Optimal Tone Reproduction Curves for Color Printing

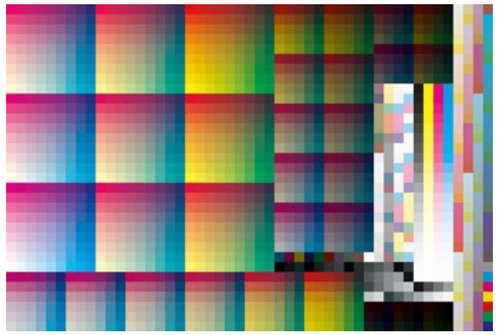
William B. Birkett, Doppelganger, LLC

And

Charles Spontelli, BGSU

The Problem

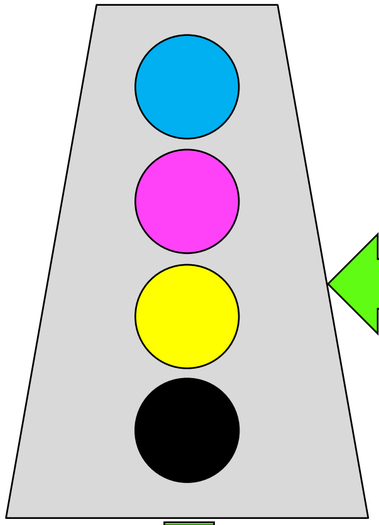
Reference Data Set

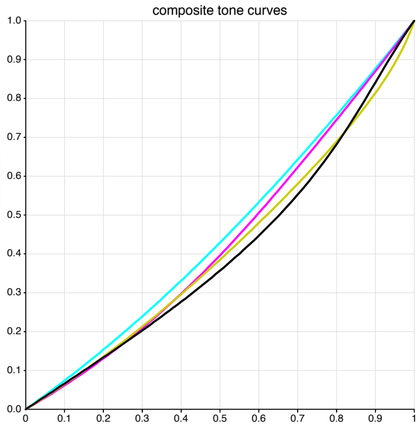


CMYK → L*a*b*

Inkjet Printer

Press





Tone Curves

Proofs are color managed to match a reference data set such as GRACoL2013 or FOGRA 51

Proof

Visual Match

Press Sheet

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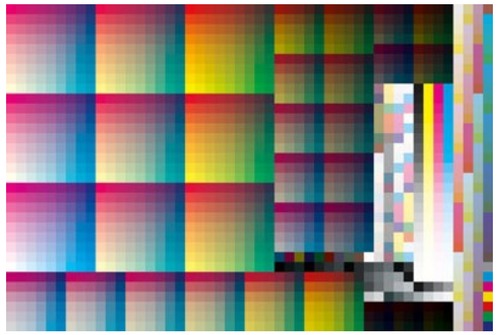

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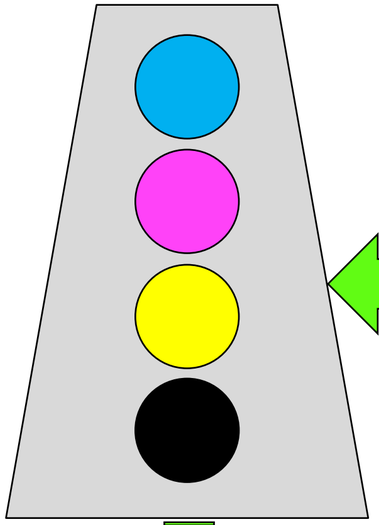

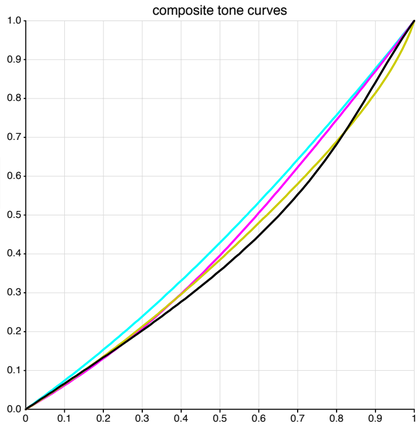

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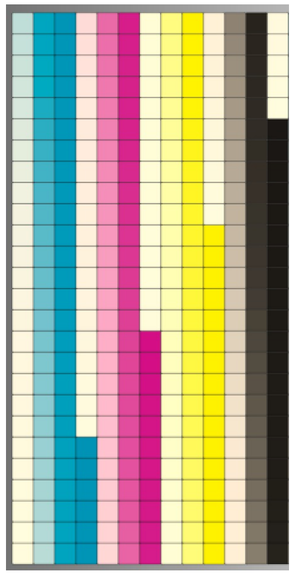
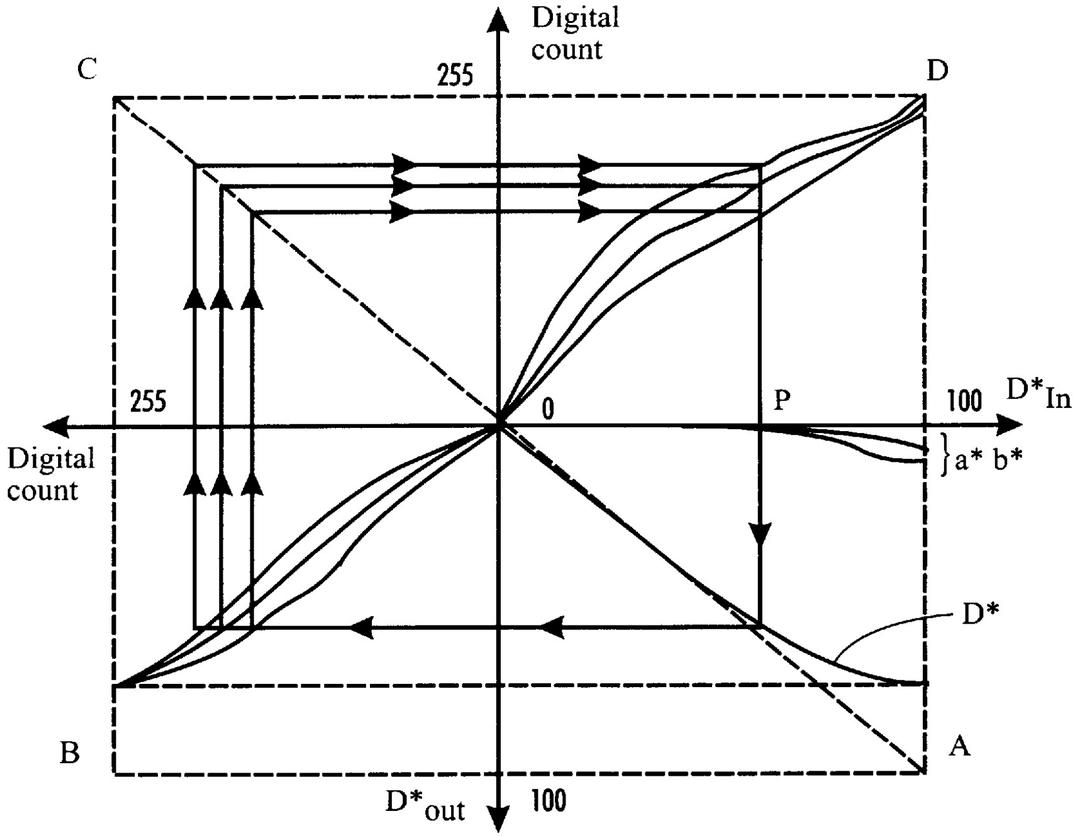
How do we make tone curves to match our proofs on press?

Existing Solutions (ISO/TS 10128:2009)

TVI

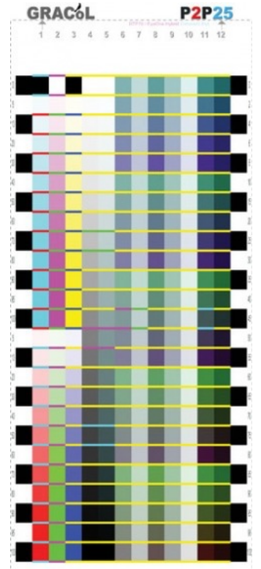


Print and measure process color ramps. Make curves to achieve target TVI values.



