Introduction to Colour Science

NPGR025

Unit 7: Digital Colour Management

Computer Graphics Charles University

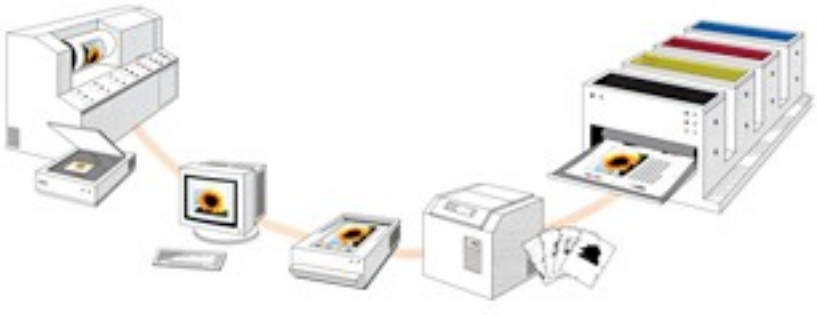
Sources
J-P Homann, Digitales Colormanagement

Overview

- Colour workflow
- Printing terminology and problems
- ICC profiles and standards

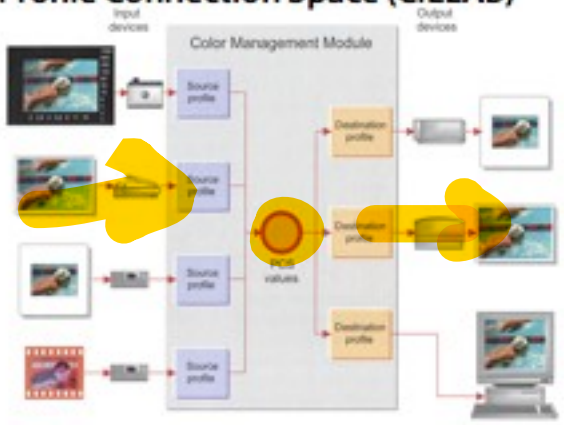
The Digital Printing Pipeline

- A chain that is as strong as its weakest link
- Exact characterisation of all links is a necessity



Colour Workflow Topology

- PCS – Profile Connection Space (CIELAB)



Scanners

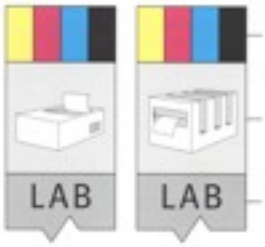
- Multi-band imaging sensors
- Wide variety of filters are used
  → raw data not directly usable
- Have to be calibrated using known targets
- Scanner profile determines exact relationship between obtained RGB values and true L*a*b values

Monitors

- Use additive colour mixing to display colour images
- Wide variety of phosphors and TFT/LCD luminaries/filters exist
- Calibration using colorimeters is essential for professional use
- Has to be performed daily for CRTs after device has warmed up
- Only valid for particular brightness
- Not always possible!

Printers

- Subtractive mixing of pigments on paper
- Much more complex to characterise than additive devices due to different
  - Printing technologies
  - Paper types
  - Inks
  - Nonlinearity of colour mixing



Characterising Printers

- It is not possible to characterise a printing device using a single profile
- Profiles differ (at least) for
  - Paper types
  - Colour intensity
- Profiles have to be computed separately for each paper/ink combination!
- Profiles are a mapping L*a*b* to/from CMYK

Colour-safe CMYK

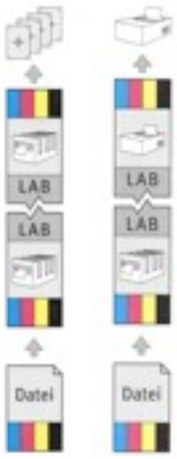
- CMYK is the de facto standard in the graphical community
- For coated papers the inter-device correspondence on professional equipment is already very high
- Scanners, monitors and smaller printers do not comply with these standards → colour management is needed for these devices

