HANS

Enabling CMY Metamers

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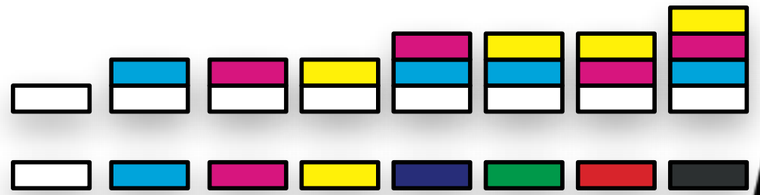

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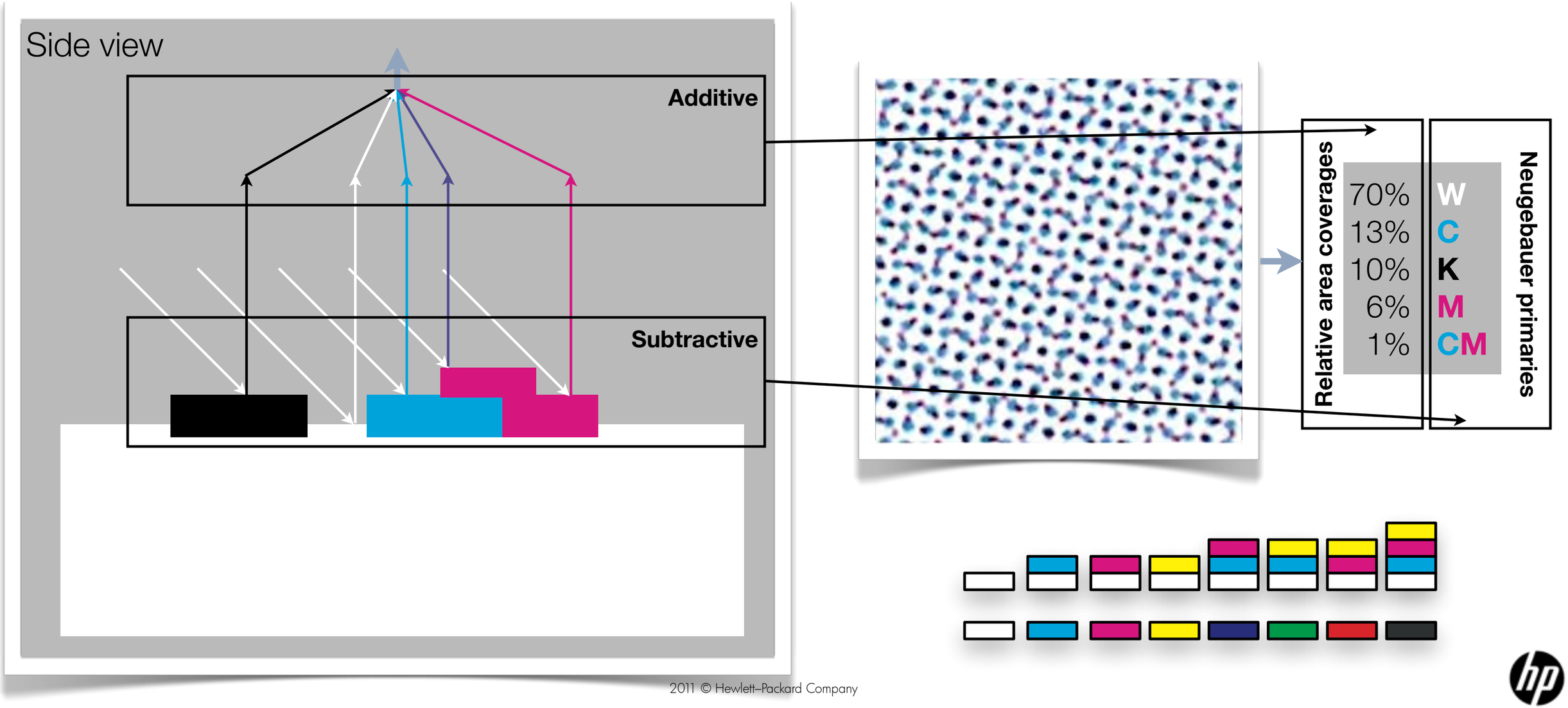
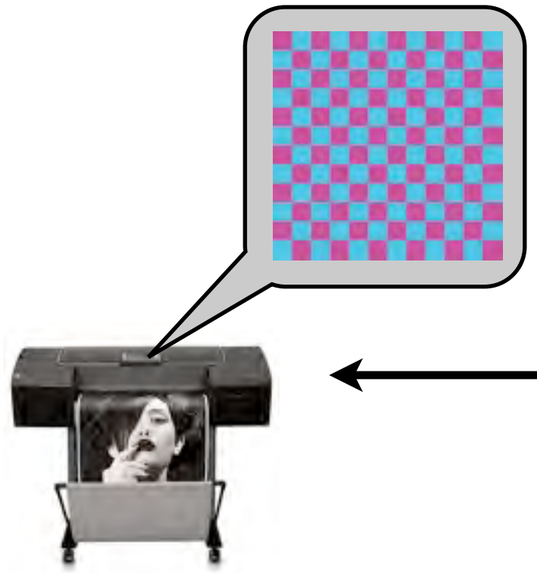
What makes printed colors?

