A Systems Approach to Color Scanning

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11/13/97

Acknowledgements

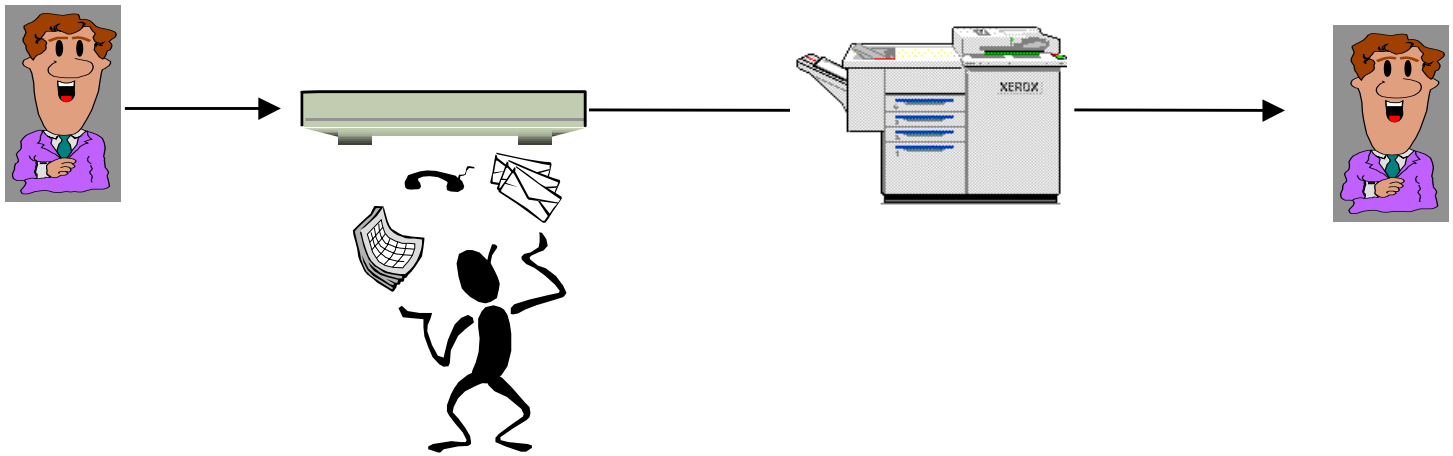
- **Good part from my PhD work at NCSU**
  - **Other contributors from NCSU**
    - **Joel Trussell**
    - **Poorvi Vora**
    - **Michael Vrhel**
- **Shen-ge Wang (ECS Project)**
  - **work, examples, slides**

Outline

- Historical evolution
- Systems Perspective
- Quality factors
- Comparative evaluation
- Conclusions
- Current Work

Historical Evolution of Color Scanning

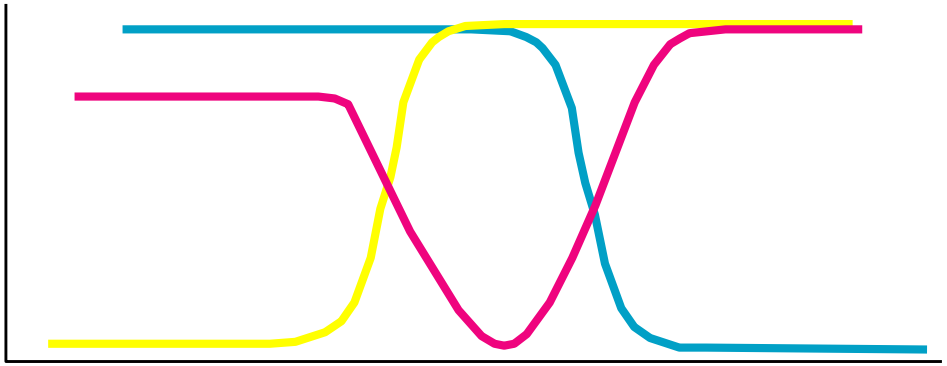
- **Original use in Color printing**
  - **Photographic inputs**
  - **Scanner directly drove printer**
  - **Closed proprietary systems with expert operator**