Colour-safe CMYK Display

- CMYK files can be directly displayed on calibrated monitors
- Useable for the display of arbitrary legacy files
- CMYK files usually do not contain a profile, so knowledge of original output medium & colour space is necessary

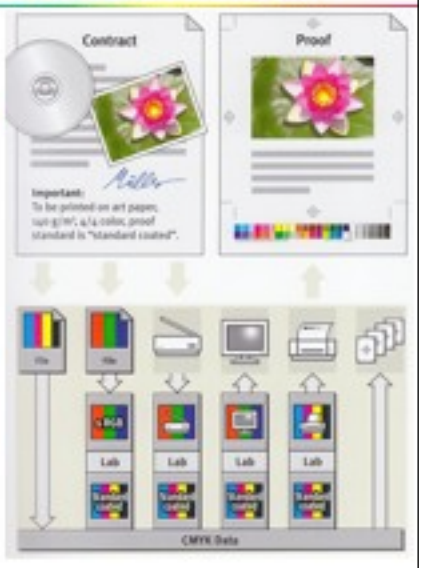
Simple CMYK Conversion

- If original target of a CMYK file is known, conversions to other targets are possible
- Problem: gamut mapping is needed
- Used for changes in paper quality and printer type
- Also applicable for proofing



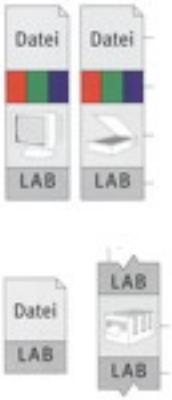
CMYK Workflow Overview

- Old standard workflow in the graphical industry
- Uses CMYK files as the base unit of data interchange
- Advantage: simplicity
- Disadvantage: limited to implicit gamut of industry standard CMYK printers (cf. Hexachrome)



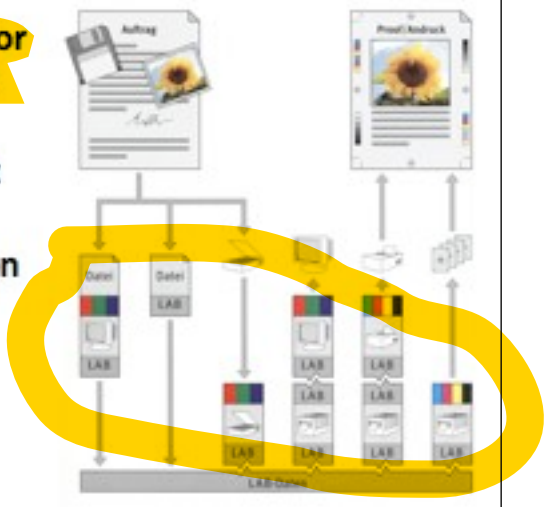
L*a*b Workflow Symbols

- Files with RGB content now have to contain the profile of their source: a reconstruction of their L*a*b content is always possible
- Plain L*a*b* files are possible
- Conversion profiles from L*a*b to L*a*b* can be defined
  - Use: conversion between printer gamuts



L*a*b Workflow

- Conceptually superior to a CMYK workflow
- Information is destroyed at the last possible moment
- No implicit restriction to CMYK gamuts



Conditions for a L*a*b Workflow

- Application support
  - Not pervasive, but present
- Filetype support
  - Reasonable
- Support for working with profiles
  - Not common, but existent
- Automatic conversion of old CMYK data
  - Problematic, needs manual intervention

The Ideal Print-job

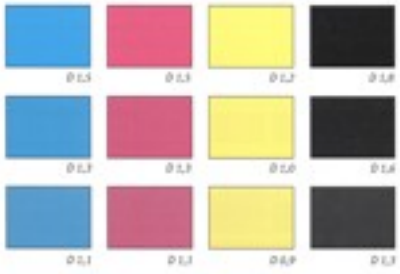
- Customer orders a printing job and provides all necessary specifics (paper type etc.)
- The preprint department processes the job and delivers a proof with a colour wedge
- Customer accepts the proof
- The printer produces the job based on the proof and comparison of the colour wedges on proof and production
- Customer is happy

