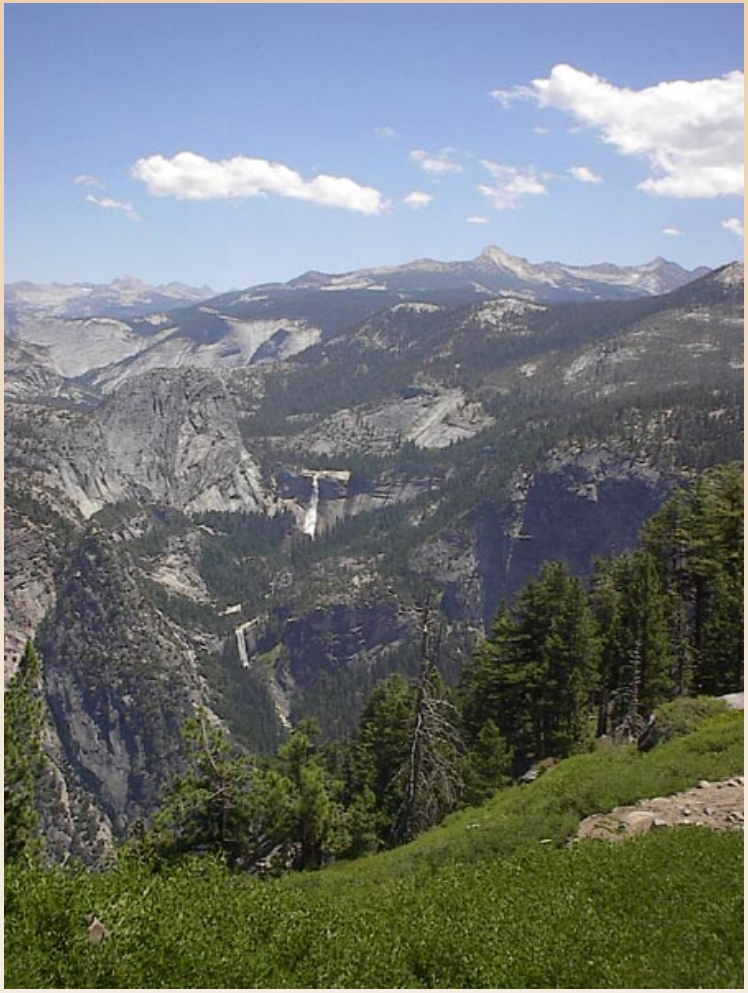




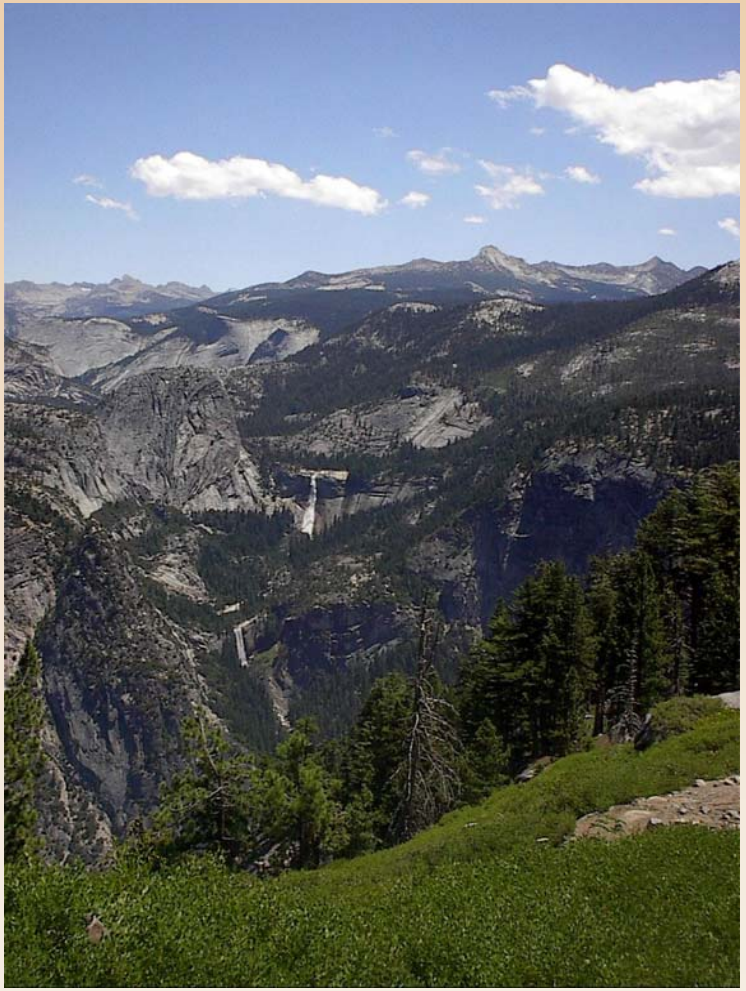
Parameter selection curve



Contrast enhancement example



Original

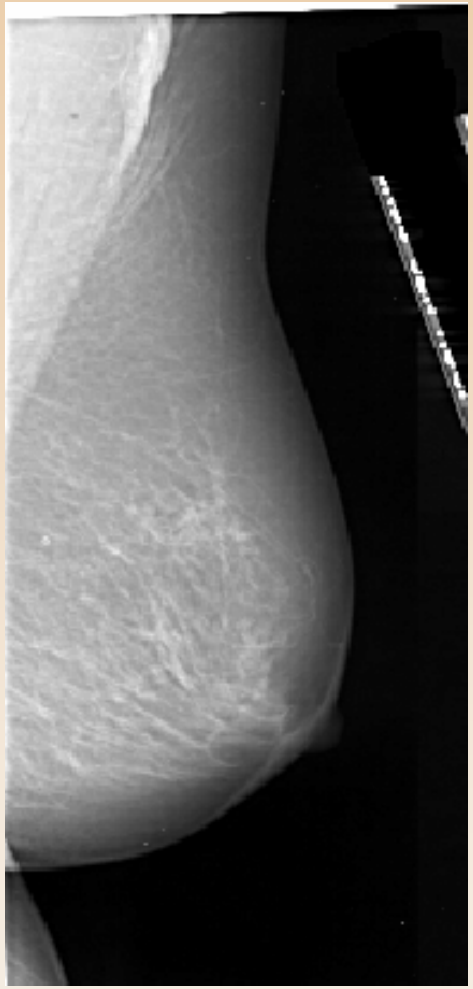


Contrast Enhanced

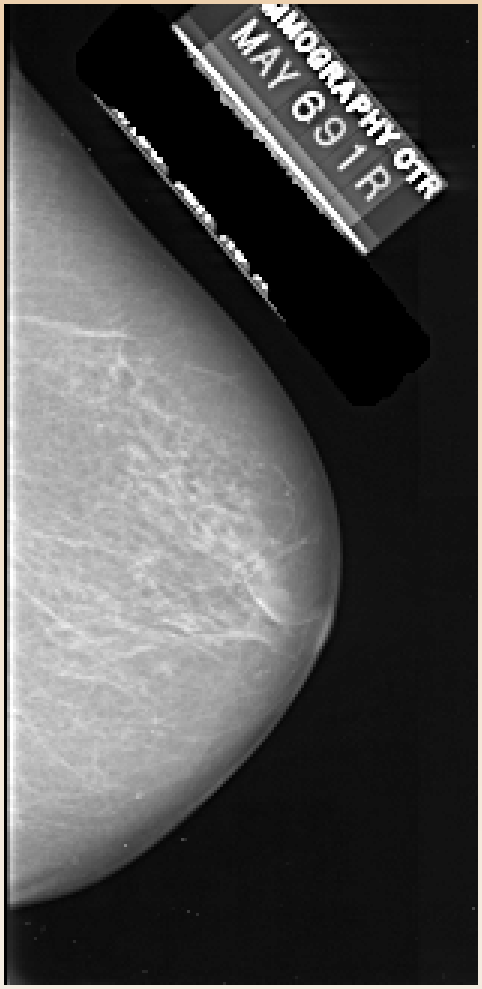
GCP-4: Eliminate the Professional Image Analyst

- Computer aided diagnostics (CAD):
  - Human radiologist have at least 15% false negatives in reading mamograms
  - Cost of human radiologist is very high
  - Legal liabilities for human interpretation are high
  - It is difficult for humans to be consistent in this type of repetitive task
- Other venues for Professional Image Analysts
  - Remote sensing data
  - Surveillance
- Advantages of automated analysis
  - Advantage with high dimensional/high dynamic range data
  - Eliminates human fatigue
  - Less subjective