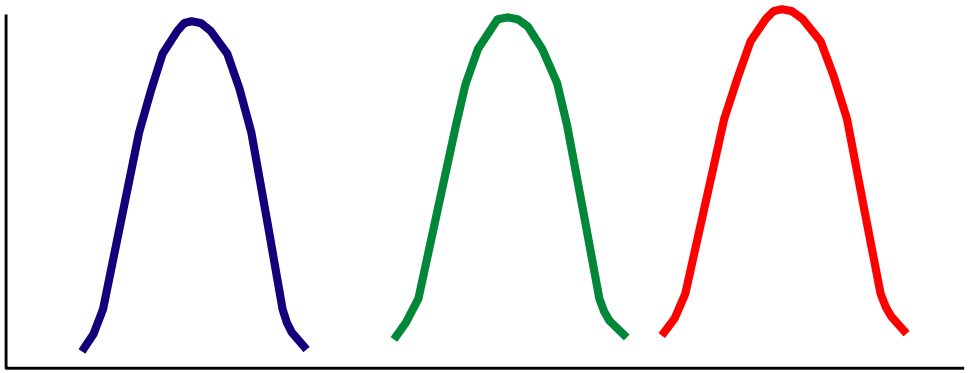
Historical Evolution of Color Scanning

- **Densitometric Scanning**

Photographic dyes

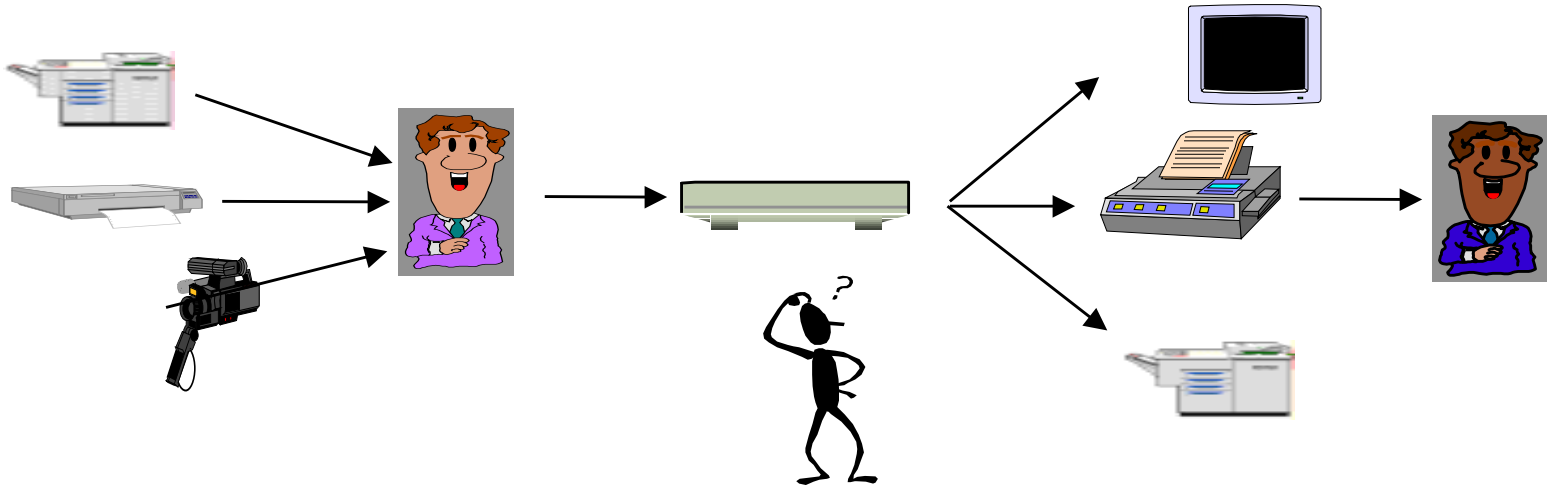


Scanner Color Filters



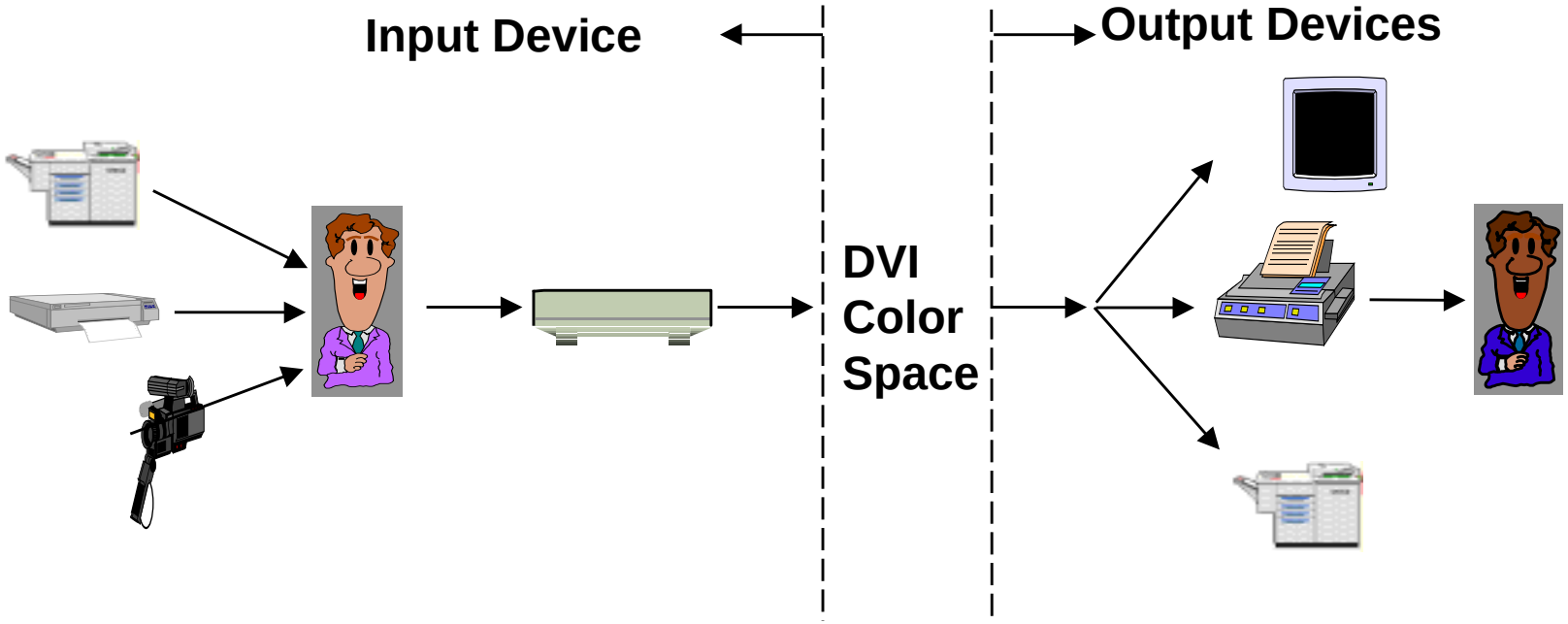
Historical Evolution of Color Scanning

- **Present scenario**
  - Digital images from scanner for multiple uses
  - Multiplicity of input media (photo,litho,xero,inkjet)
  - Open networked systems with novice users
- **Two major problems**
  - Not feasible to relate each I/O device pair
  - densitometry unsuitable for input measurement