Print color formation



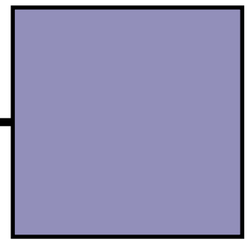
Analog from digital

From color to halftone pattern



color separation
linearization
calibration
halftoning

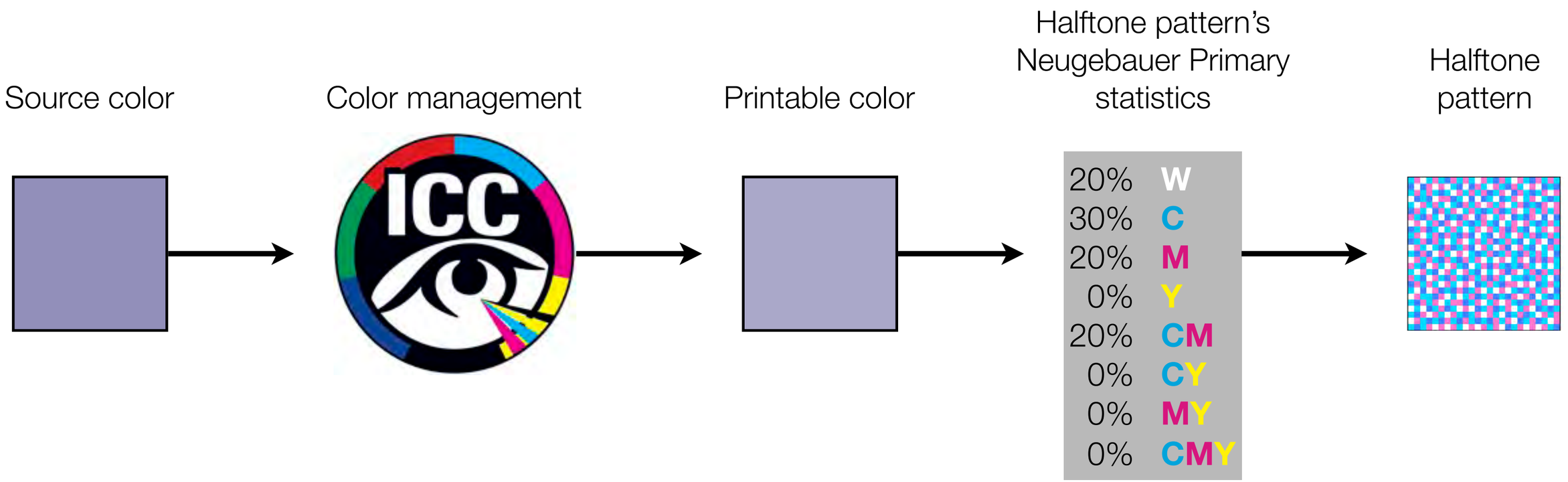
color management
color appearance model
device characterization
color enhancement
gamut mapping



CIE L*a*b*
sRGB
SWOP CMYK
...