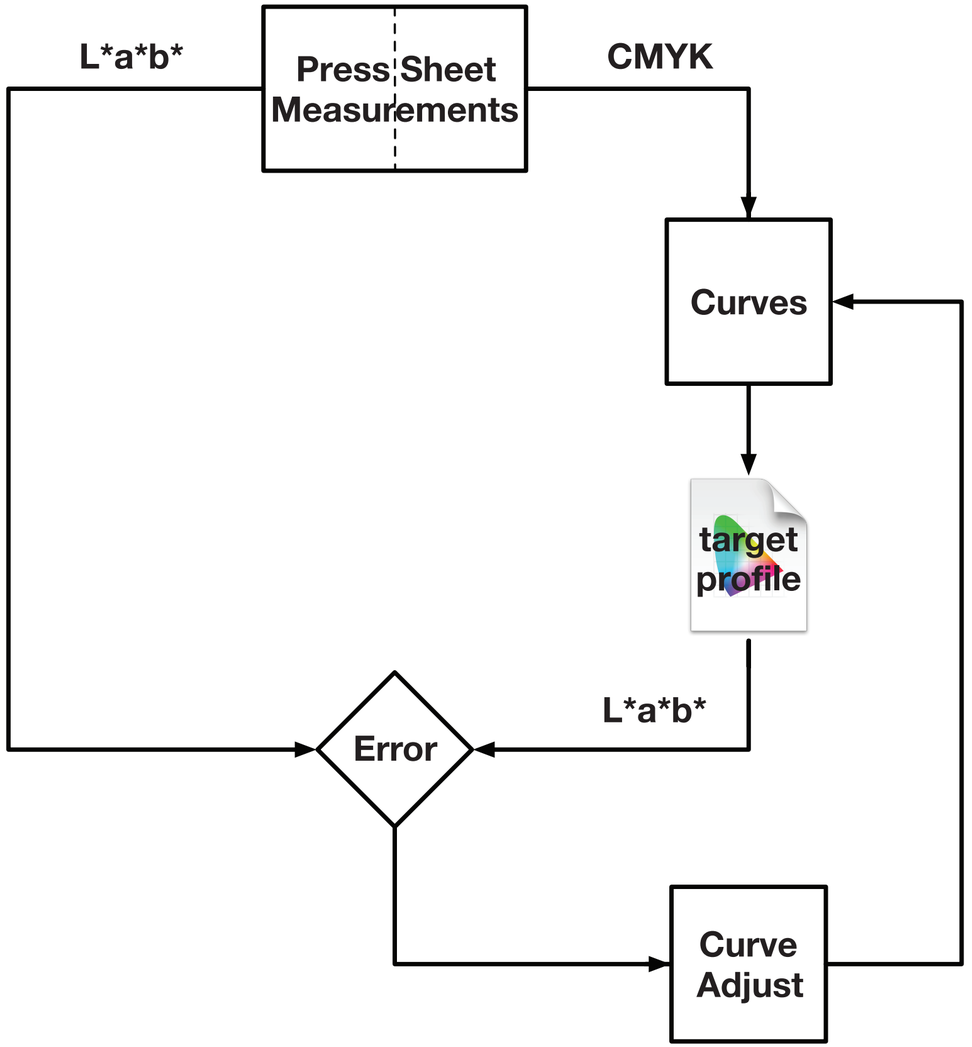
Jones Diagram

Near-Neutral



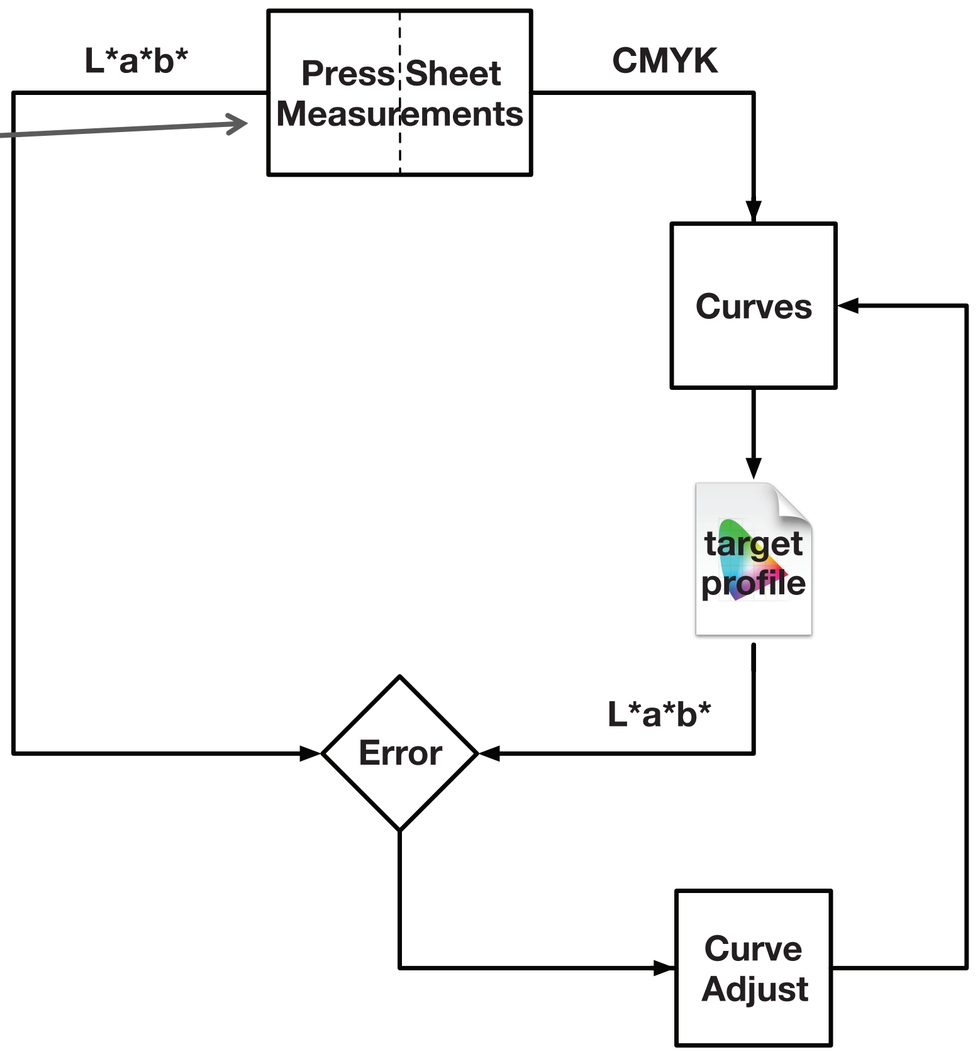
Print and measure CMY gray and black ramps. Make curves to achieve target gray balance and NPDCs.

The OPTIMAL Method



The OPTIMAL Method

Print a test chart with standard inks and color gamut. Measure the samples.



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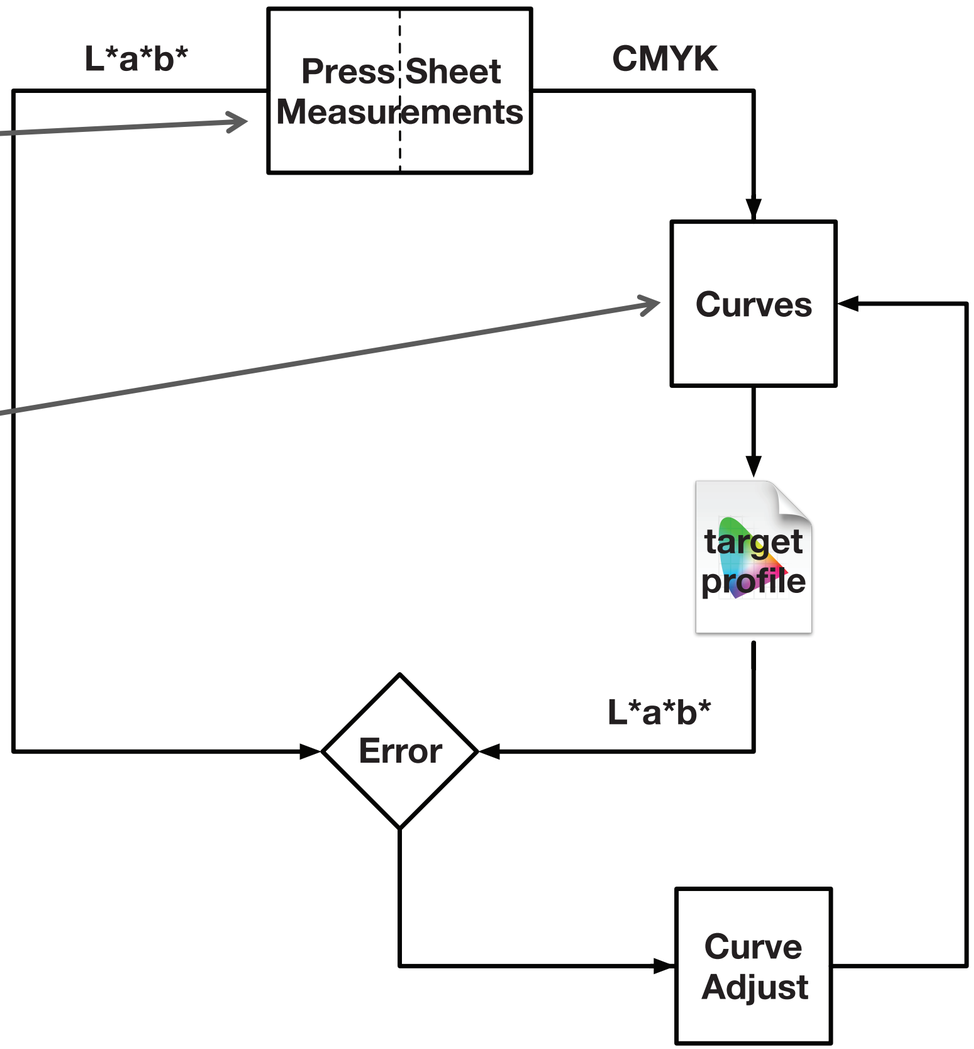