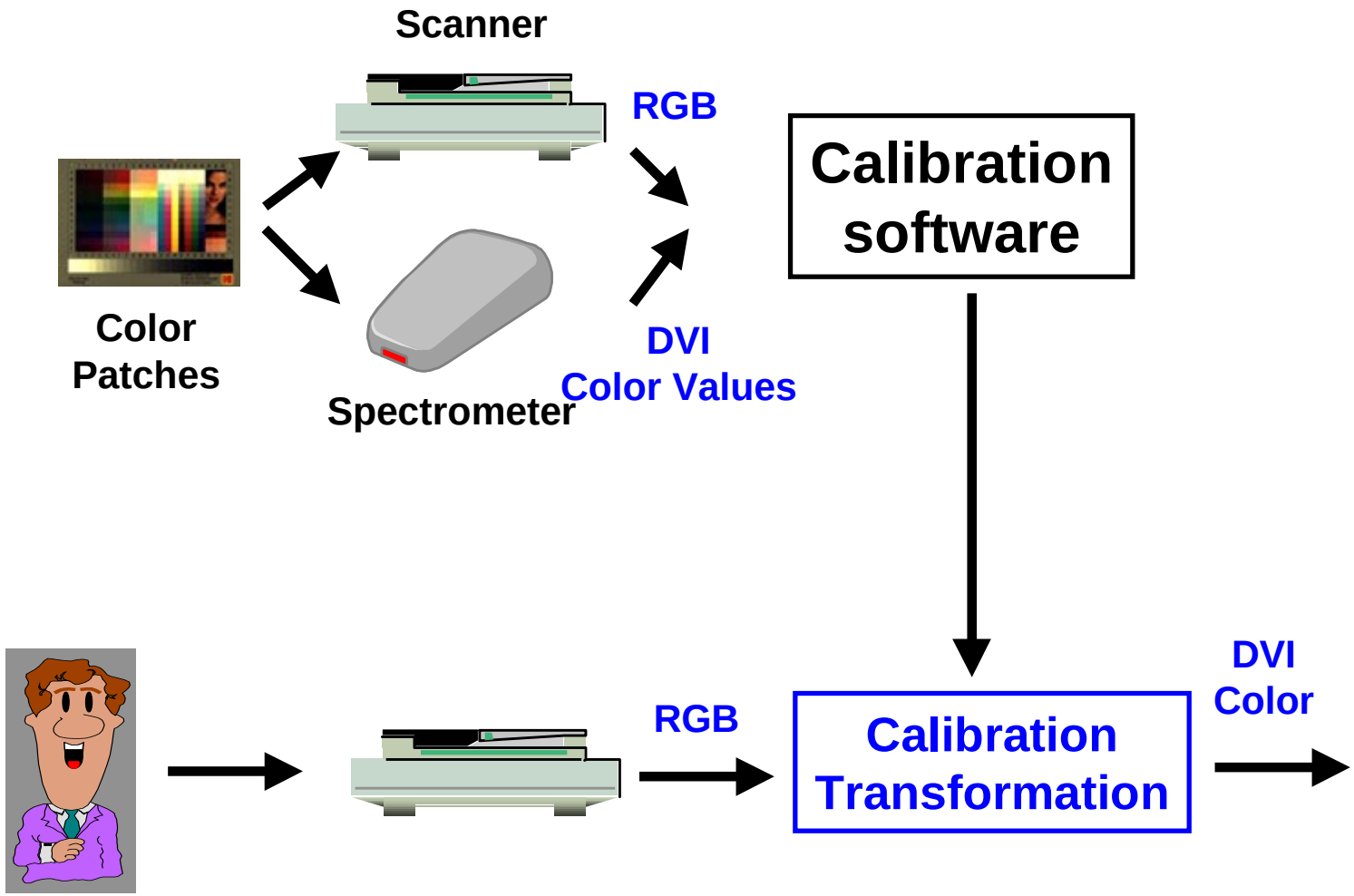


Device Independent (DVI) Color

- **Use common language for communication**
  - calibrate I/O devices to a DVI color space
  - decouples problem and eliminates operator
- **Devices Need Calibration**