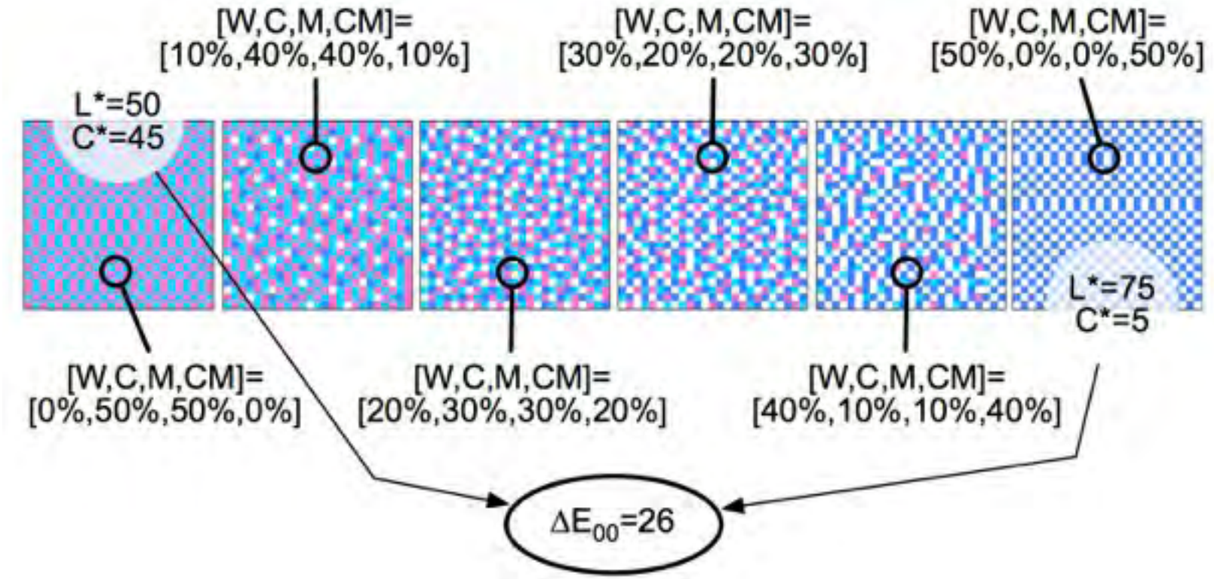
Controlling print color – a first principles approach

How do we get from color to halftone pattern?



How does this differ from traditional color control?

	Traditional	*New*
Color separation	'How much of each ink should I use for each color?' Output: **ink amounts**	How much area should I cover with each Neugebauer Primary' Output: **Neugebauer primary area coverages**
Halftoning	Decides where to place ink drops based on color separation constraints. Controls: **spatial** and **overprinting** properties	Decides where to place ink drops based on color separation constraints. Controls: **spatial** properties only
Ink amounts v. patterns	1:1	1:many



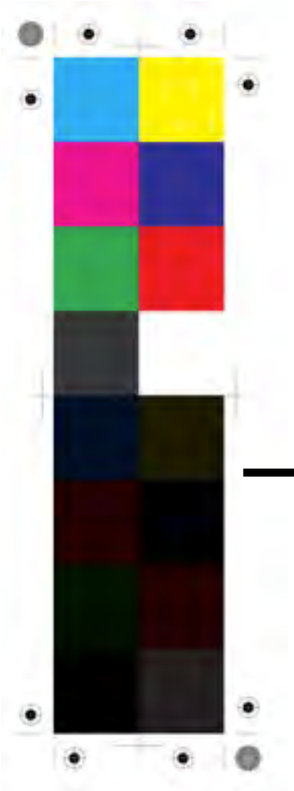
Specifying Neugebauer Primary area coverages provides access to **vastly greater space of printable patterns**.

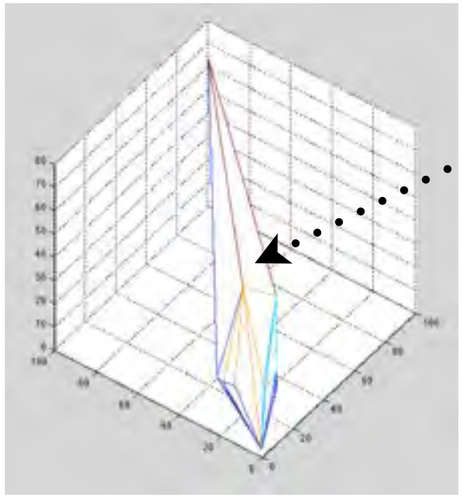
k^n v. n

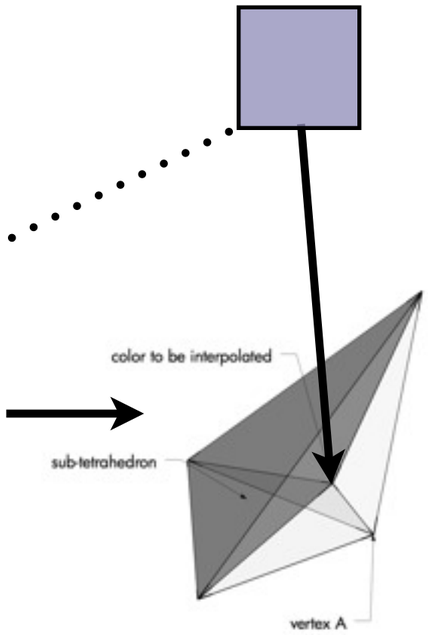
(for system where up to k-1 ink drops per pixel can be specified for n inks)