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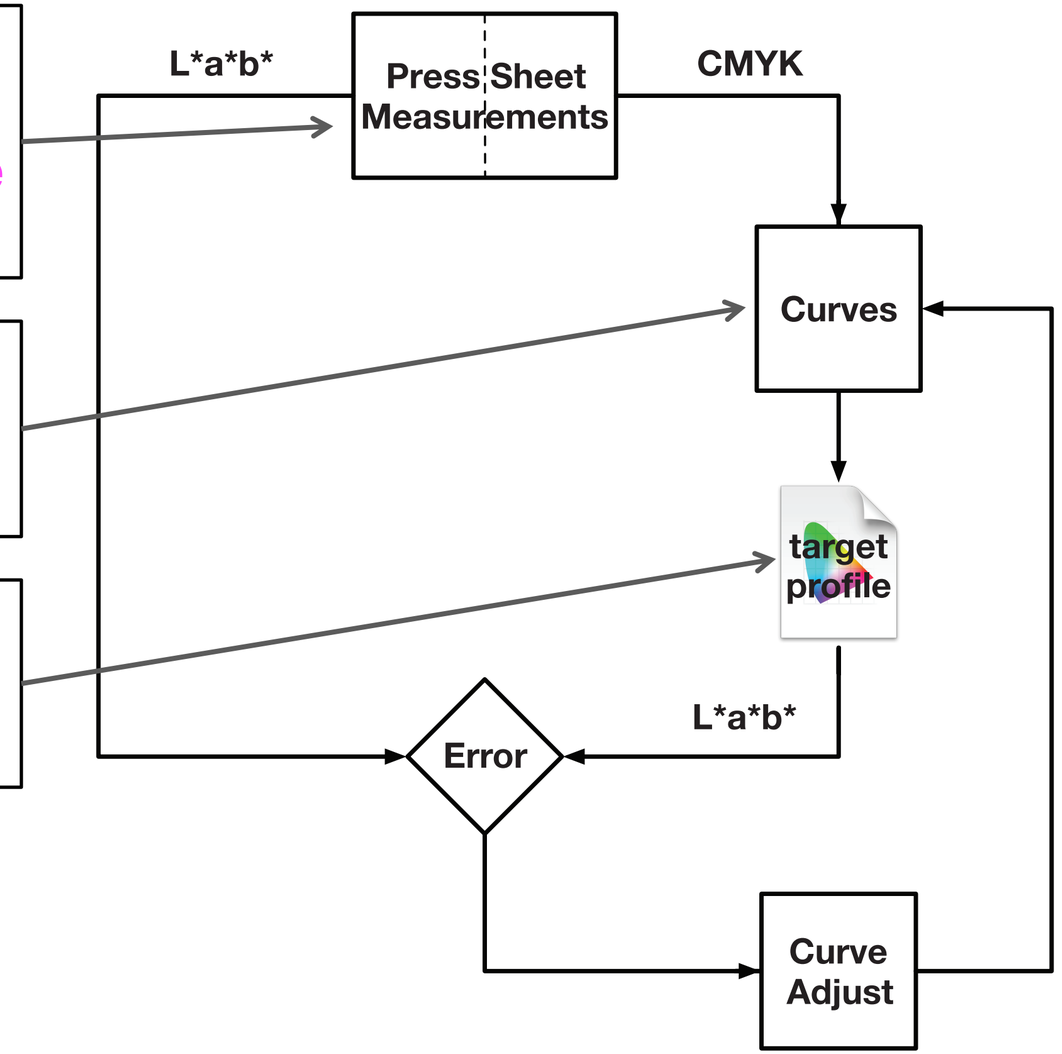

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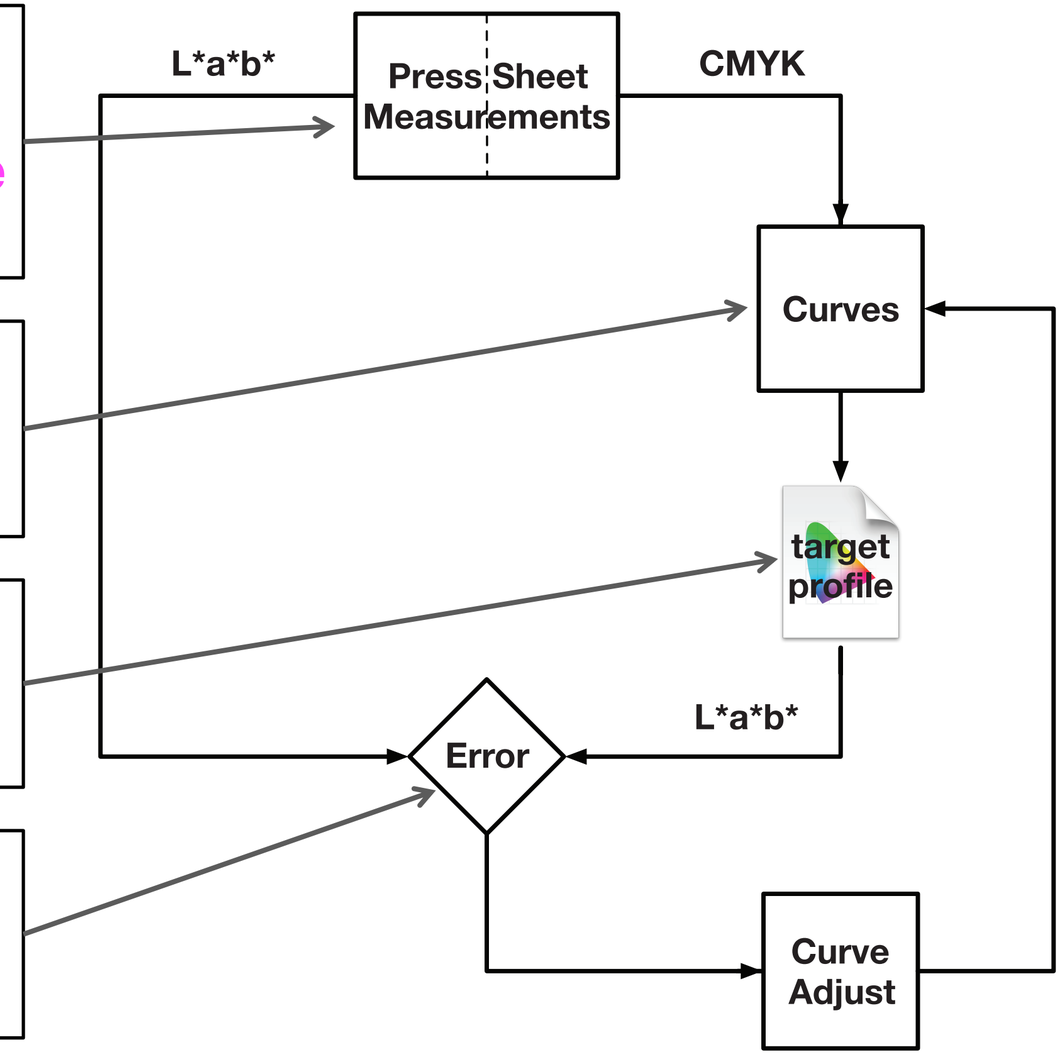

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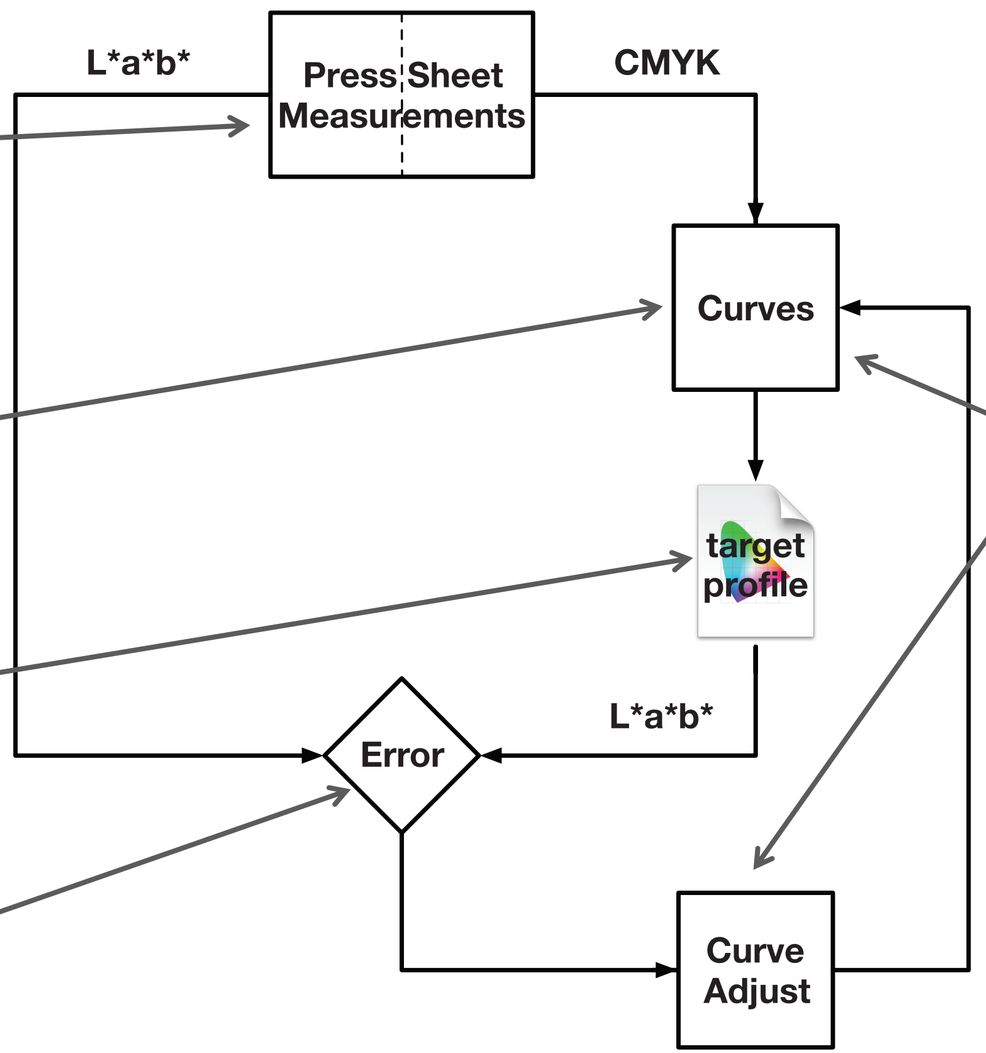