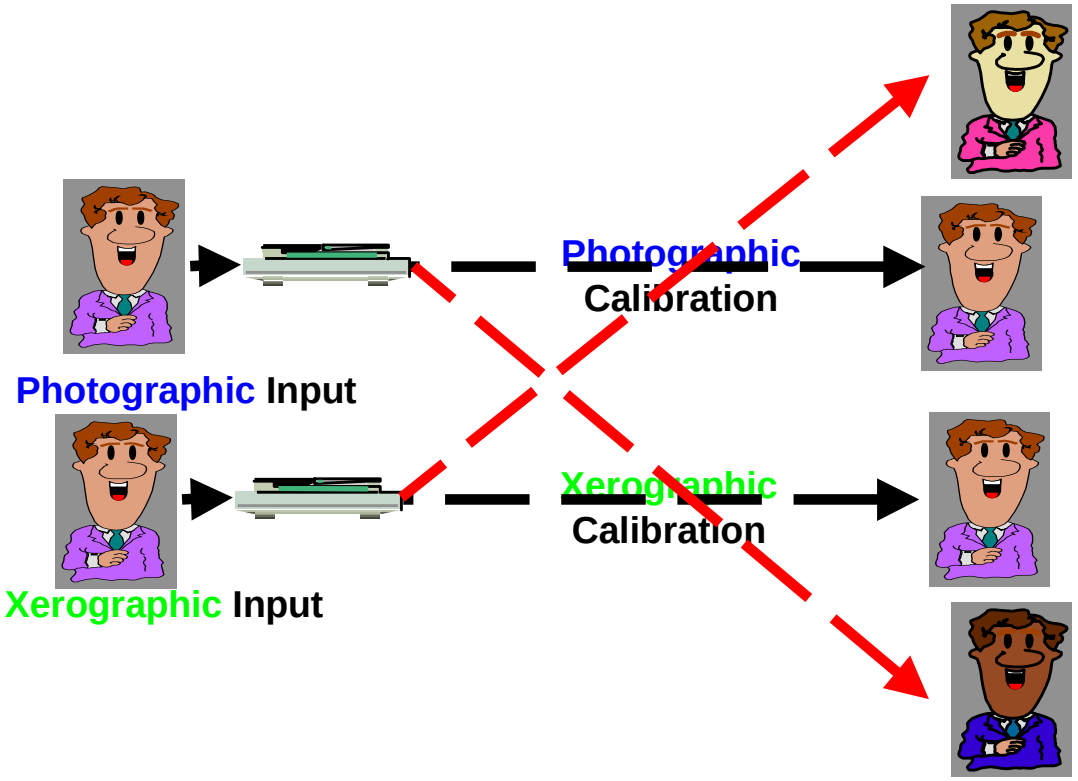


Scanner Calibration



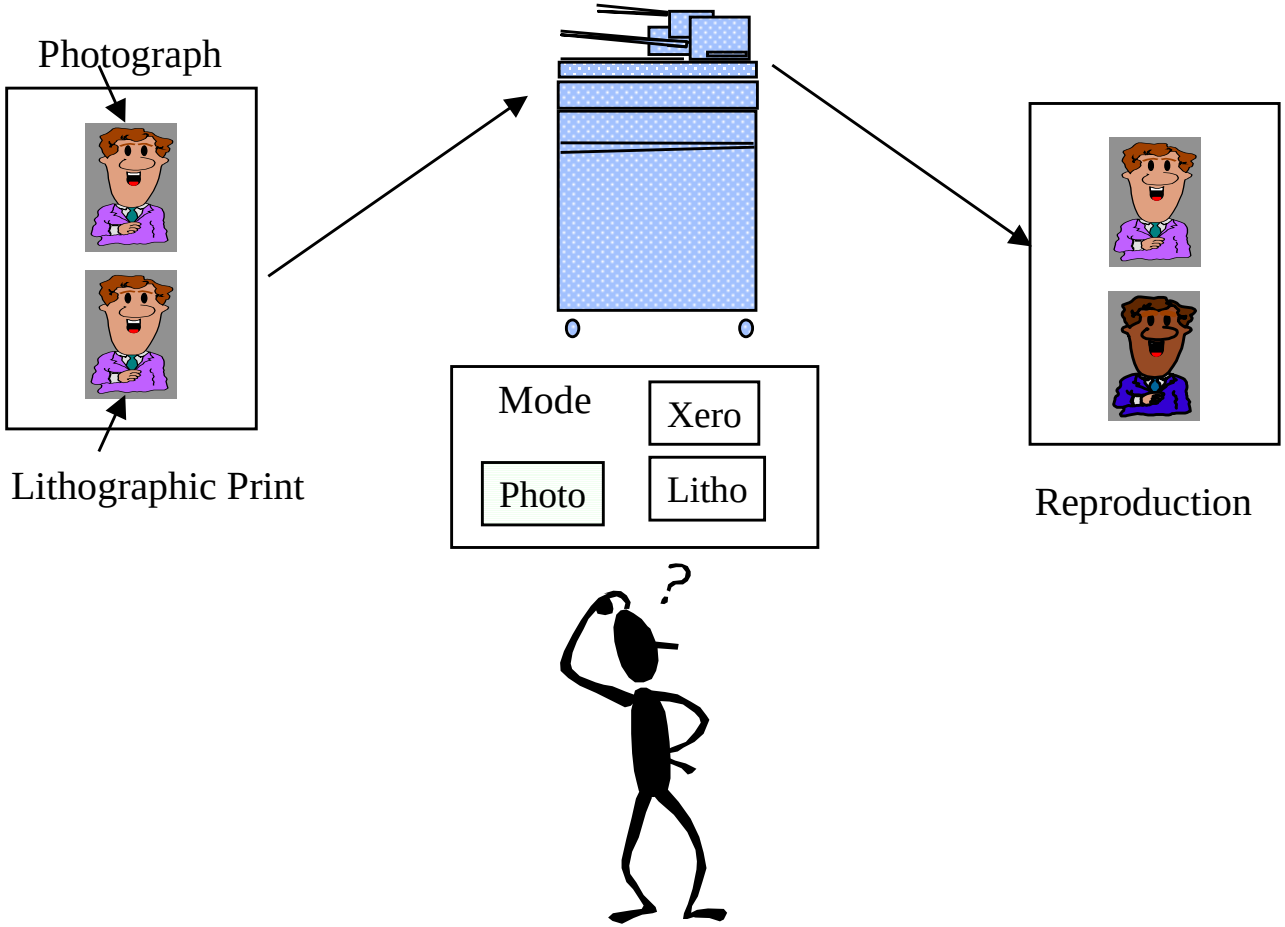
Scanner Calibration

- **Limitation of current color scanners: Different input media require different calibration**

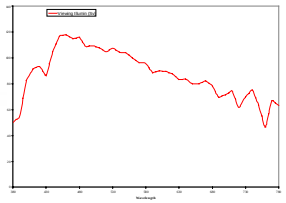


Scanner Calibration

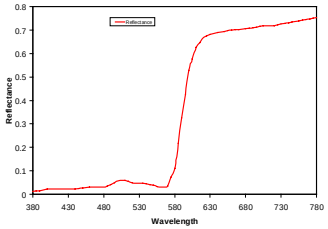
- **User must identify medium**



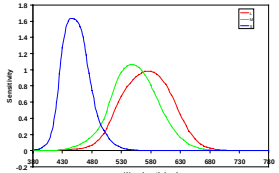
Problem: Eye and Scanner See Color Differently



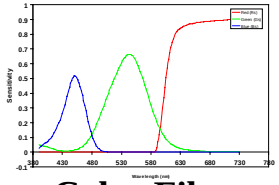
Viewing Lamp



Document reflectance



Cones



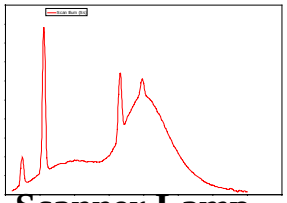
Color Filters

L= 247
M = 142
S = 30

Eye Responses

R= 247
G = 42
B = 22

Scanner Responses

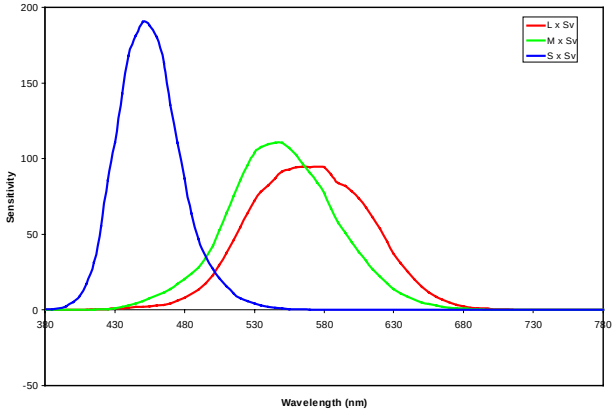


Scanner Lamp

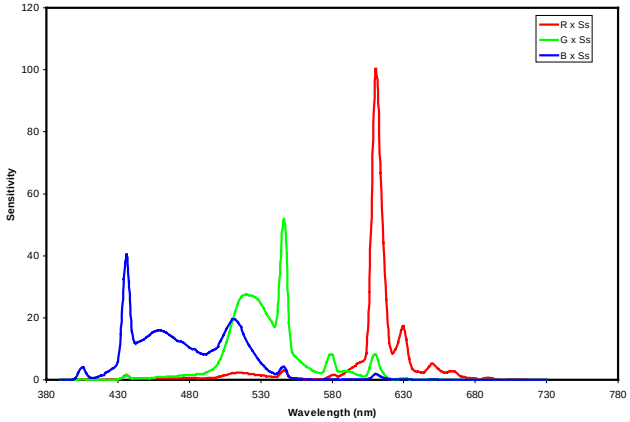
Requirement for Matching Eye

- **Luther-Ives Condition:**

Linear transform



$=$ **T**



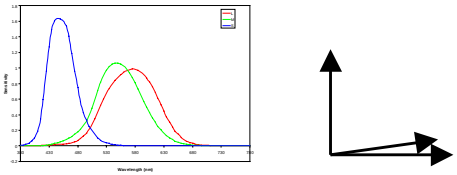
Viewing illum x Cone Sensitivities

Scanning illum x Filter Transmittances

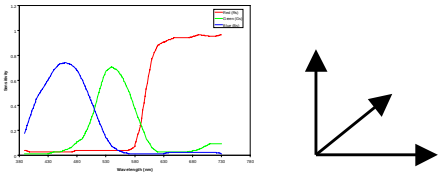
$$A_L = T\ G$$

Colorimetric Scanning

- **Why isn't everybody doing it already ?**
  - **Fabrication of filters that match the eye is not easy**
  - **Signal to noise issues**