From theory to practice

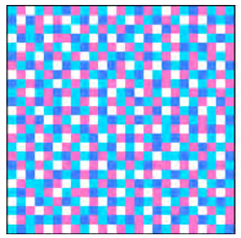
A minimal Halftone Area Neugebauer Separation setup (CMYK, 1bpp)







20%	W
30%	C
20%	M
0%	Y
20%	CM
0%	CY
0%	MY
0%	CMY
0%	K
0%	KC
0%	KM
0%	KY
0%	KCM
0%	KCY
0%	KMY
0%	KCMY



Print & measure Neugebauer primary (NP) CIE XYZs

Compute convex hull & tetrahedralize hull NPs

Find printable color's enclosing tetrahedron

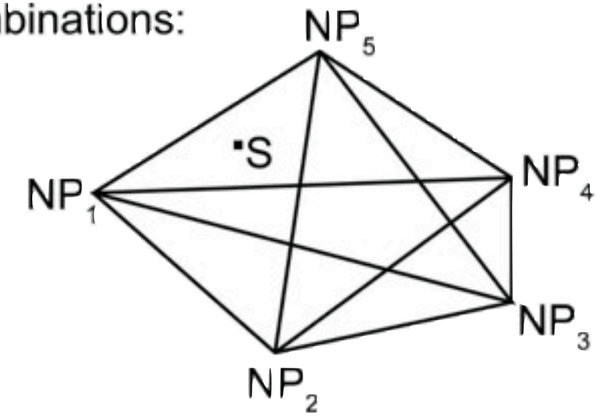
Barycentric coordinates are vertex NP areas

Select one NP per pixel & diffuse NPac-NP error

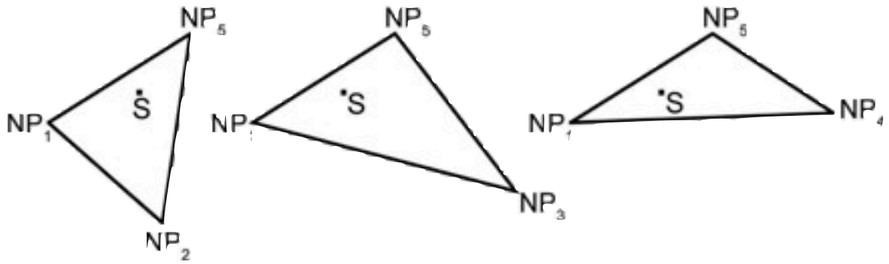
Optimizing HANS

- Form all polyhedra using the k^n NPs
- Find all colors for which NPacs are to be optimized enclosed by each polyhedron
- Compute barycentric coordinates
- Evaluate each candidate (grain, ink use, color constancy, ...)
- Assign combined score
- Select best NPac for each color

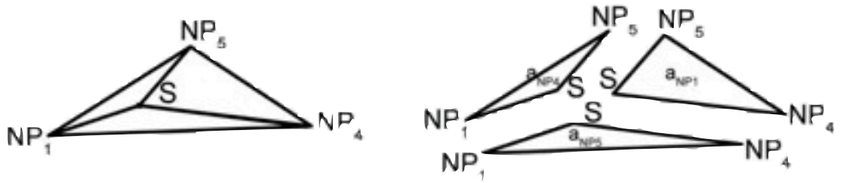
All combinations:



Sample metamers:



Barycentric coordinates – NP area coverages:



$$\sum_{i=4}^{k^n} \binom{k^n}{i}$$

CMY 1dpp: $k^n=2^3=8 \rightarrow$ 163 polyhedra
CMYK 1dpp: $k^n=2^4=16 \rightarrow$ 64839 polyhedra
CMYKcm 2dpp: $k^n=3^6=729 \rightarrow$ **2.8×10^{219}** polyhedra