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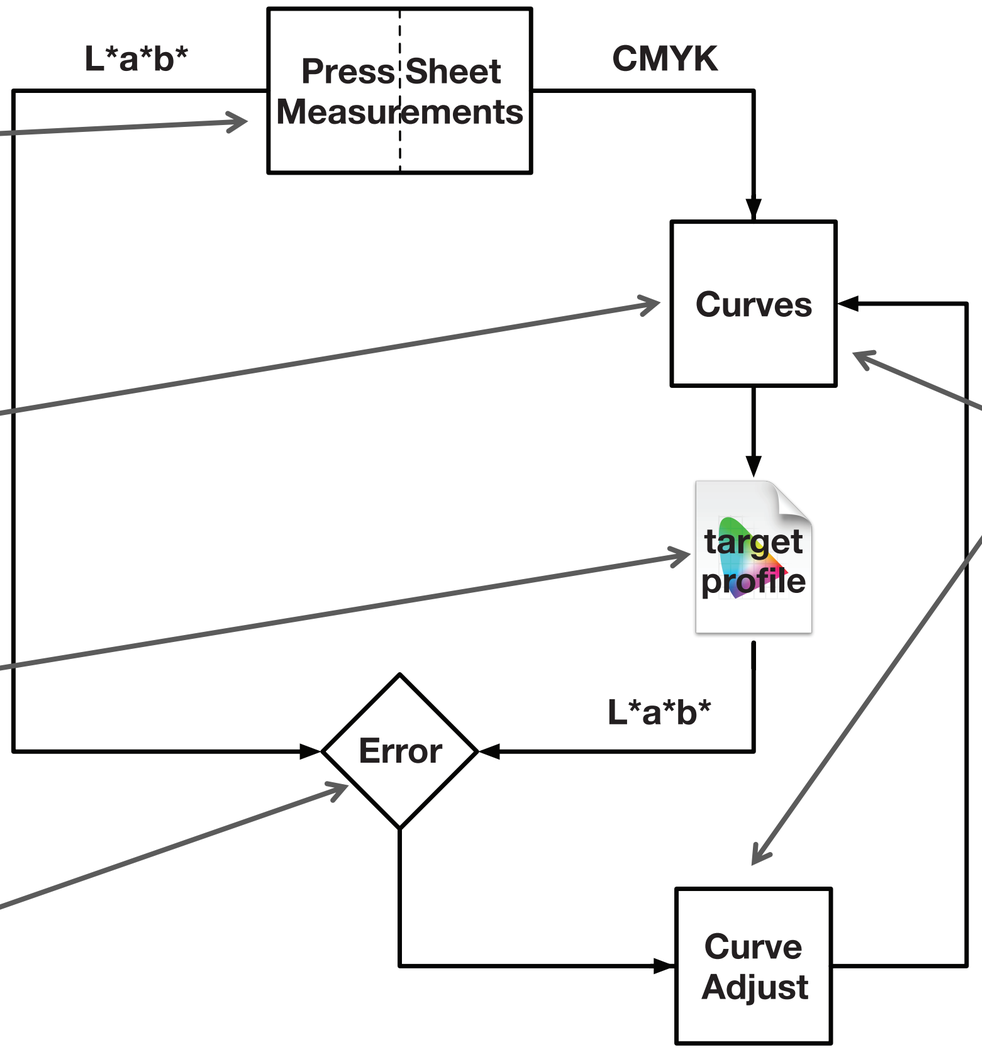
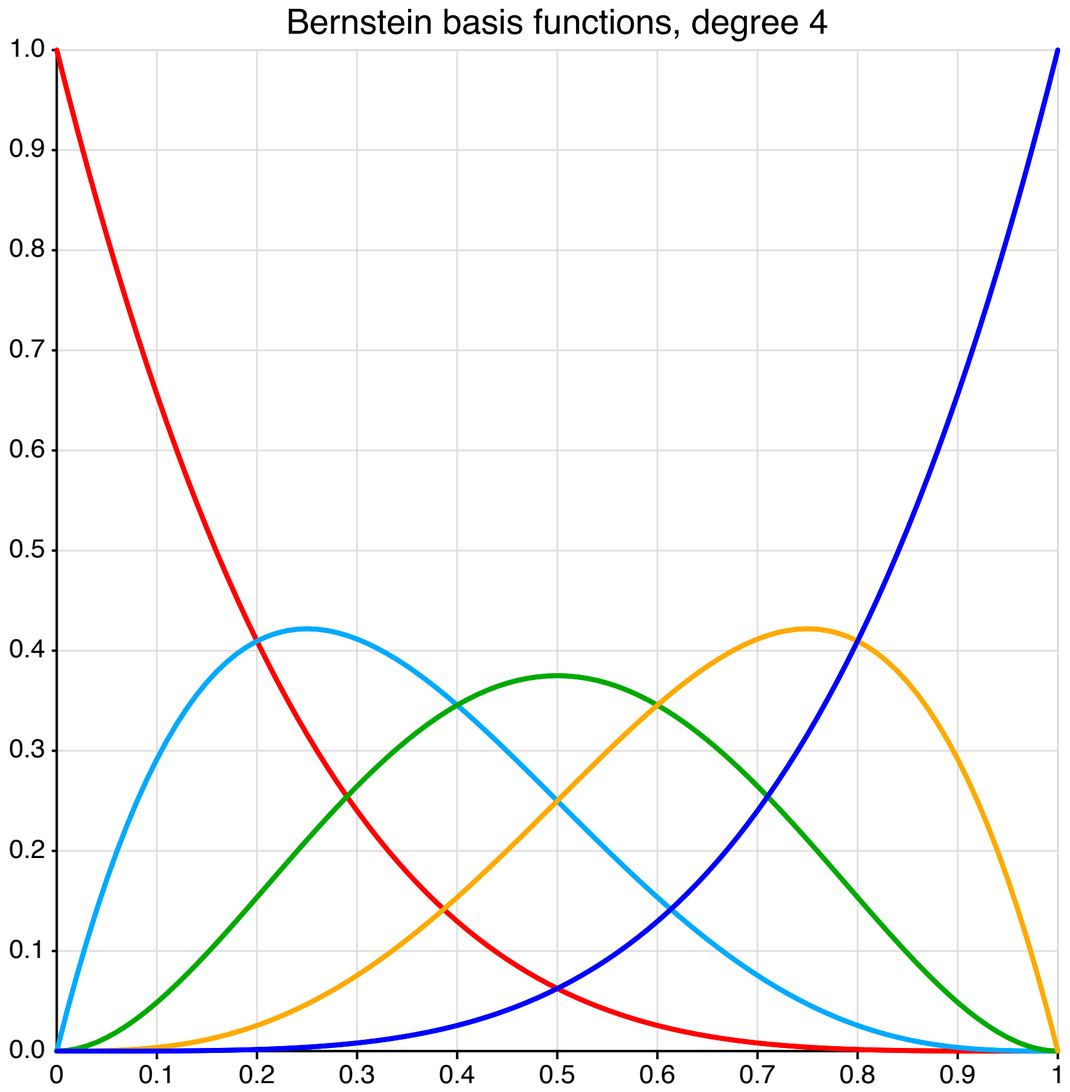


Adjust curve parameters to reduce overall error of all samples.

Repeat until the error cannot be reduced any further.

Parametric Curves

- **Bernstein Polynomials**
  - **Model Tone Curves**
  - **Bernstein Basis Functions**
  - **Smoothly divide tones into regions**



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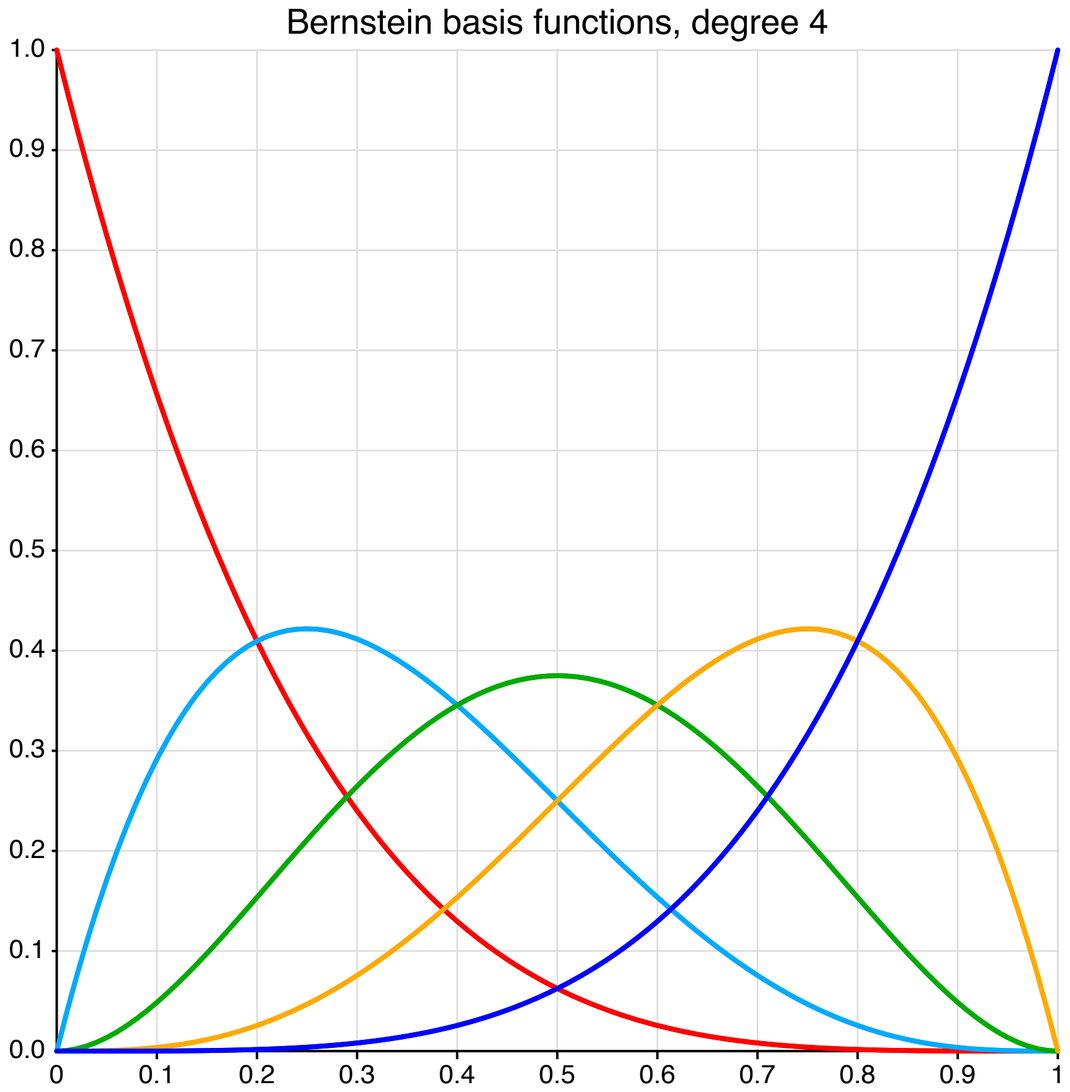
Each tone curve is a linear combination of the basis functions. The curve is defined by an array of coefficients, e.g. [0, 0.3, 0.6, 0.5, 1] for each function.