Poor SNR

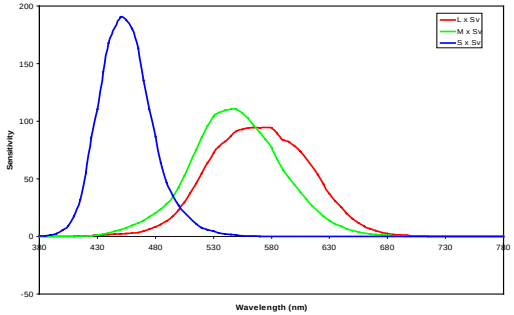


Good SNR

  - **Material and fabrication constraints**
  - **Cost constraints**

Measure of Goodness

- **Needed to evaluate one set of scanner sensitivities in relation to another**



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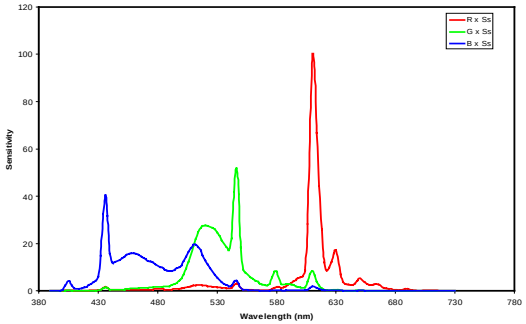
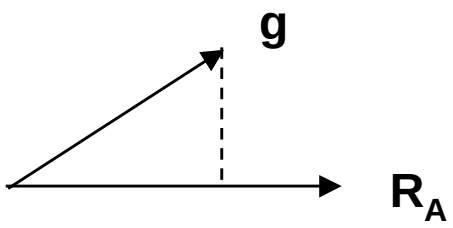


- **Wish list**
  - **agreement with perceptual evaluation**
  - **readily computable**
  - **account for differing noise performance**
  - **continuous and differentiable function of scanner sens**
- **Useful for design as the quantity to be optimized**

Existing Measures

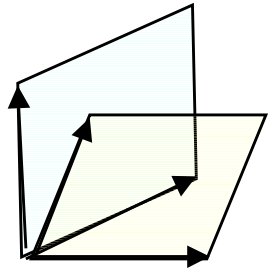
- **Luther-Ives condition**
  - binary measure of goodness
  - little utility in design
- **Neugebauer's Quality Factor**
  - Single filter evaluation
  - Closeness to a color mixture curve
  - Average for multiple filters



$$q_n(\mathbf{g}) = \left(\frac{\|\mathbf{P}_{A_L}\mathbf{g}\|}{\|\mathbf{g}\|} \right)^2$$

New Measures

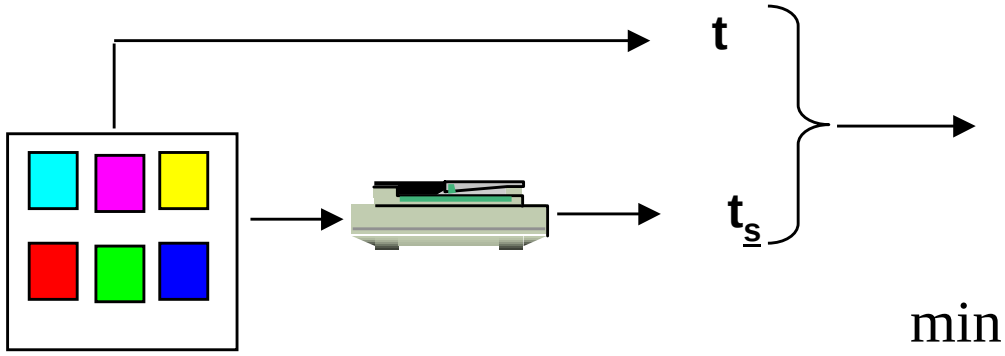
- **Vora-Trussell measure**
  - **generalizes Neugebauer quality factor**
  - **arbitrary # of filters**
  - **noise unaccounted for**
  - **non-linearities in perception ignored**



$$q_v(\mathbf{G}) = \frac{tr\left(\mathbf{P}_{\mathbf{A}_L}\mathbf{P}_{\mathbf{G}}\right)}{3}$$

New Measures

- **Comprehensive Figure of Merit**
  - **based on minimum achievable error in CIELAB**
  - **takes measurement noise into account**
  - **simplification using small error approximation**
  - **computationally simple and analytic**
  - **encompasses other measures as sub-cases**