Normal Mammograms*



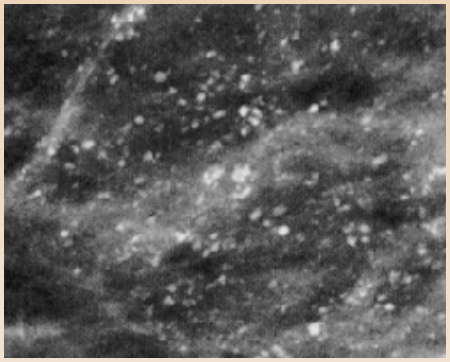
Mediolateral oblique (MLO)



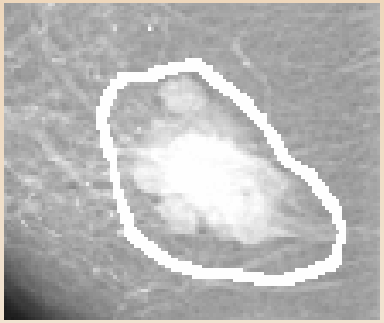
Craniocaudal (CC)

*courtesy of Edward Delp

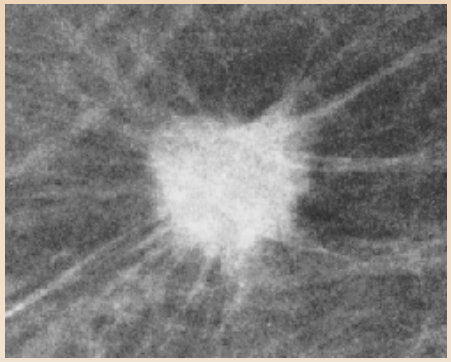
Three Major Breast Cancers*



Micro-calcification



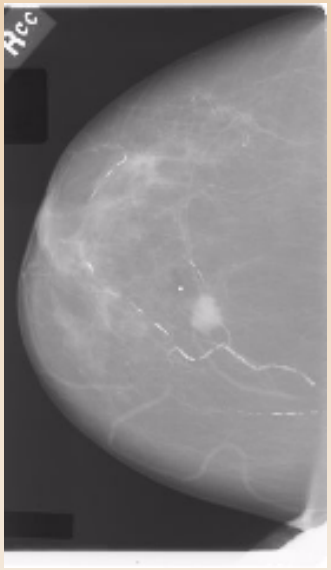
Circumscribed Mass



Spiculated Lesion

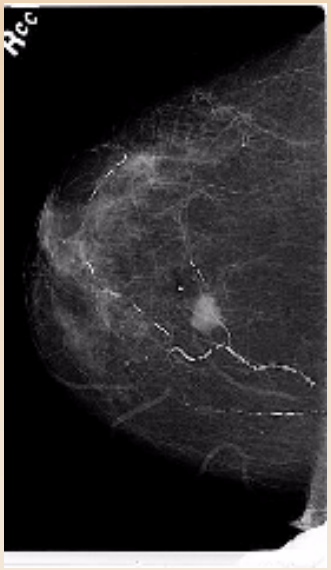
*courtesy of Edward Delp

Full-field Normal Analysis - Spiculation*



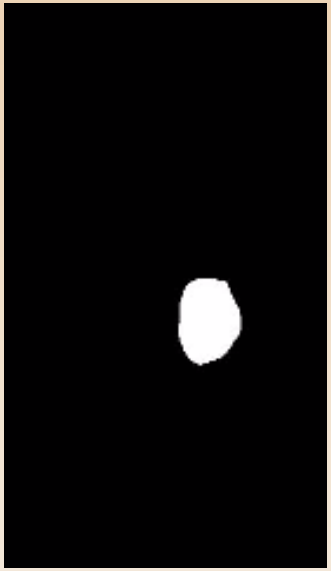
(a)

Original Mammo



(b)

I_E

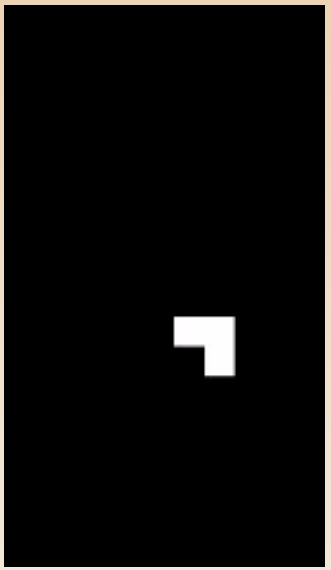


(c)

Ground Truth

(d)

Visualization Of *5* Labels



(e)

Binary Result

*courtesy of Edward Delp

GCP-5: Extraction of Image Pedigree

- Where did the image come from?
- What sensor acquired the image?
- What device rendered the image?
- Have their been any modifications to the image?