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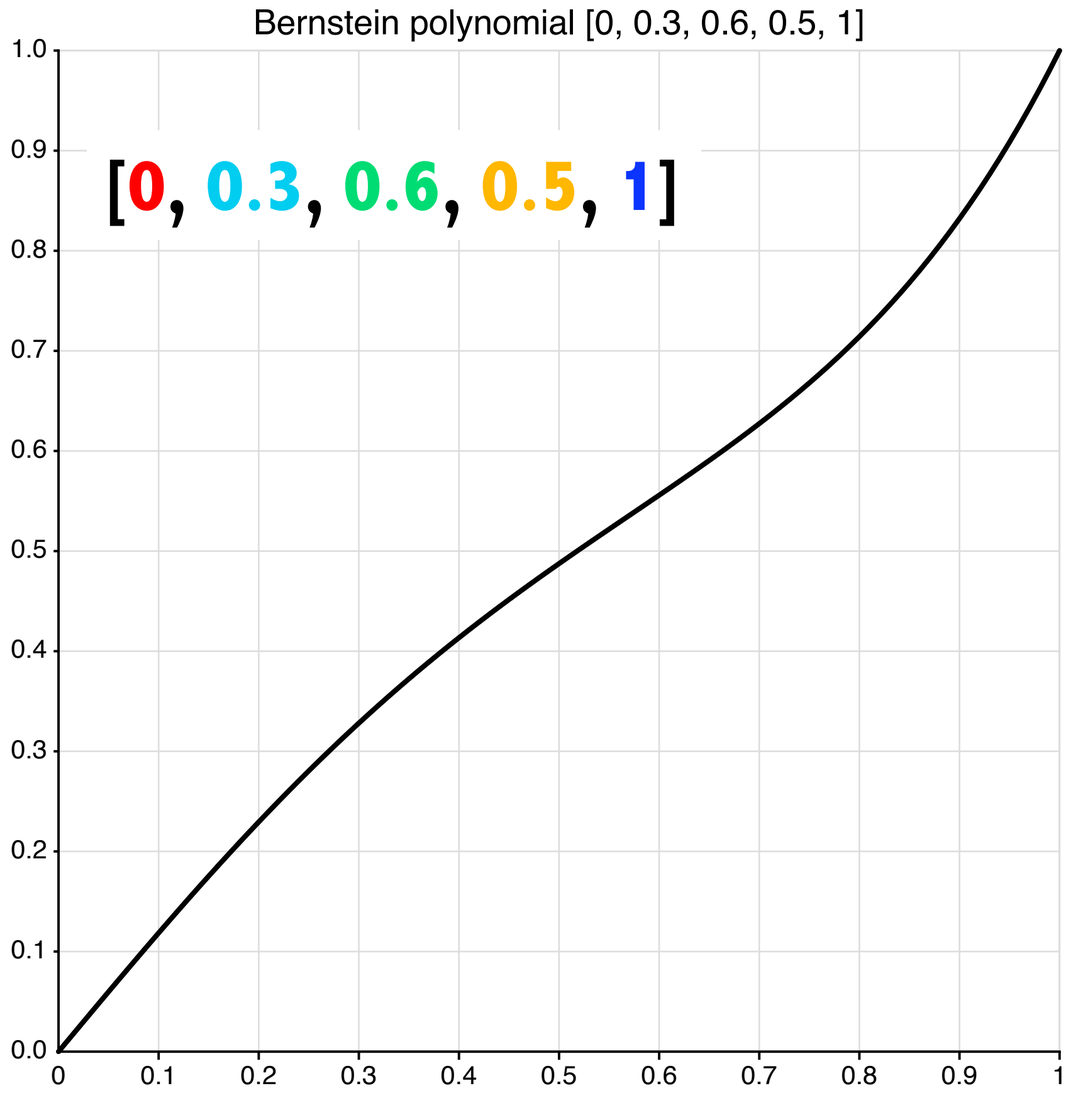

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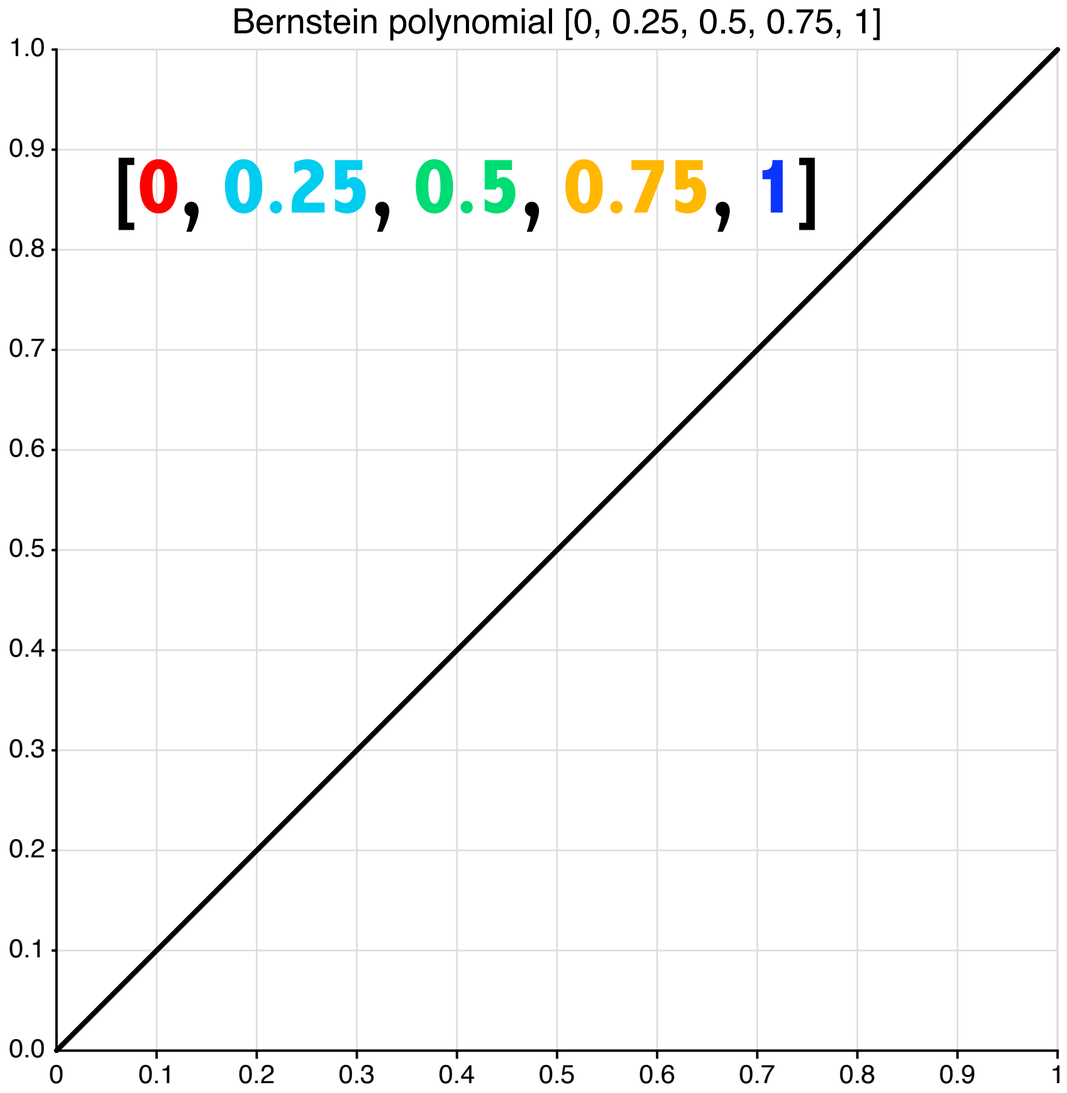
A surprising Bernstein property is that coefficients spaced equally from 0 to 1 yield the identity function (a 'linear' curve).