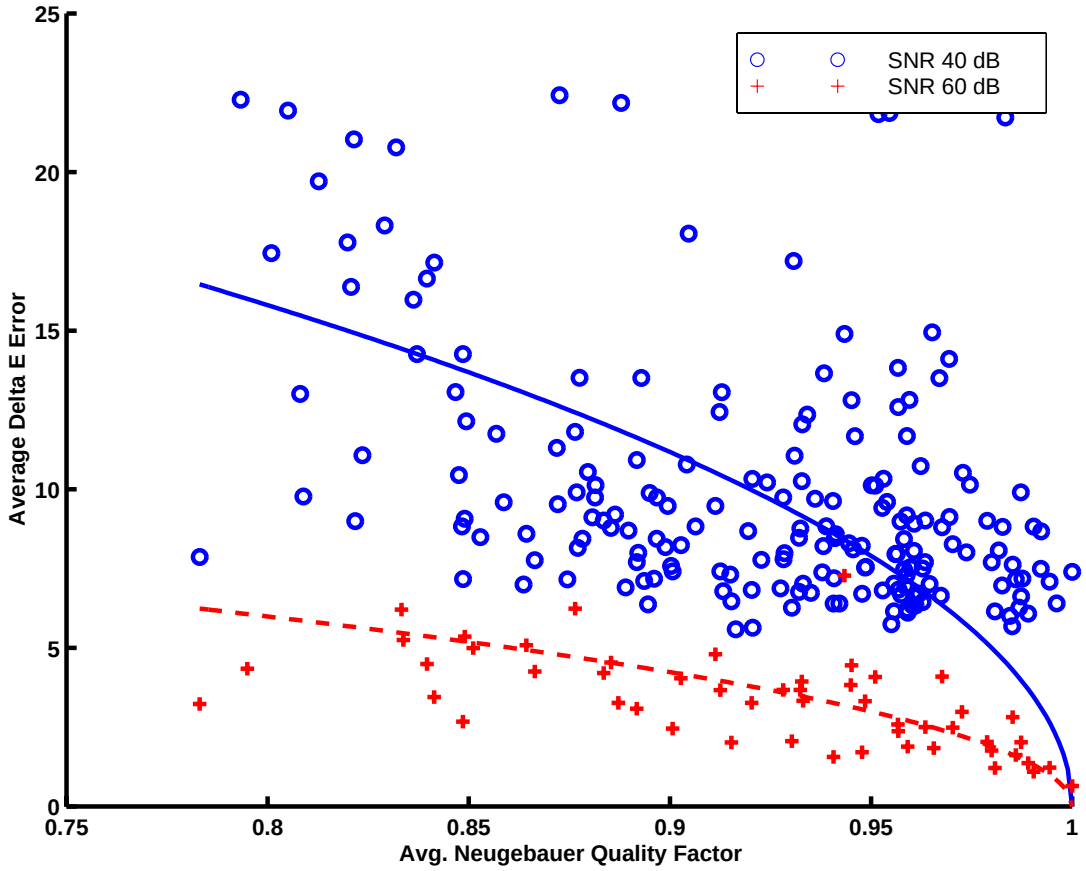
Perceived color difference

$$\min_{\mathbf{B}} E\{\|F(\mathbf{t}) - F(\mathbf{B}\mathbf{t}_s)\|$$

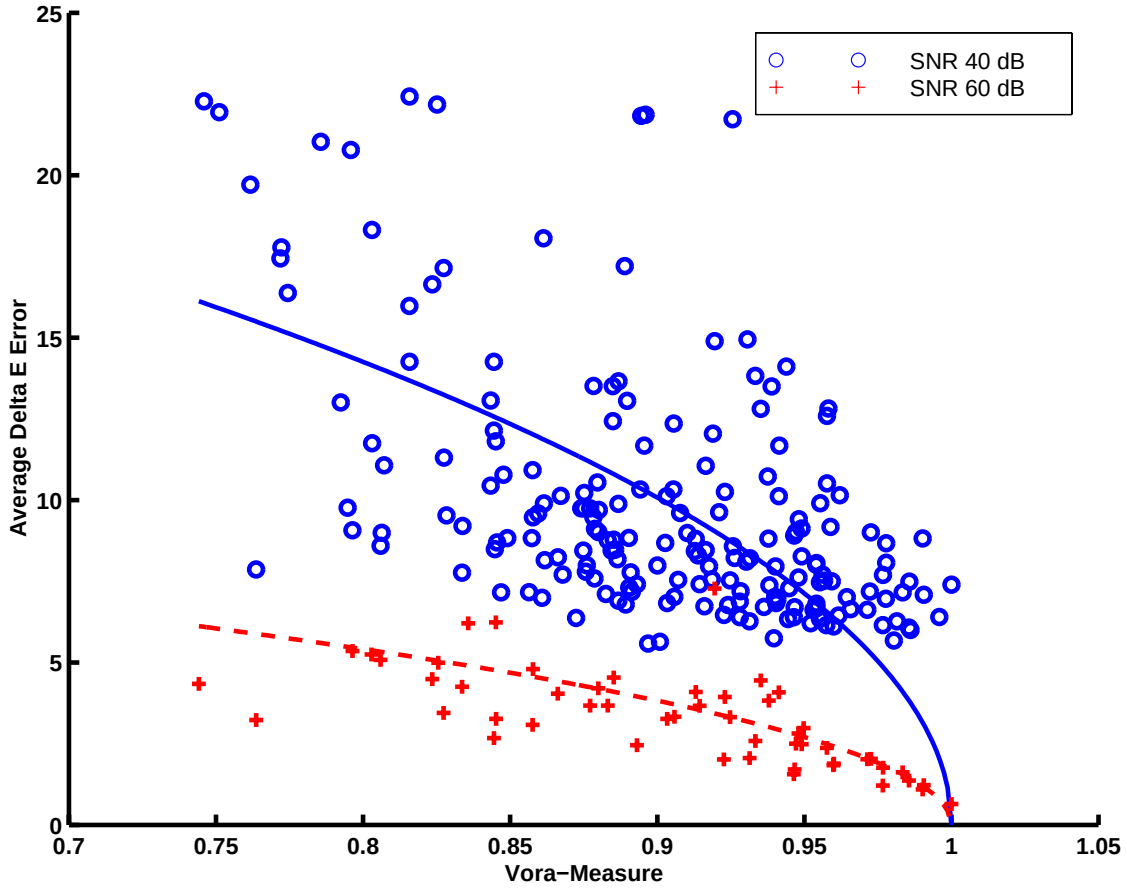
Comparative Evaluation

- **251 Filter sets**
  - **Parameterized filters with Gaussian transmittances**
  - **parameters varied to obtain large set**
  - **base set designed to optimize Vora-measure**
- **Reflectance dataset**
  - **240 Kodak Q60 target**
  - **120 Dupont paint catalog**
  - **64 Munsell chart**
- **Signal independent noise at SNRs of 40, 50, 60dB**
- **Measures computed from sensitivities, statistics**
- **Avg. ΔE^*_{ab} from simulated noisy measurements**
- **Scatter plots of measures vs. Avg. ΔE^*_{ab}**