Print-job Fallacies

- Saving money by omitting the proof stage, or using cheap proofing methods
- Using the wrong paper for analog proofs (which are done on the actual printing machine, as opposed to digital proofs, which are done on special equipment)
- Omitting colour wedges from the proofs
  - In this case the printer can only try to get the colour balance right, with all this entails

Paper Type Characteristics

- Key characteristics are
  - Tone value increase (Tonwertzunahme)
  - Solid density (Volltondichte)
- The latter has values between 0.9 and 1.9
- Measured with a densitometer
- Only standardised for CMYK inks

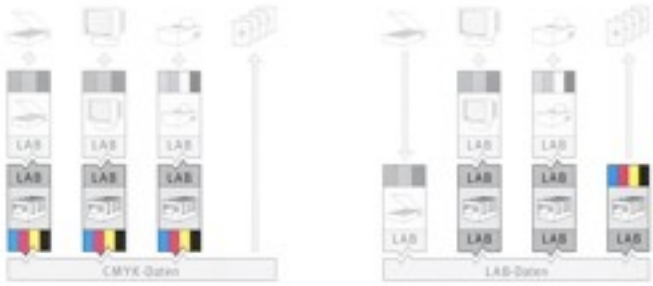


Paper Types

- Coated papers
  - Used for high quality four colour printing, e.g. for books and magazines
- Uncoated papers
  - Equivalent to laser printer / copier papers
- Newsprint
  - Cheap, uncoated papers of low quality for mass use

The Role of CMYK Printer Profiles

- L*a*b workflow concentrates profile usage to a single instance
- Every application of a CMYK <-> L*a*b profile generates errors

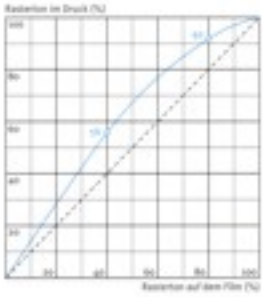


Tone Value Increase

- On coated paper, inks dry as a separate layer
- Uncoated papers, especially newsprint, soak up at least part of the inks
- Offset print works through rasterization
- Dot placement accuracy is crucial
- If paper soaks up ink, dots grow larger

Characterising TVI

- Two methods exist:
  - Providing key values for dot gain (Tonwertzunahme) at either 50% or 40% and 80%
  - Providing the complete curve (only valid for the specific setup it was measured with)



TVI Example

- A raster for 40% neutral grey covers 40% of the area with raster dots and leaves 60% uncovered
- A TVI of 16% means that the raster covers 56% of the surface when printed, and only leaves 44% free
- This leads to a considerable darkening of the rastered area
- This problem is at its worst for newsprint

TVI Consequences

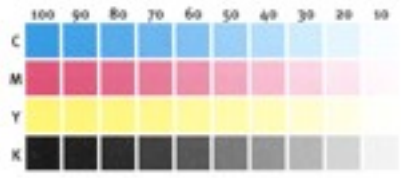
- Coated papers allow highest solid densities, and therefore highest saturations (more pure ink = deeper colours)
- Apart from allowing only weaker solid densities (and hence less saturated colours), uncoated papers suffer from higher TVI, which in turn leads to further loss of contrast and saturation especially in the dark tones (inks run into each other)

Grey Balance

- A classical problem is that equal amounts of CMY inks do not yield neutral grey colours
- Euroscale inks need 62% C, 50% M and 50% Y for this
- A printer can change the colour balance of a print job by altering the ink feed to the press
- Correction of bad input data is only possible for uniform colour shifts

Colour Wedges

- Essential tools for matching of proofs and production print runs
- Usually contain both CMYK & spot colour, grey and rastering information
- Size and pattern are dependent on the desired accuracy and the job properties