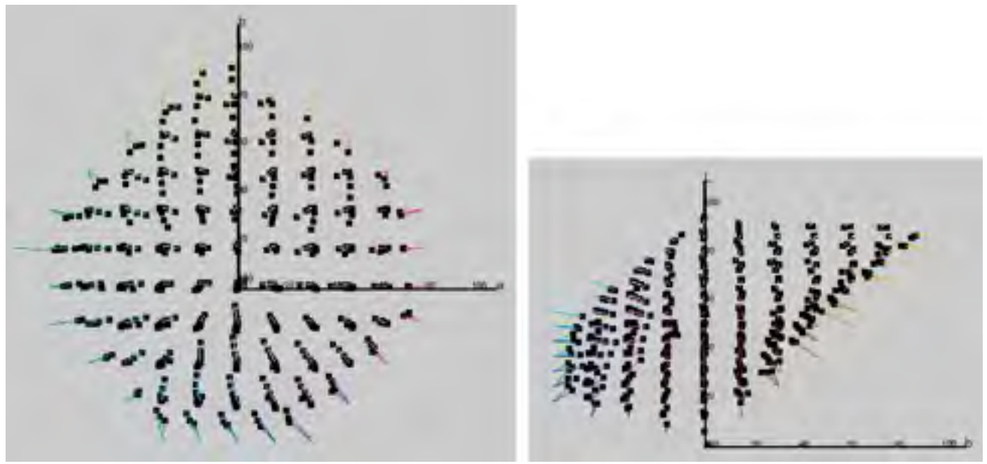
Reductio ad absurdum – the CMY case

- With **traditional**, colorant space **control**: no metamers
  - each in-gamut color matched by **one CMY colorant amount combination**
- Even at max. 1 drop per pixel, CMY colorant set has 2^3=8 Neugebauer Primaries
  - 3D colorimetric space to 8D NP space results in 1:many mapping
  - 163 polyhedra span gamut and provide metamers
- mid–gray: 115 metamers
- mean 13% ink use difference between metamer using most and least ink for each color
- More metamers still if more than one drop per pixel is used

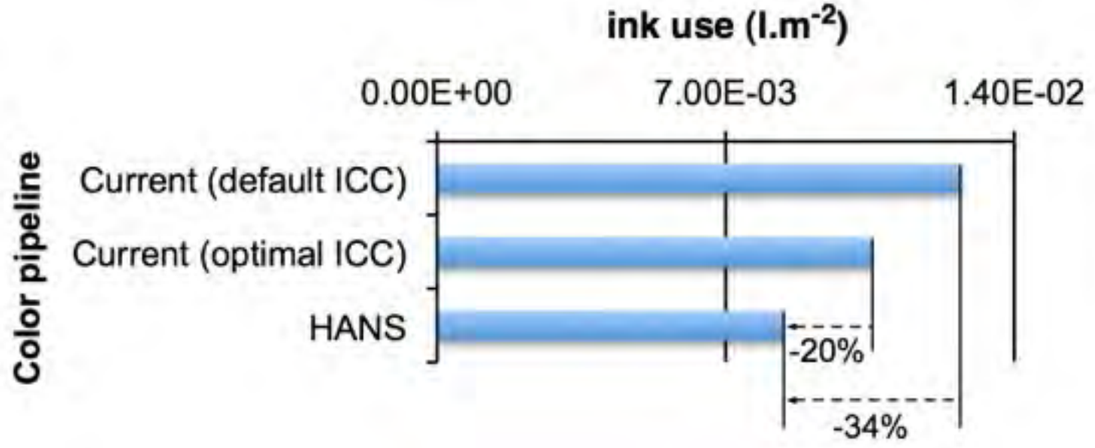
Does it work?

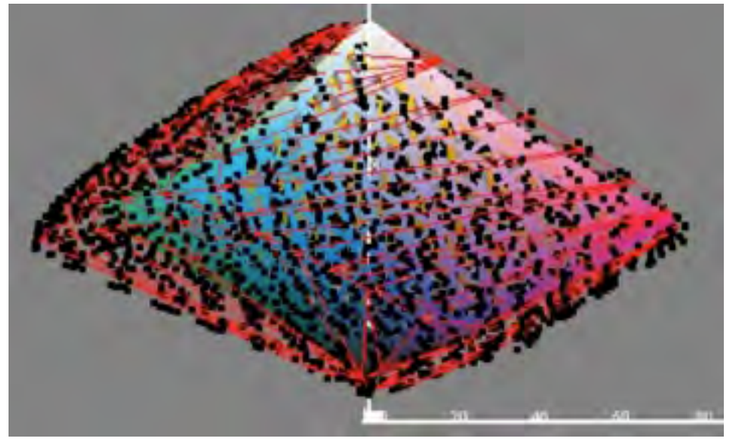
Test setup: ‘Can we find NPacs that use less ink?’