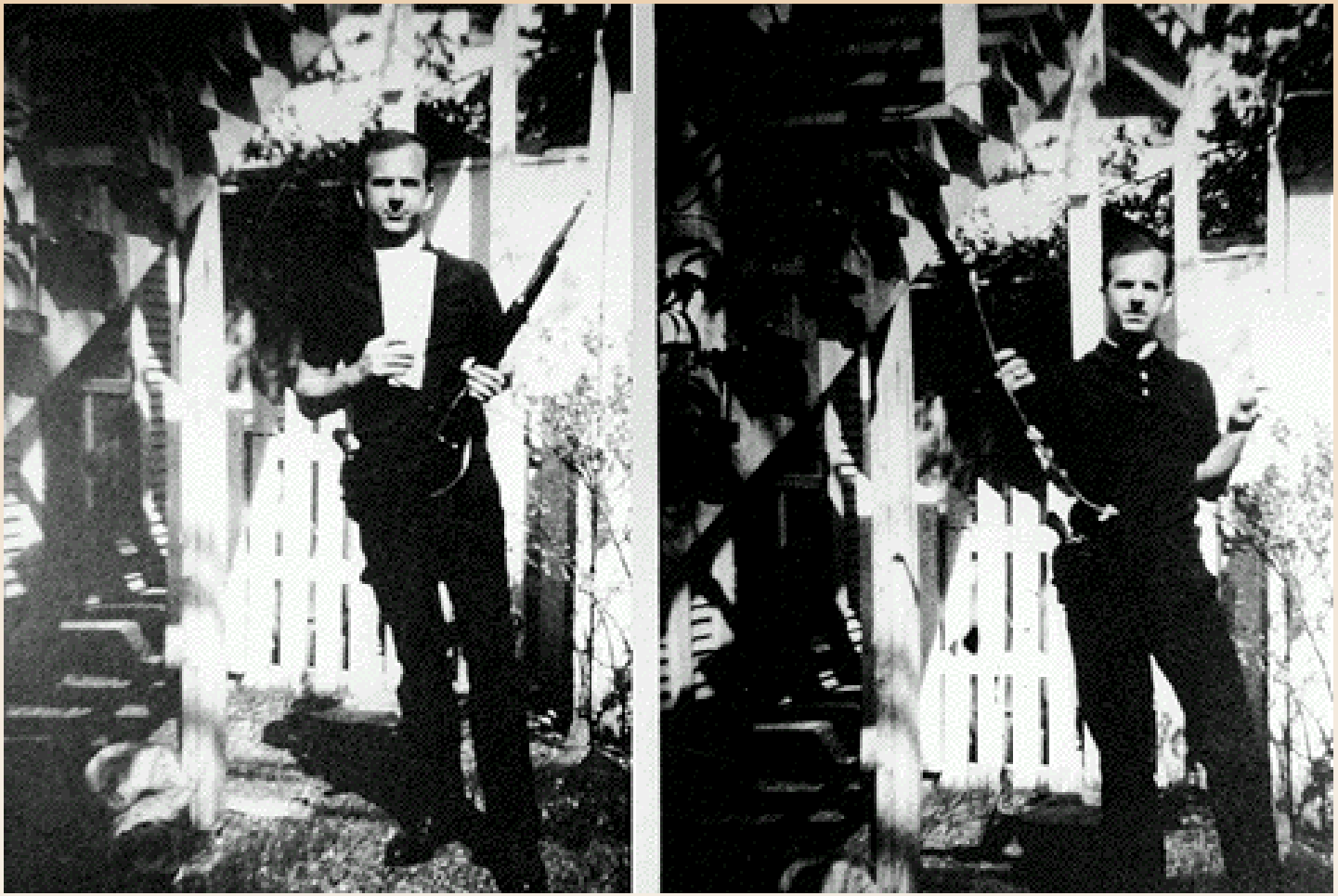
Why is Watermarking Important?*

*courtesy of Edward Delp

Why is Watermarking Important?*

*courtesy of Edward Delp

Why Watermarking is Important?*



*courtesy of Edward Delp

Why is Watermarking Important?*

*courtesy of Edward Delp

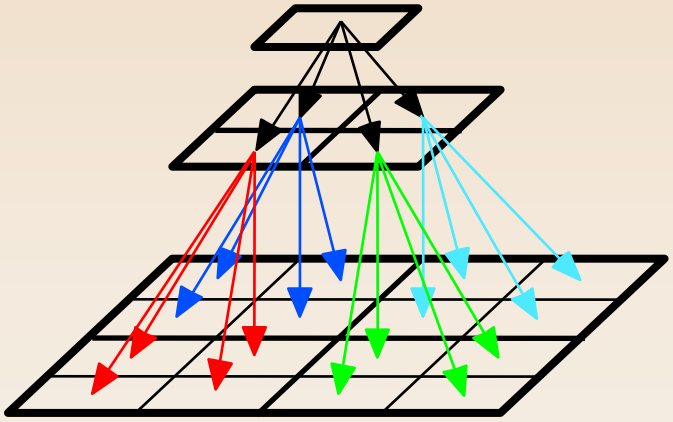
GCP-6: Tools for Managing the Information Explosion

- Personal Media