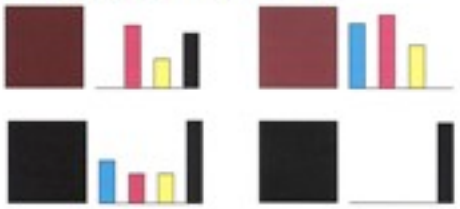


Colour Wedge Example

- One of many standardised bars offered by FOGRA (www.fogra.de)
- Offers the possibility to check rasterization quality separately from colour purity

Colour Separation

- To make life more interesting, CMYK is an ambiguous colour model which leaves some freedom in how a colour is mixed



- This degree of freedom mainly concerns how much "real" black is used

Colour Separation Goals

- Coated papers: high image sum densities (Farbsumme) are used to achieve high saturation

- Uncoated paper: low image sum densities are used to stop dots running into each other

- 100% (K) ISD vs. 213% (47%C 33%M 33%Y 100% K) ISD

Black Composition

- Problem: systematic approach to using black during CMYK separation
- Long vs. short black (brightness)

Wide vs. Narrow Black

- Wide black reduces the image sum density, which makes it ideal for newsprint
- Drawback: skin-tones appear greyed out

Black Composition Example

- Since K is printed on top of CMY, replacement of CMY components with K is called under colour removal

Black Composition Control

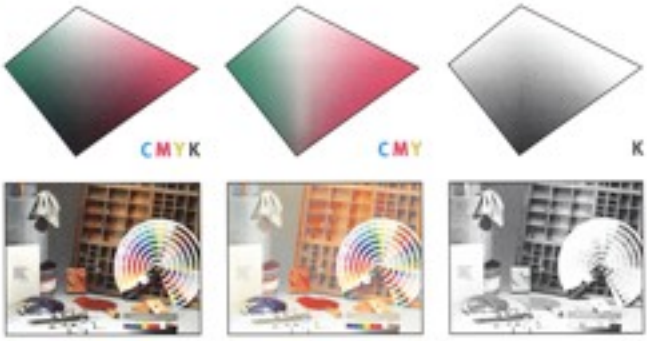
- Usually achieved through specification of curves which control the relative amount of CMY and K to be used

Under-colour Addition (UCA)

- CMY replaces most of the black in the image
- Good, saturated colours are the result

Grey Component Replacement

- Reduces colour as much as possible
- Strong GCR typical for newsprint – weak colours, very low ISD



Weak GCR

- Reduces K to the darkest areas of the image
- Sometimes referred to as "skeleton black" (Skelettschwarz)

ICC Profiles

International Colour Consortium

- Founded by various software companies to provide a workable interchange standard for colour data
- ICC profiles aim to provide mapping between different device categories, even those with widely differing gamuts, and L*a*b

ICC Profiles #1

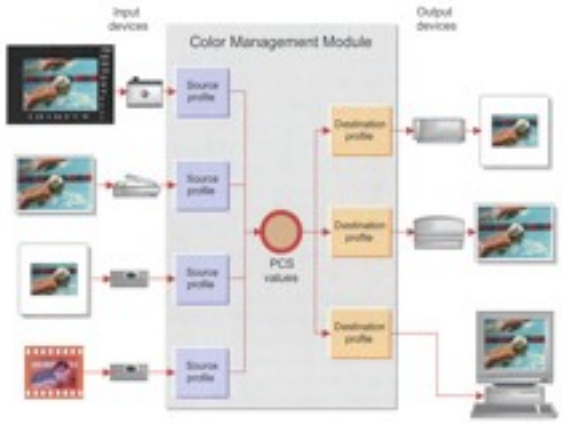
- Provide a mapping between colour spaces
- Enumeration is impossible due to colour space sizes
- Tables of representative samples are used instead; interpolation is used in-between

ICC Profiles #2

- Several subtypes of ICC profiles exist:
  - Look-up table (LUT)
  - Matrix shaper (for RGB)
  - Generic colour space
- # of samples in LUT varies with accuracy of profile: between several dozen to 32000
- Transformation L*a*b → CMYK has additional problem of black composition ambiguity
  - Solution: any given ICC profile uses one fixed black composition algorithm