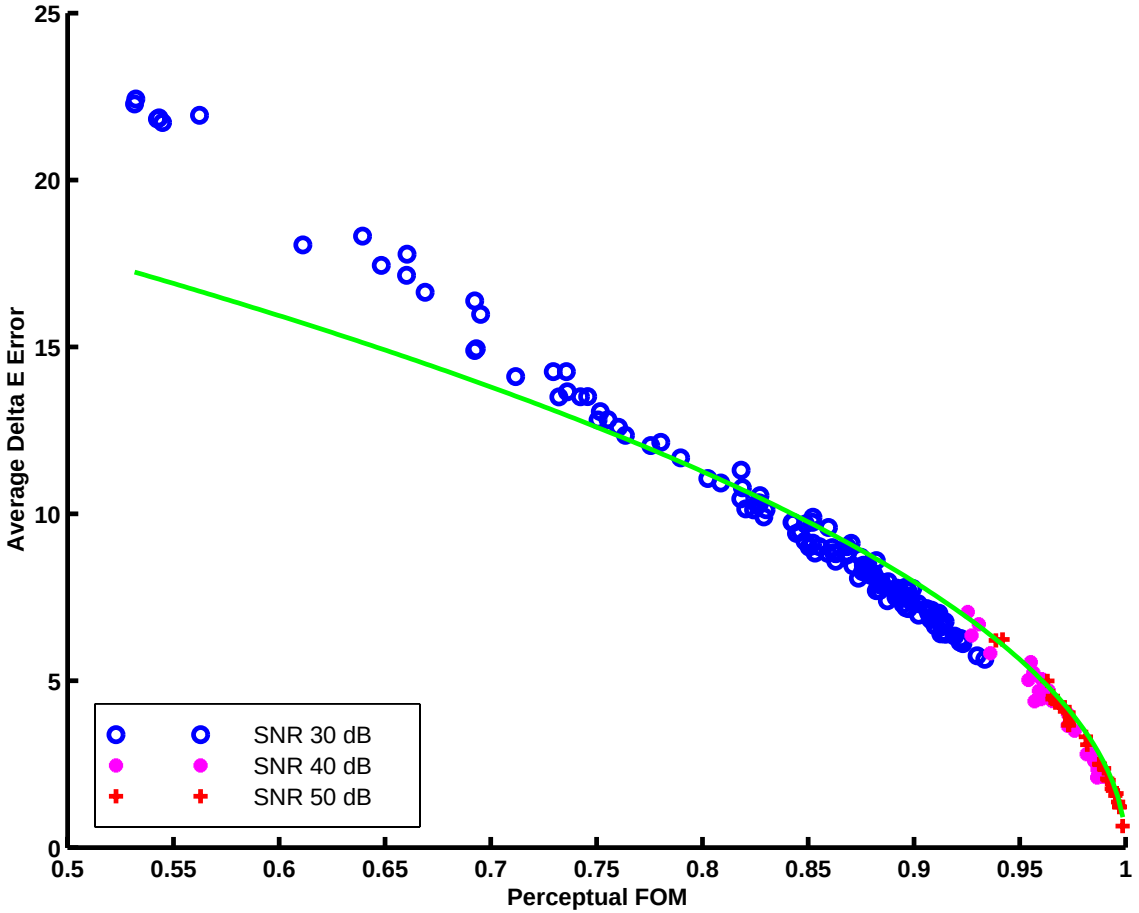
Comparative Evaluation



Comparative Evaluation



Comparative Evaluation



Conclusions

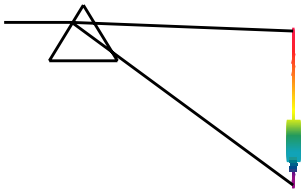
- **A comprehensive figure of merit for evaluation of scanner colorimetric quality is defined**
  - **useful in evaluation and design**
  - **Existing measures are in poor agreement with perception**
  - **New figure of merit provides excellent agreement with Avg. ΔE^*_{ab} over wide range of SNRs**
  - **under appropriate simplifying conditions the new figure of merit collapses to the existing measures**

Work in Xerox (ECS/CADISYS/DITC)

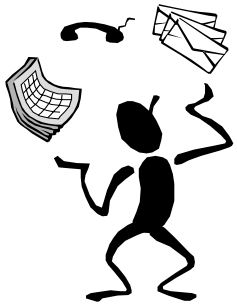
Three Approaches to counter Media Dependence

- **Colorimetric scanning**
  - match the eye

- **Four-filter scanning**
  - quasi-spectrophotometer

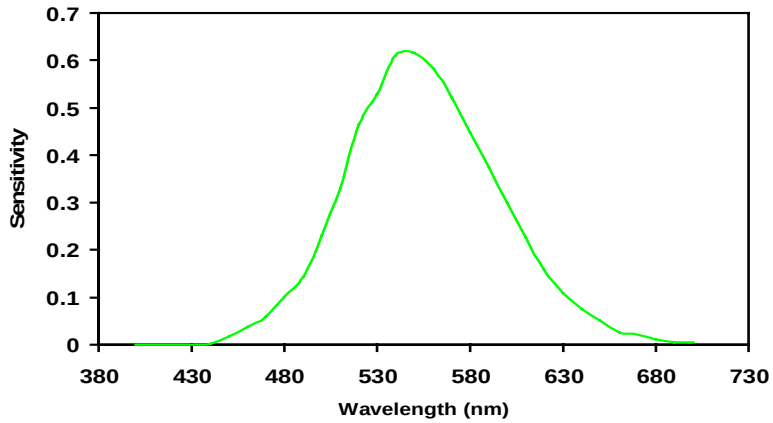


- **Media identification**
  - automated expert



Colorimetric Scanning

- **Design algorithms**
  - approx colorimetric filters with actual materials
  - well separated red, green, and blue for high SNR
- **Sample design (glass filter)**

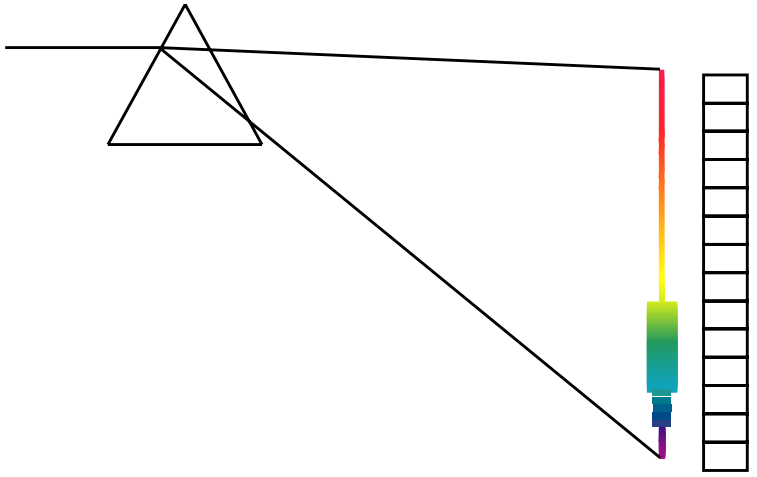


Q-factor = .9992

- **FWA coated filter design**
  - work ongoing

Scanning with more than 3 filters

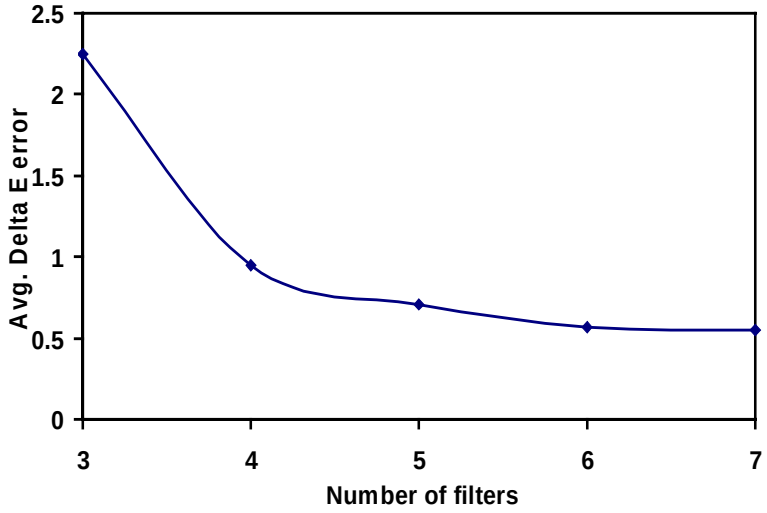
- **Spectrophotometer**



- **Spectrophotometry Extremely Slow and Expensive**
- **How much information do we really need ?**