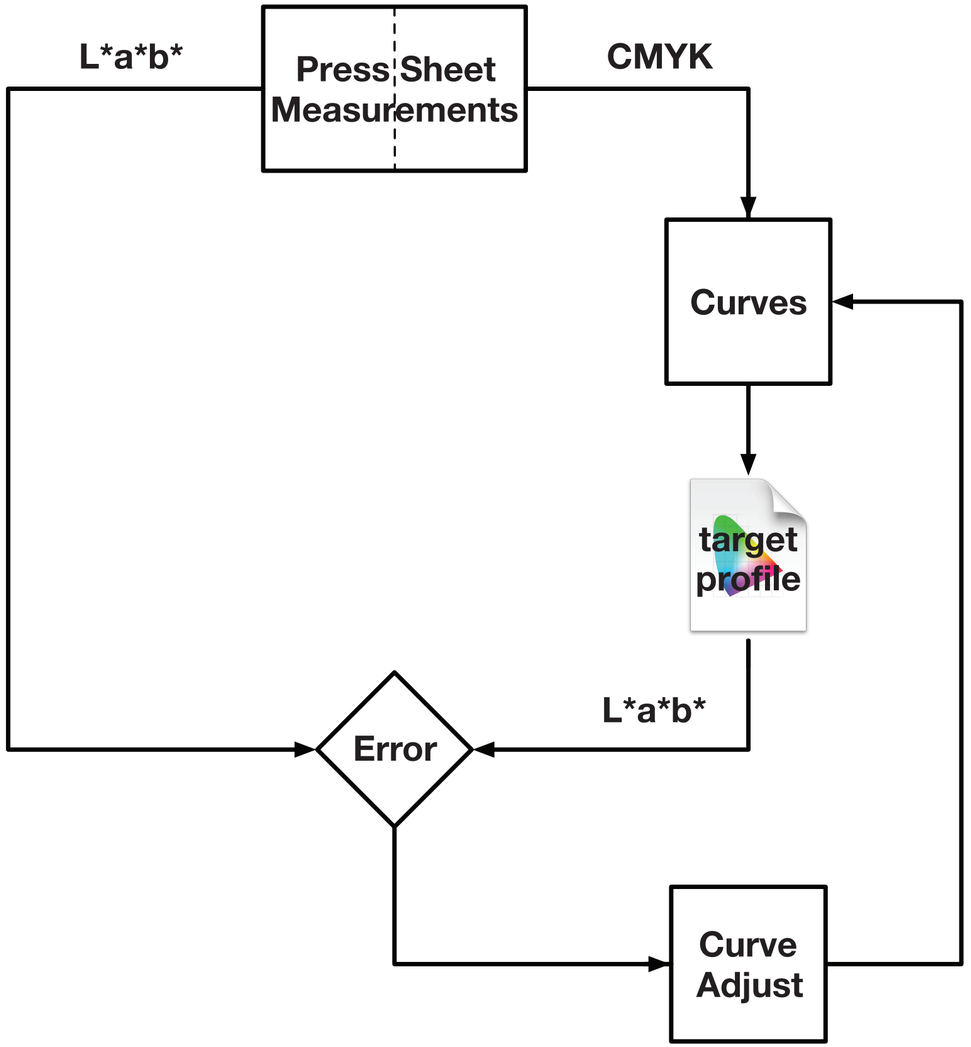


Numerical Optimization

- Tone curves adjusted for **minimum error** using **numerical optimization.**
- **Gauss-Newton method** adjusts all of the curve parameters **simultaneously**.

Carl Friedrich Gauss

Sir Isaac Newton



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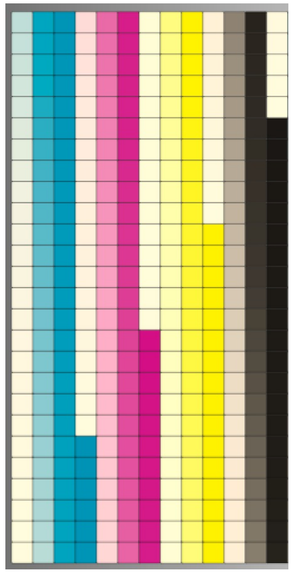
    - Describes the change in the **L*a*b* values** of each sample for a small change in each of the **curve parameters**
  - *Goal – minimize* ***error values*** (Δy)
    - Normal equation - gives a **least squares solution** (for a linear system)
    - Printing process (target profile) is not linear
    - Multiple iterations (4-5) needed to reach minimum error

Sample Sets

- **Bound** to the calculation method
  - *TVI – only pure process colors*
  - *Near-Neutral – only gray CMY and pure K colors*

TVI



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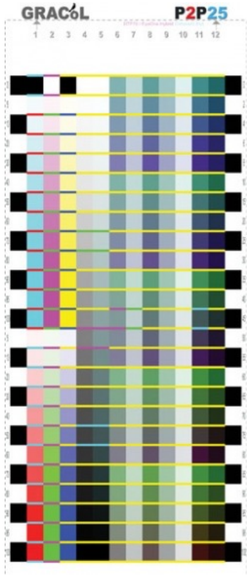

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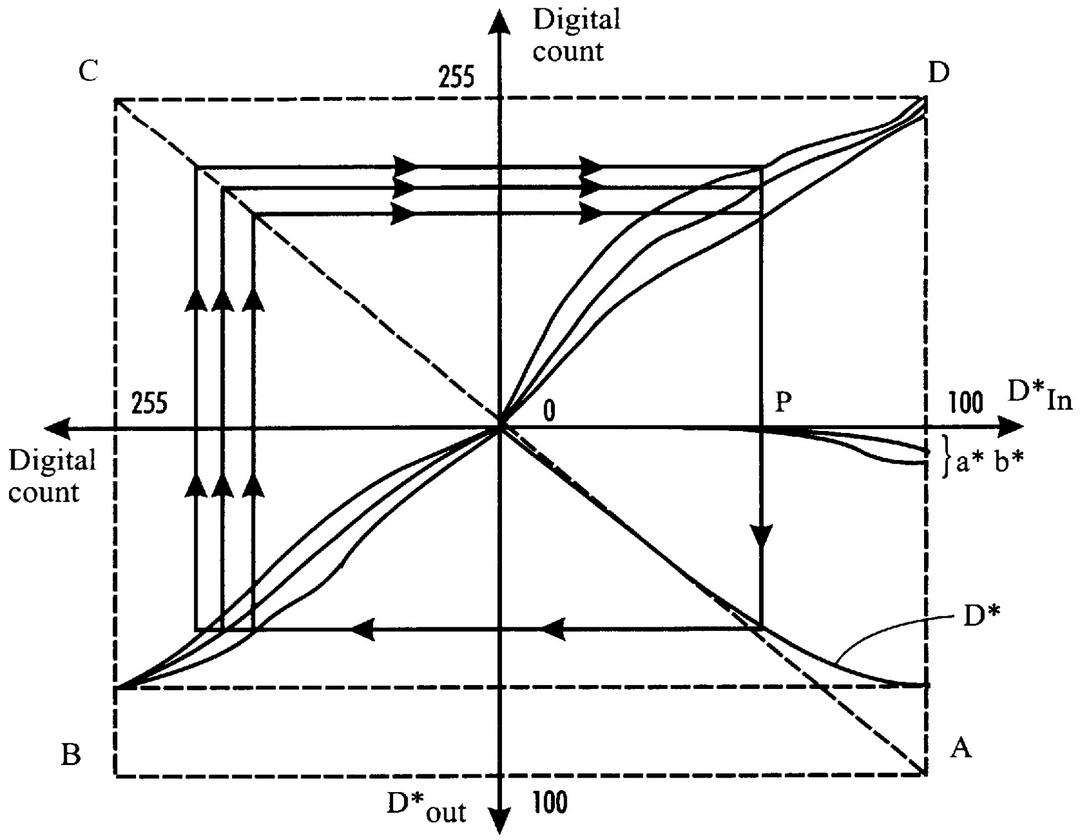
  - *Jones, 1920*
  - *Murray, 1936*
  - *Elijiw & Archer, 1972*