ICC Profile Use

- PCS – Profile Connection Space (CIELAB)

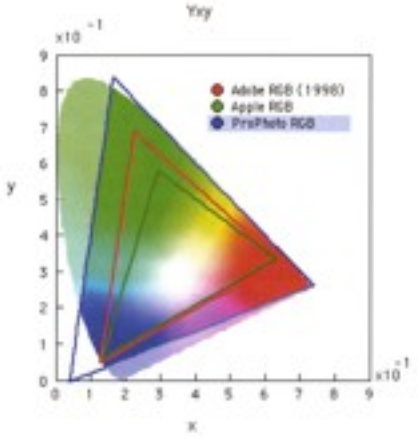


Tagged and Untagged Images

- All images can be tagged with an ICC profile
- Untagged images are treated in screen space
- Colour setup in image processing apps (e.g. Photoshop):
  - Default ICC profiles
    Which ICC profile to use by default
  - Conversion strategy
    What to do in case of a mismatch
  - RGB working spaces

RGB Working Spaces #1

- All common spaces use 24 bits per pixel
- Small working space:
  - Not very expressive
- Large working space:
  - Contains lots of colours, but bits are wasted on colours which are rarely needed



RGB Working Spaces #2

- Apple RGB: small gamut (smaller than CMYK)
- Adobe RGB: good all-round choice
- Kodak ProPhoto: very large, hence wasted accuracy
- sRGB: too small, distorts the blue region of the colour space (if image has lots of data in that region)
- ECI-RGB: popular in Germany for digital photography
- Monitor space: should not be used by professionals

RGB Spaces #3

- GIF, BMP: no provisions to store colour space information
- JPEG: EXIF headers can contain RGB primaries - support in software is rare, professional cameras offer choice and store info
- TIFF: colour space information possible, rarely used
- PSD (Photoshop): colour space information as standard

Photoshop Profile Commands

- Choose Working Space
  - Choose meaning of internal 8-bit representation
  - Gamut mapping may be necessary for display
  - Gamut warning available
- Assign Profile
  - Inform Photoshop of the meaning of the RGB values in a file
  - Mainly useful for untagged data
- Convert to Profile
  - Converts internal data to target space

Image Types

- Type A - "Relative"
  - Relative values - measured in terms of some maximal output device capability (monitor) or reflectancy (paper)
  - Can apply to both subtractive and additive images (!)
- Type B - "Absolute Radiometric Values"
  - Captures of reality - "scene reference images"
  - This is what digital cameras ought to capture!

Maximal Difference in Brightness

- Type A
  - (Photographic slides: three orders of magnitude)
  - Computer screens: two orders of magnitude
  - Printouts: a range of roughly 10 luminance units
  - 8 bit images: 256 steps (!)
- Type B
  - Real world: more than 6 orders of magnitude (excluding the solar disc)

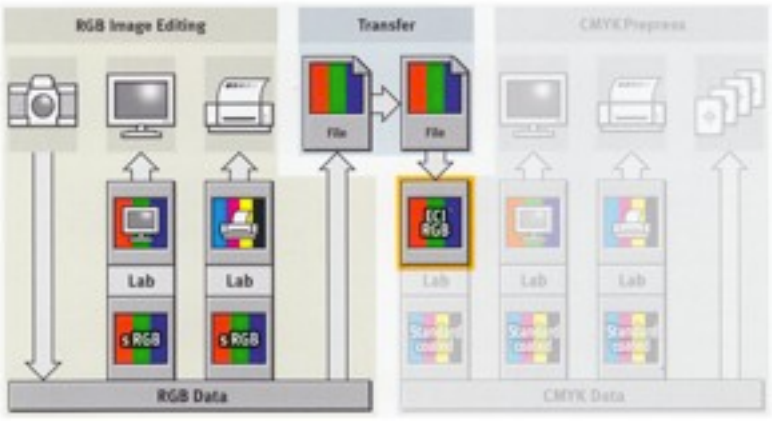
Conventional Image Formats

- Usually RGB (TIFF, PNG, JPEG)
- TIFF: also CIE L*a*b*
- 8 bits per channel → post-processing artefacts!
- TIFF: 16 BPC possible
- „Brightness ends at 1“ → always relative!
- No physical meaning of values
- Advantage: compact size, standardised
- Disadvantage: large amounts of information are destroyed