  - Digital photos
  - Video content
- Public media
  - Movies
  - Audio

Browsing with a Similarity Pyramid*

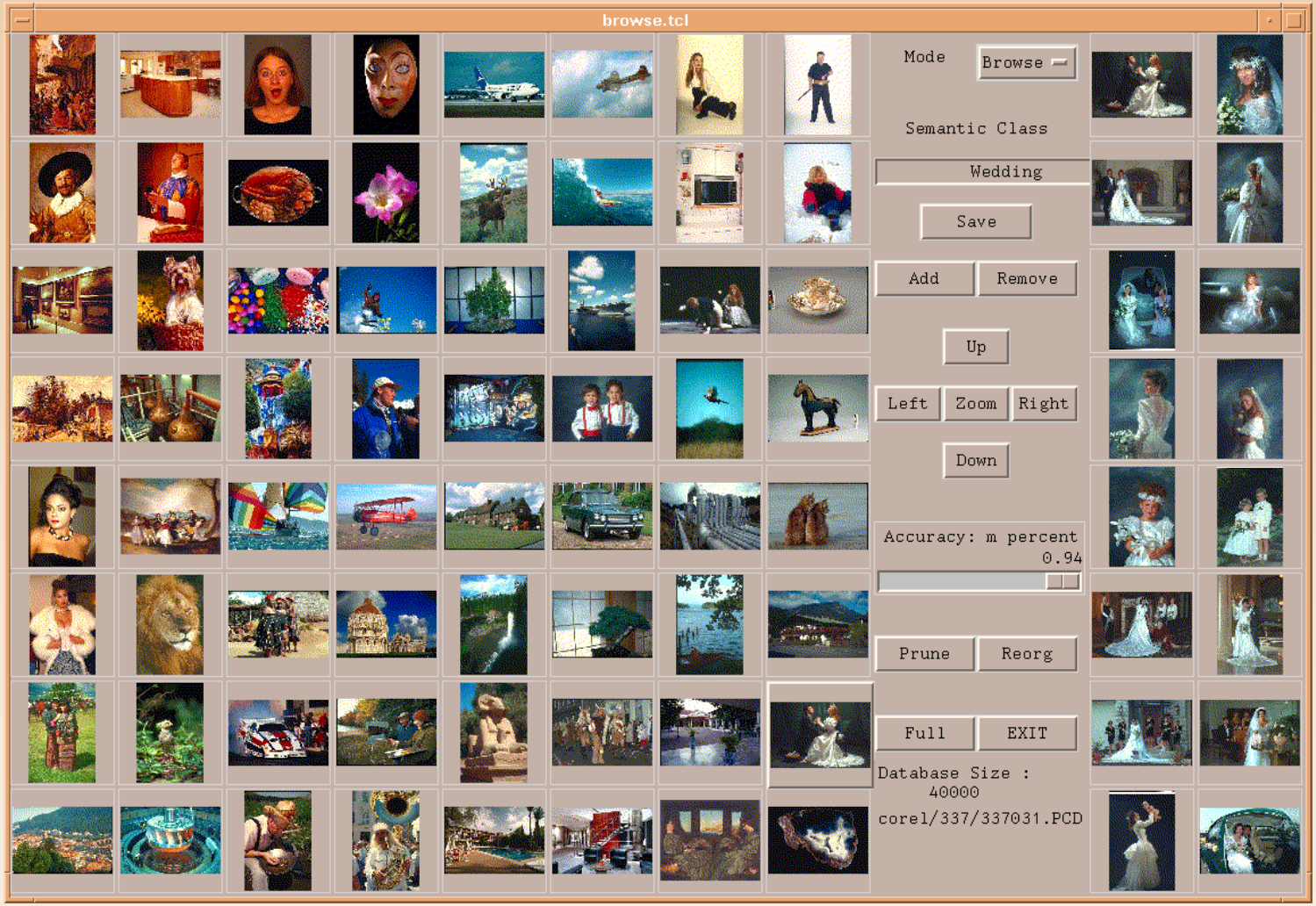
- **Organize database in pyramid structure**
- **Top level of pyramid represents global variations**
- **Bottom level of pyramid represents individual images**
- **Spatial arrangement makes most similar documents neighbors**