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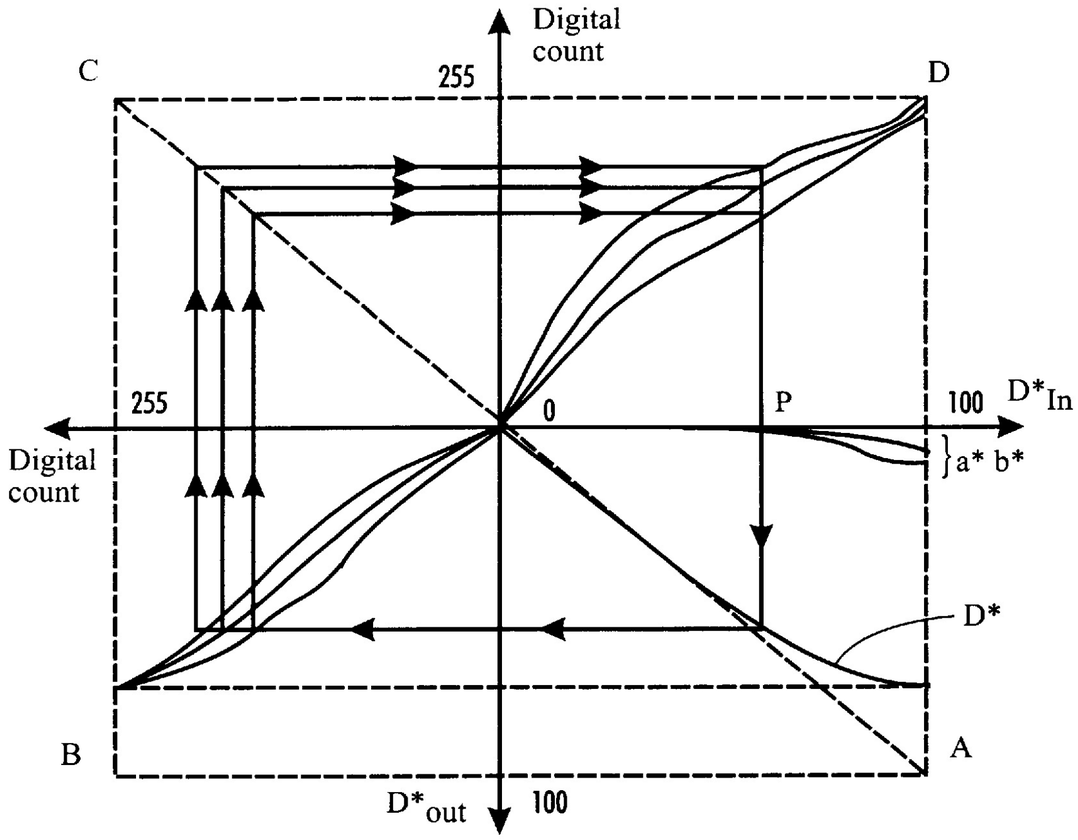
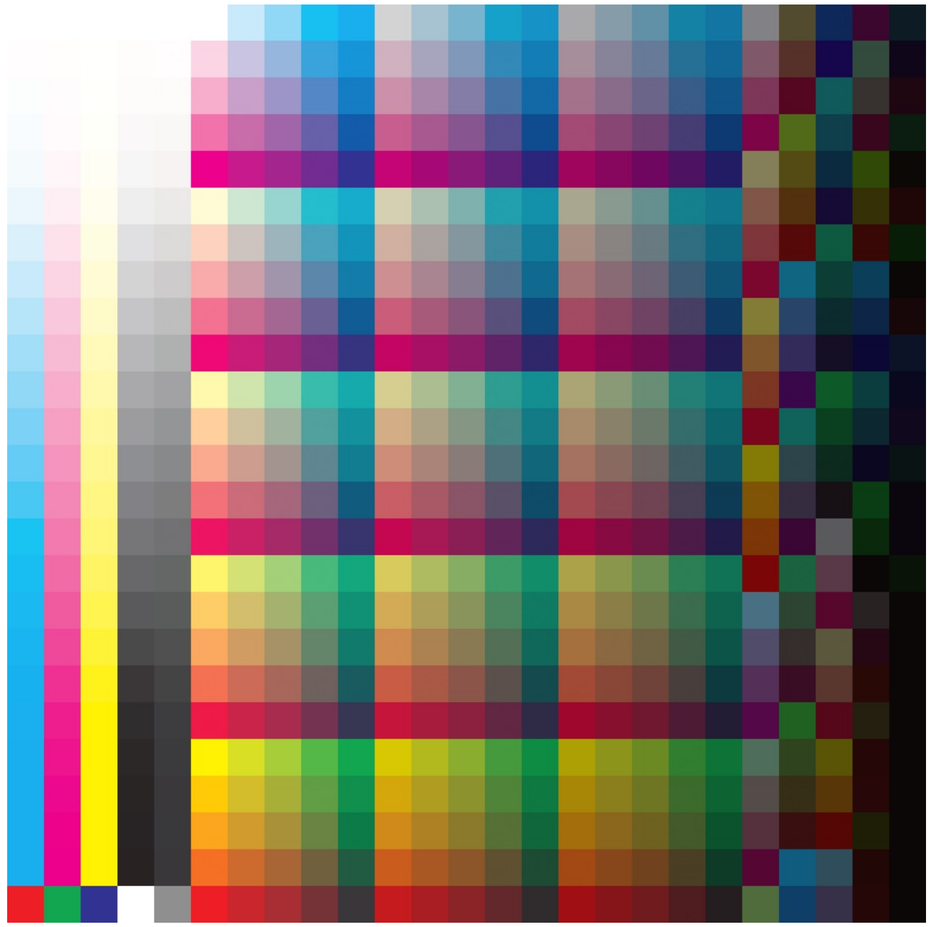
- **Made obsolete by computers and colorimetry.**



Jones Diagram

Sample Sets

- **OPTIMAL** method is flexible
  - Any number of samples
  - Any CMYK color mixtures



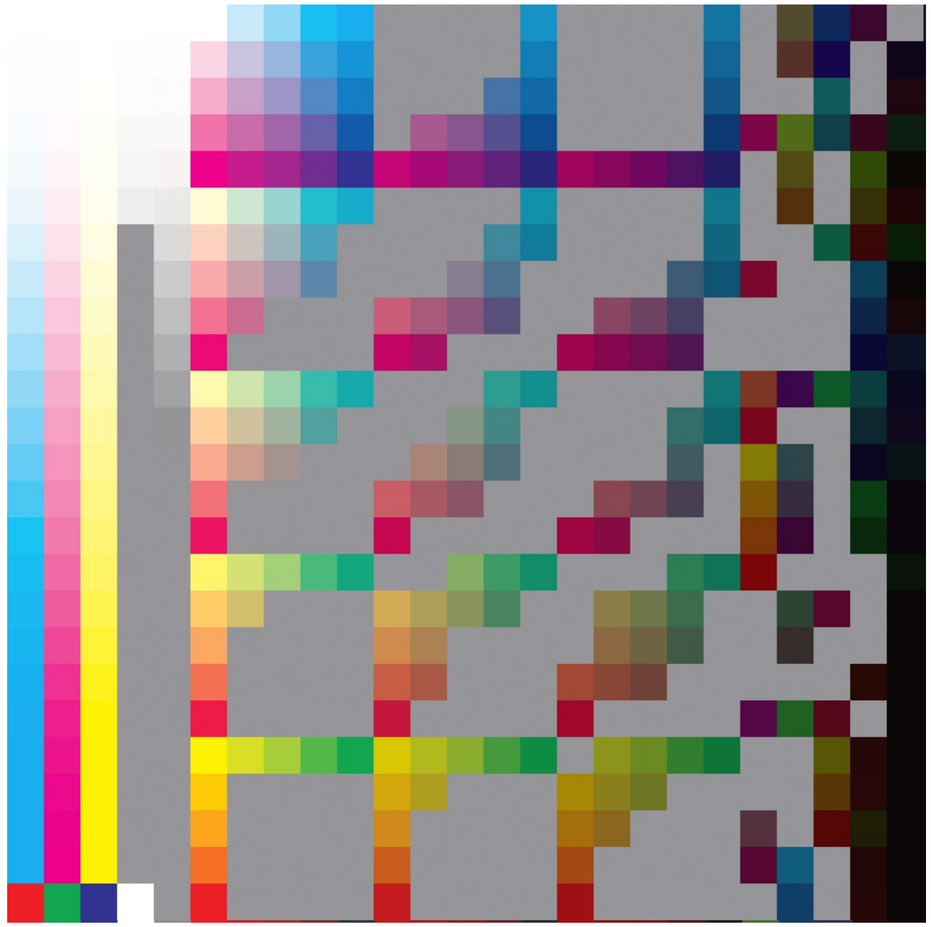
PressCalZ (625 samples)

Sample Sets

- **OPTIMAL** method is flexible
  - Any number of samples
  - Any CMYK color mixtures

- Sample **Selection**
  - Select colors likely to be printed
  - **Round-Trip** (using color profile)
  - Select colors with **ΔK ≤ 10%**
  - Accounts for profile UCR/GCR

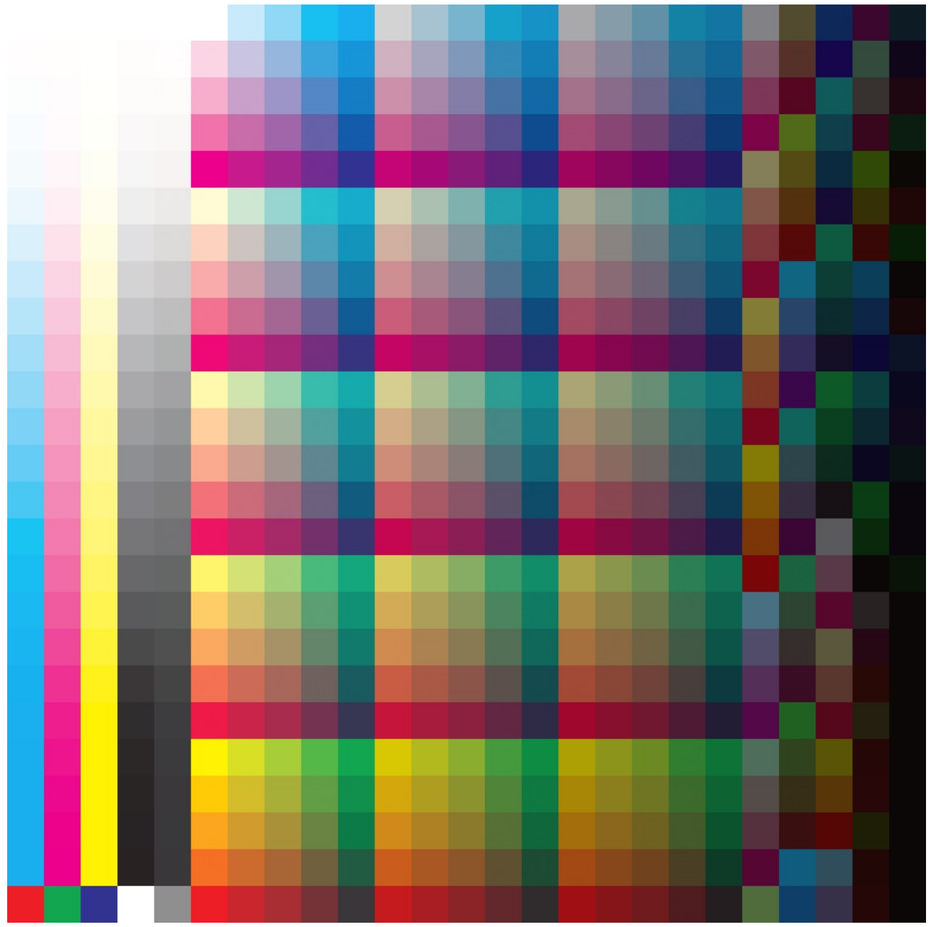
ΔK ≤ 10%



PressCalZ (356 / 625 samples)