High Dynamic Range Formats

- Often CIE Luv or Lab colour space
- Floating point components → (potentially) large range
- Radiance RGBE, Pixar Log and LogLuv TIFF, ART XYZ (uncompressed), OpenEXR
- Values have physical meaning
- Advantage: compact size (!), standardised, few quantization errors
- Disadvantage: compression can introduce artefacts, not understood by Photoshop et. al.

The Importance of Tagging Images



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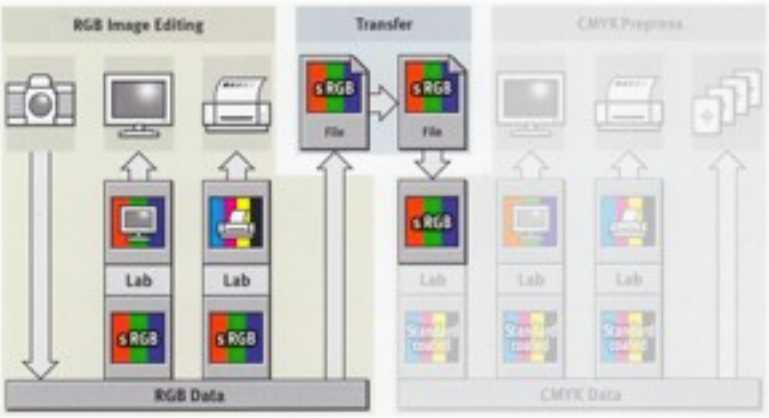

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Rendering Intents

- Hardwired gamut mapping techniques written into the ICC profiles via the tables
- Several tables – one for each purpose – exist within a single ICC profile
- Four categories:
  - Absolute and relative colorimetric intent
  - Photographic rendering intent
  - (Saturation intent)

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http://www.goominet.com/unspeakable-vault/

Colorimetric Intent

- Essentially amounts to clipping of out-of gamut values
- Absolute strictly maintains all in-gamut colours, while relative may alter their brightness
- Applicable whenever certain important spot colours (e.g. corporate logos) have to be preserved
- Contrast is destroyed in out of gamut areas

Photographic Intent

- Colours are compressed into the display gamut
- Differences in focus: perceptual aims at preserving overall balance, while saturation attempts to maximise use of the display gamut
- In most systems, this intent is used for screen → CMYK transformations

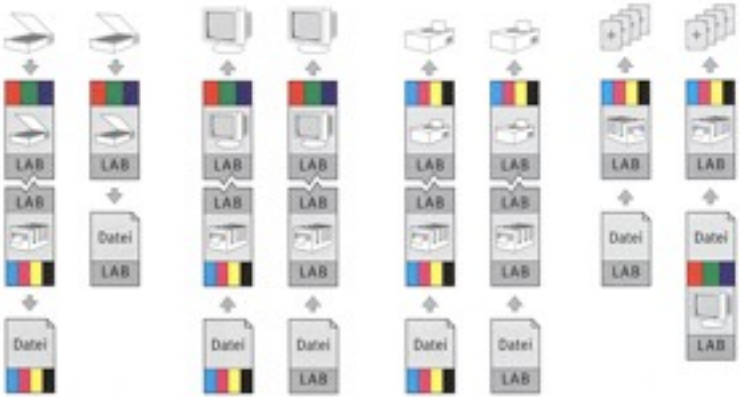
Colorimetric vs. Photographic Intent

- Photographic intent:
  - Theoretically the optimal intent for photographs
  - Implementation of how the compression is done is left to the vendors
  - Reproducibility of results highly problematic
- Colorimetric intent:
  - With depth compensation, it becomes useable for photographs
  - Good reproducibility