- **Example using images:**



*with Jau-Yuen Chen and John Dalton

Browser Interface*



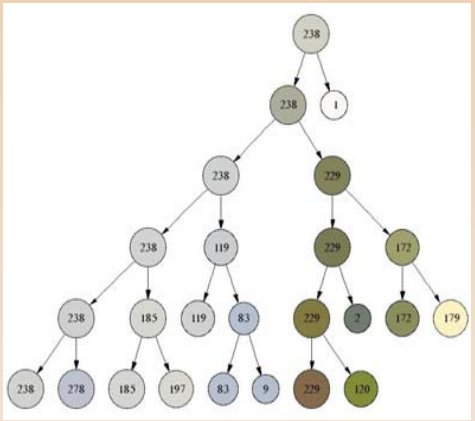
Similarity Pyramid **Control Panel** **Relevance Set**

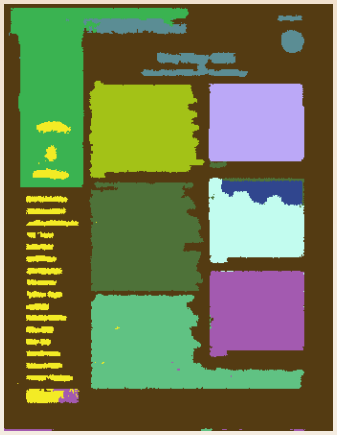
*with Jau-Yuen Chen and John Dalton

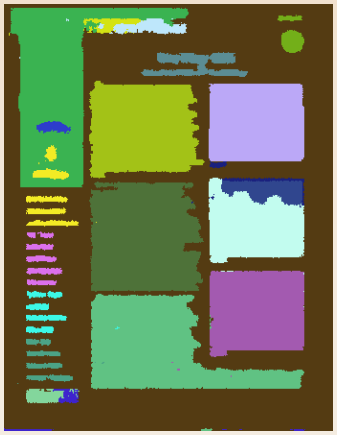
GCP-7: Documents that Write Themselves

- Slurping up information from the web
  - Written content
  - Images/video/graphics
  - Organization
- Document creation
  - Computer automated versus computer assisted
  - Composition versus copying

HDD Construction: A Region Merging Example*







*with Ilya Pollak and Jan Allebach

Document Image and Corresponding Tree*

Turfgrass Disease Profiles — Gray Snow Mold — BP-101-W

snow cover exceeds 90 days. For taller mown turf, some less conspicuous symptoms may occur after 40 days of snow cover.

Disease Control Options

Cultural Control Options

Areas of turf killed by gray snow mold infection may be repaired by over-seeding as soon as possible in the spring. Unfortunately, cool season turfgrass species appear to be uniformly susceptible to gray snow mold, so use of resistant varieties is not an option at this time. Cultural practices that limit symptom expression and lessen the likelihood of poor quality turf during the green-up period in spring involve mowing and snow management. Continued mowing of lawns, landscapes, sports fields, and golf course roughs to a height of 2 1/2" into the dormant period will decrease the risk that matted turf will provide favorable environmental conditions for disease development. Snow management (strategic snow removal and use of snow fences) will limit the opportunities for extended periods of snow cover in locations where quality turf is a high priority. Figure 5 shows snow mold damage to turfgrass adjacent to a sidewalk where show was piled for more than 120 days.