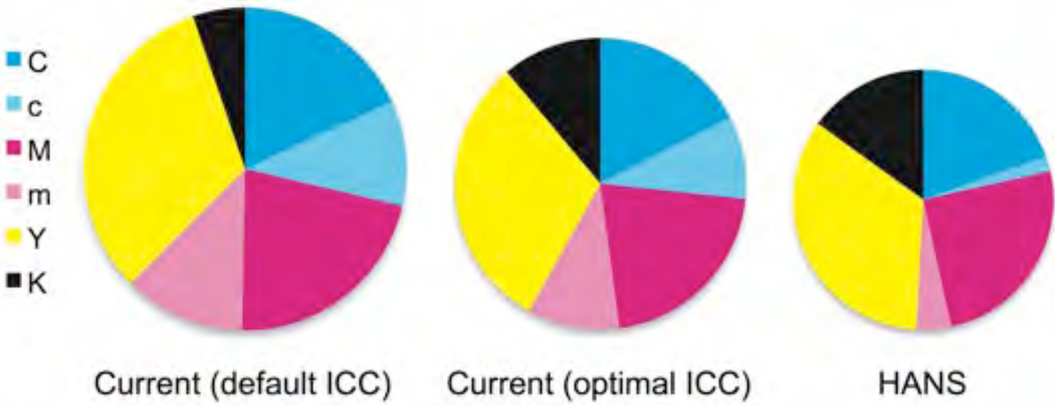
- Printer: **HP Designjet L65500**
- Inks: **CMYKcm** latex
- Substrate: Avery Self-Adhesive **Vinyl**
- Color samples: **748** Lab-uniform **ISO coated v. 2** samples
- Color workflows compared:
  - Ink space separation, GCR optimized for low grain, ink space halftoning (**current default**)
  - Ink space separation, maximum GCR optimized for low grain, ink space halftoning (**current optimal**)
  - NPac space separation (optimized for minimum ink use) and halftoning (**HANS**)

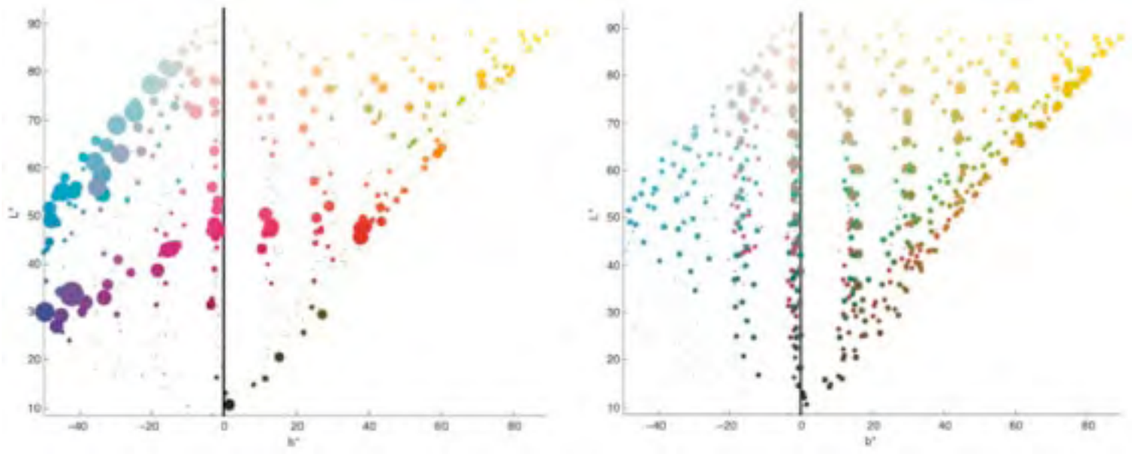


Results – ink use









What next?

Challenges and benefits

- Challenges:
  - **printer model accuracy** (the more accurate the better the optimization)
  - **computational efficiency** (weeks of computation per substrate)
  - **optimization** (efficient models of print attributes, efficient traversal of NPac space)
- Benefits:
  - **greater & direct optimization** (more from the same printer-ink-substrate)
  - **explicit trade–off among print attributes** (grain v. ink use v. color constancy)
  - **inkset agnosticism** (same process for CMY 1bpp and CMmYKkNnRGB 2bpp)

- More detail at this year's IS&T/SID Color and Imaging Conference (subject to acceptance)

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