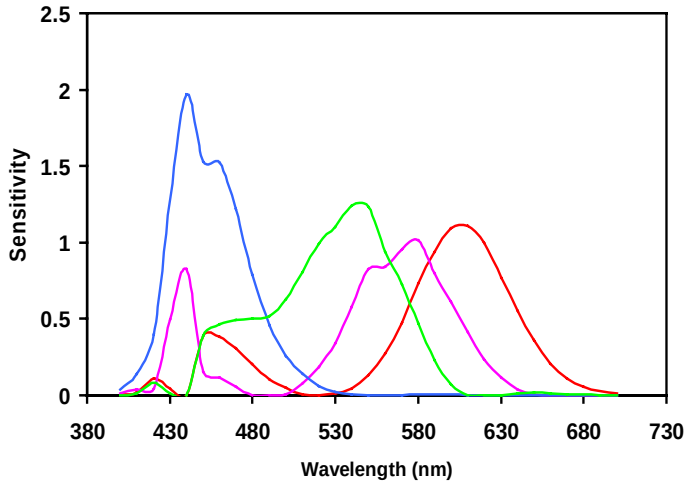
Four Filter Scanning

- **Goal:**
  - record spectral information (more than eye)
- **Enables matching of eye under several lights and provides manufacturing flexibility**
- **Requirements:**
  - 3 too few and 36 too many
  - 4 filters pretty good



Four Filter Scanning: Status

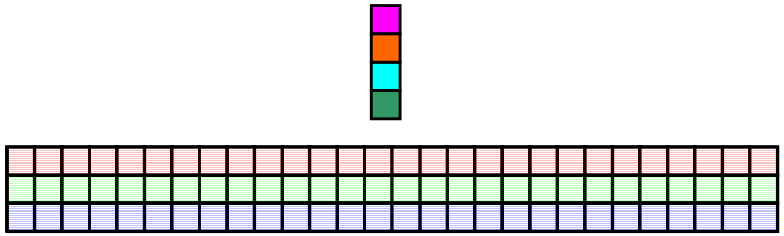
- **Preliminary filter designs**



- **Not designed for manufacturability**
- **Collaborating on FWA designs**
  - **using color filter coatings**

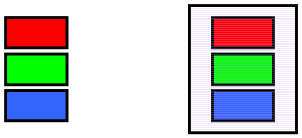
Media Identification

- **Goal:**
  - Identify the scanned medium (automated expert operator)
- **Makes system easier to use**
- **Requirements:**
  - sufficient spectral information to differentiate document types



Media Identification: Status

- **Simulation**
  - **overlay transparency/filter with existing RGB channels**

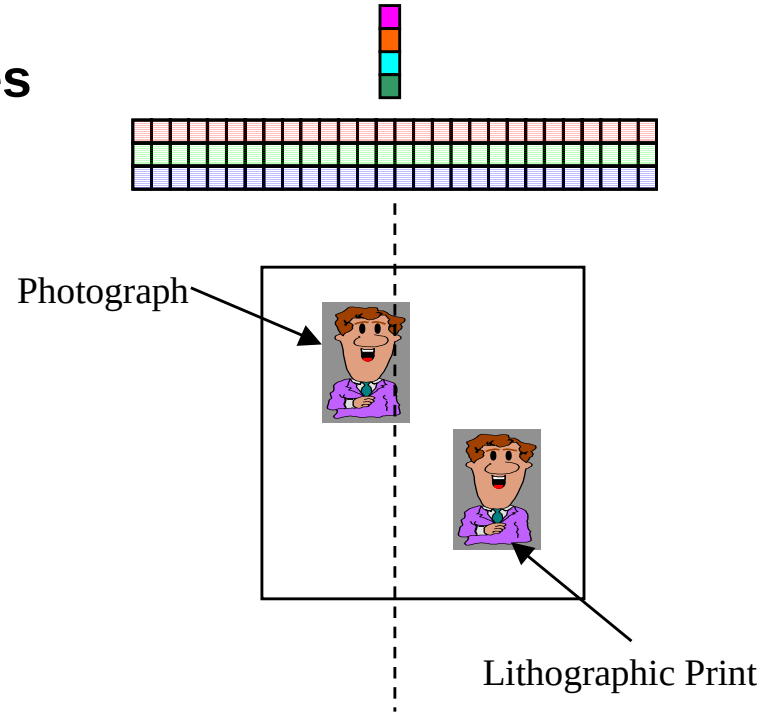


- **Encouraging results**
  - **90% classification accuracy for photo, litho and inkjet media**

		Classified as		
Input Medium:		Photographic	Lithographic	Inkjet
	Photographic	0.94	0.05	0.01
	Lithographic	0.05	0.85	0.10
	Inkjet	0.06	0.01	0.93

Media Identification

- Interim solution
- Works for single material pages
- Problems with:
  - mixed media pages
  - new media types
    - inkjet
    - hi-fi color

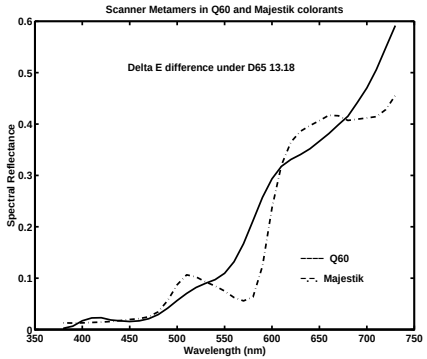


Summary

Approach	Single calibration	Design Modifications	Status	Multiple Viewing Illuminants
Colorimetric	✔	Major	Needs Work	✘
Four Filter	✔	Major	Needs Work	✔
Media Identification	✘	Minor	Available	✔

Colorimetric Scanning

- 3-D representations of the object spectrum in both cases
- Current (non-colorimetric scanners)
  - Different 3-D representations in scanner and eye due to differences in sensitivities and illuminants
  - Colors that appear identical to scanner can appear different to eye and vice-versa



Scanner RGB (140,79,6) for both

ΔE*ab Difference of 13.17 Units

Media Dependence Cross-tests

Train	Testing (Ave. ΔE)			
	Photo.	Litho.	Xero.	Inkjet
Photo.	0.95	4.14	3.83	3.43
Litho.	4.32	0.78	1.90	2.40
Xero.	3.97	1.82	1.11	1.86
Inkjet	4.68	3.33	3.57	1.21

ΔE = 1: ~ Just Noticeable Color Difference

Max. ΔE ~ 3 Ave. ΔE

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