Control with Fungicides

Contact, local systemic, and systemic fungicides are available for gray snow mold control. Since snow cover is essential for infection and disease development, it is important to have protection in place prior to the initial snow fall. Under conditions favorable for gray snow mold development, unprotected turf can suffer severe damage (Fig. 6 center), compared to turf protected with effective fungicides (Fig. 6 right). In central Indiana, most golf course superintendents apply a contact fungicide between Thanksgiving and the Christmas holidays. Frequently used contact fungicides are chlorothalonil (Daconil®) and PCNB (Turfcide 400®). Creeping bentgrass treated with PCNB must be dormant (or approaching dormancy) at the time of application because the fungicide is toxic to actively growing bentgrass at rates effective for snow mold control. In some cases, especially if the duration of snow cover was greater than normal, superintendents will apply fungicides again during a late winter thaw or very early in the spring. This application can be made with an effective systemic fungicide if grass is beginning to grow. Otherwise, contact or local systemic fungicides are preferred. The late-winter/early spring application will help turf recover sooner and will offer protection against late development of pink snow mold.

Figure 4

Figure 5

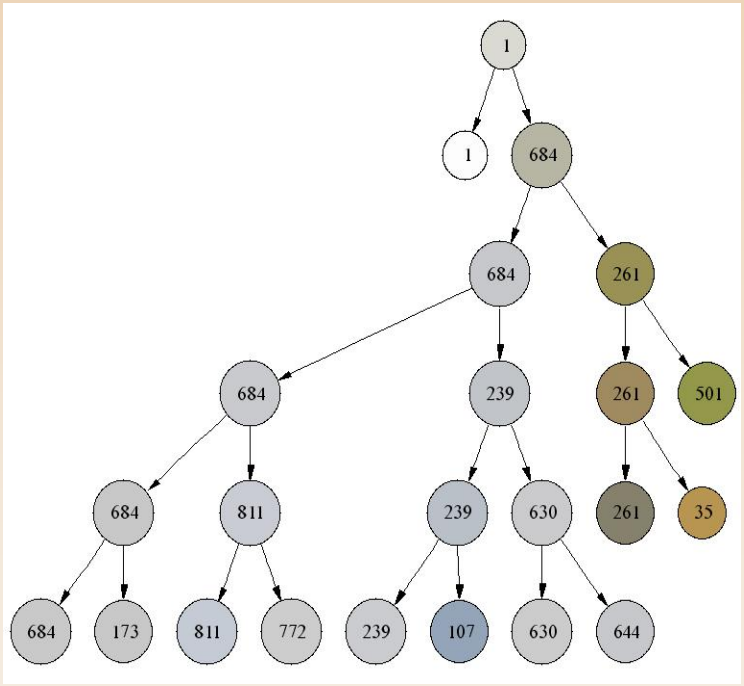
Figure 6

Gray Snow Mold Control for Lawns

Fungicides are not recommended for use against gray snow mold on home lawns. Lasting damage can be avoided by careful attention to cultural control options. Also, in almost all cases, affected turf will recover in spring with moderate levels of maintenance. Cultural control options include appropriate mowing until the turf enters dormancy in late fall and avoiding the accumulation of snow in piles along driveways and sidewalks. Recovery of turf from affected patches may be hastened by raking the matted turfgrass, which facilitates air movement within the turf canopy.

New 5/01

Knowledge to Go — Purdue Extension



*with Ilya Pollak and Jan Allebach

PURDUE UNIVERSITY

Matching Experiment 1

Query Image

PURDUE UNIVERSITY

Looking for the “Other Axis”*

- What is *really* important is often not what we are focused on.
- Music
  - We thought it was audio fidelity
  - It was ease of use, style, fun
- Images
  - We think it is quality
  - It might be ???

*quoted from Reiner Eschbach

(My first cut at)

The Grand Challenge Problems of Digital Imaging

- GCP-1) Inversion of Complex Physical Systems
- GCP-2) Automated Extraction of Perceptual Organization
- GCP-3) High Level Interpretation for Image Processing and Render
- GCP-4) Eliminate the Professional Image Analyst
- GCP-5) Extraction of Image Pedigree
- GCP-6) Tools for Managing the Information Explosion
- GCP-7) Documents that Write Themselves

- Important questions:
  - Are there others that should be added to the list?
  - What, if anything, should we do with this information?