Demonstration

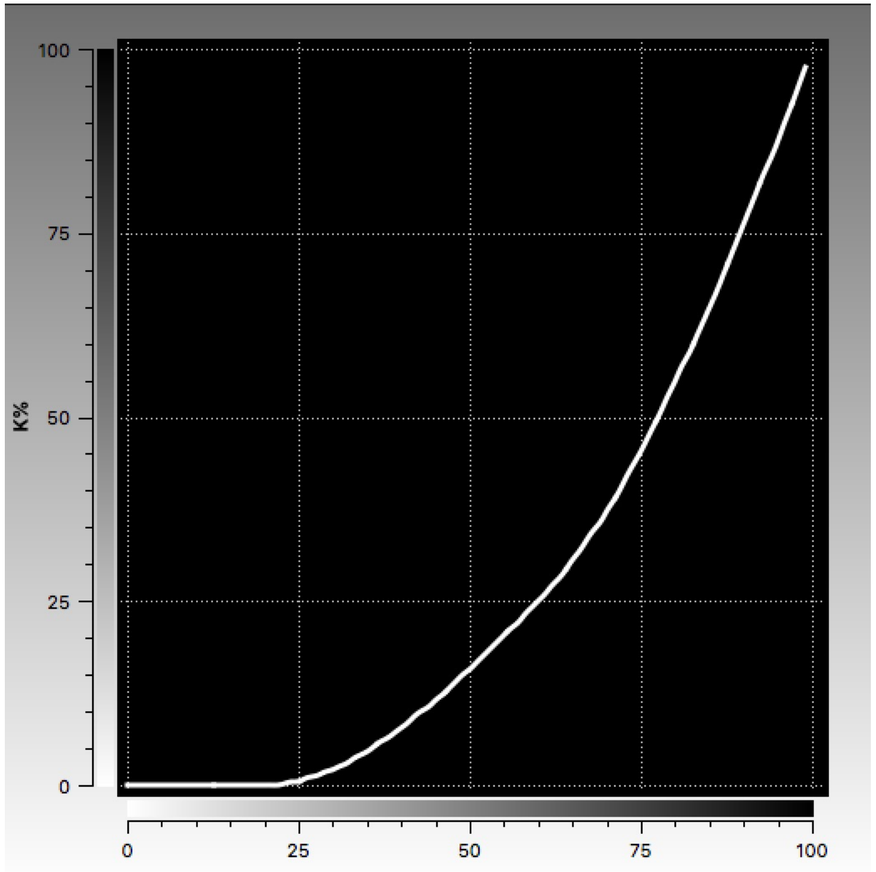
Press: Heidelberg 105XL
Paper: Endurance Silk (Veritiv)
Ink: Toyo Hyplus
Plates: Agfa Energy Elite Pro
(Positive-Working, Thermal, Linear)
Screening: Agfa Sublima 240 lpi XM
(Cross-Modulated) Hybrid (AM/FM)
Test Chart: PressCalZ
Instrument: X-Rite i1Pro 2 / i1iO
Measurements: Spectral – M0, M1, M2
Data Sets: 10 (5 sheets x 2 charts)
Date: July 28, 2017



PressCalZ (625 samples)

Demonstration

Reference Data: CGATS21-2-CRPC6.txt
Source: ANSI CGATS Standards Committee
Reference Profile: GRACoL2013_CRPC6.icc
Source: Idealliance
Software: X-Rite i1Profiler
Black Start: 20%
Black Curve: heavy
Total Ink: 320%



Black Curve

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We developed the **OPTIMAL** method using our **color tool kit**. The color tool kit is a set of Perl modules that implement many color management functions. There is no GUI. We run the software from a text editor.

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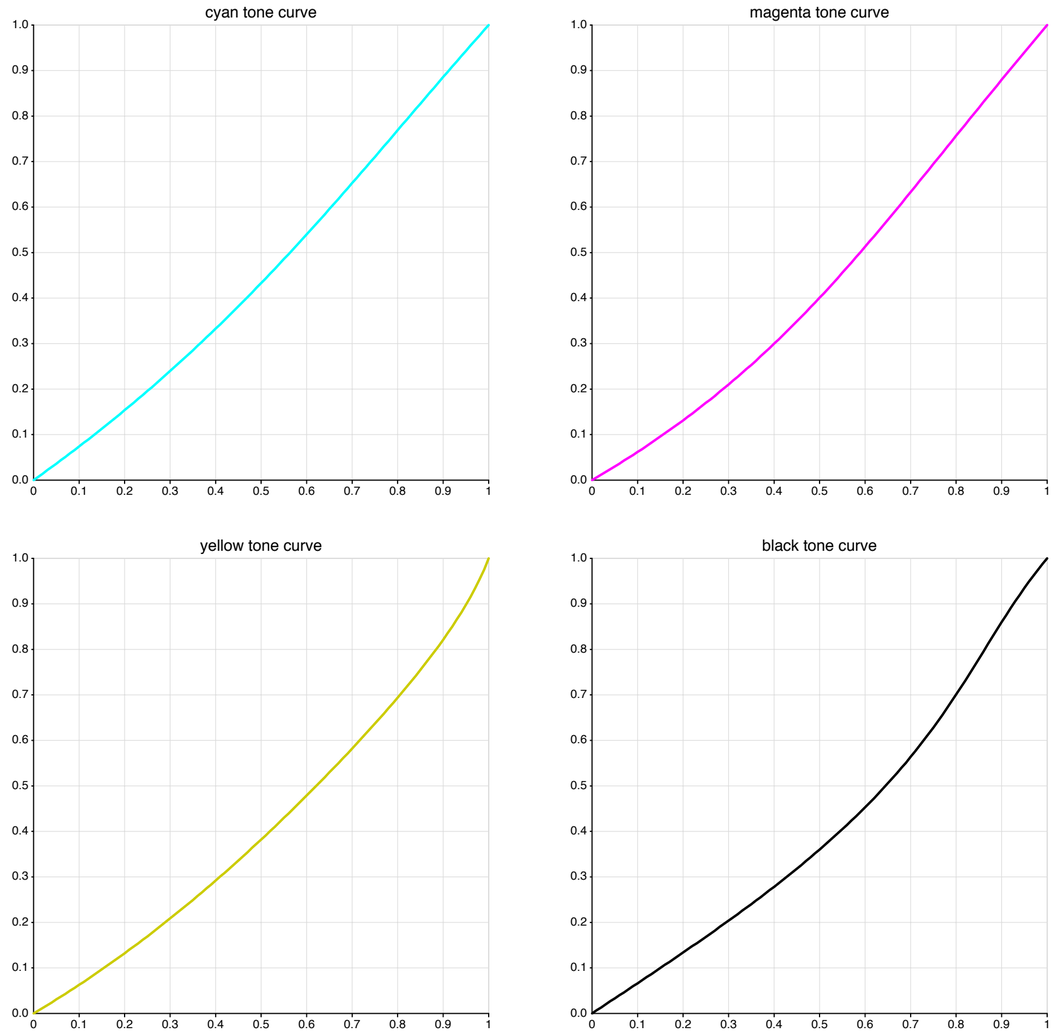
First, we will show you how curves are created. Then, we will simulate a press run using color management, to show how well the curves perform.



Advantages

- **Targets the proofing reference profile/data set**
  (e.g. GRACoL2013, FOGRA 51)
- **Flexible**
  - Any printing process
  - Any number of inks
  - Any gray balance
  - Any sample set
  - Any error metric
  - Adjustable curve complexity
- **Powerful**
  - Samples may contain any mixture of inks
  - Accounts for the effects of UCR/GCR
  - Accounts for ink trapping variations (including black ink)
  - Makes curves for multiple references with a single test run

Advantages

- **Robust**
  - Reliable (no surprises or failures, with a well-chosen sample set)
  - Smoothes process and measurement variations
  - Small impact from bad or missing sample measurements
  - Outliers may be identified and removed
- **Easy to learn and use**
- **Uses standard mathematical techniques**
- **Open source software implementation available**
- **Free (no patents, royalties, training fees, or certification fees)**

Questions?

Some possible topics…

- Bernstein polynomials
- Optimization
- Sample sets
- Flowchart
- Reference data sets
- Black generation
- N-channel curves (CMYKOGV, CMYK + spot, etc.)
- Gray balance
- TRAND (G7)
- Colorimetric tone value (CTV)
- Software
- Open source

Conclusion

- Read the TAGA paper for more details
- **Open source** software available on request
- **CONTACTS**

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Charles (Chuck) Spontelli csponte@bgsu.edu