PRI vs. CRI

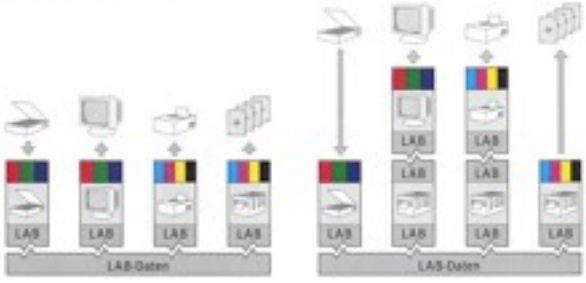
What Works Well Using ICC

- "Well" means without human intervention



Postscript Colour Workflow

- Version 1: no CM
- Version 2: L*a*b based CM, but no printer characterisation
- Version 2016: PC for CMYK colours



Problematic Tasks

- Conversion from old CMYK data to L*a*b requires manual intervention to raise contrast
- When converting CMYK to CMYK using a ICC – based L*a*b intermediary and the standard photographic rendering intent far too much saturation is destroyed

Problems with ICC Workflows

- Black and grey objects
  - Transformation via L*a*b* destroys black composition
- Spot colours
  - Transformation via L*a*b* discards this information
- No possibility to optimise specific transforms
- Partial solution: device link profiles
  - ICC profiles that do not use the source → L*a*b* → destination path

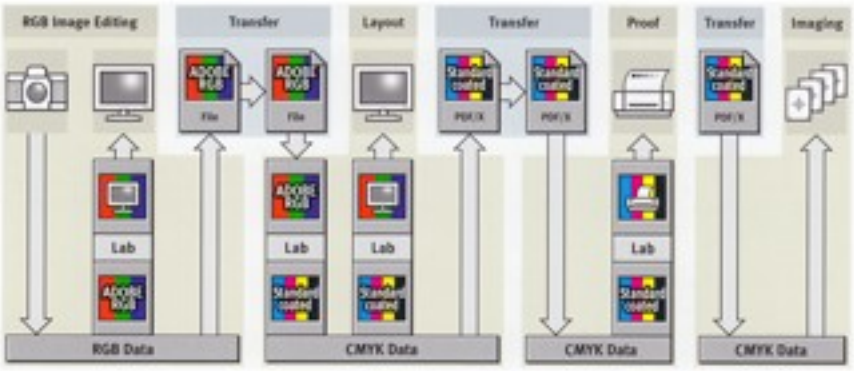
PDF / X

- Acronym stands for PDF Exchange
- Intention: a standard for PDF files that guarantees the stable interoperability of files with different links in the repro chain
- Focus: stable colour reproduction; graphics and text capabilities of PDF remain unaffected
- ISO15930 standard
- Original idea:
  - No individual profiles for any objects in the file
  - "Output intent" for entire file in header

PDF/X-1a and PDF/X-3

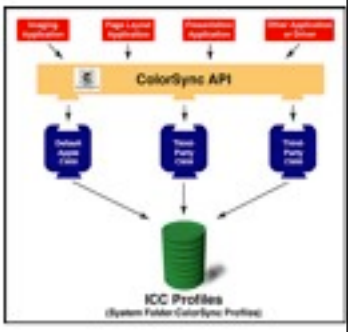
- Both restrict PDF content w/r to colour content to a well-defined subset of PDF functionality
- Parallel developments
- X-1a:
  - Only CMYK and spot colours are permitted
  - Directly useable by printers, stable
- X-3:
  - Arbitrary colour models / profiles permitted
  - Somewhat problematical

PDF/X Workflow



ColorSync

- Technology introduced by Apple to provide system-level colour matching capabilities
- Total integration into OS X
  - All applications have to use it
  - Interactive, colour-managed PDF as display language



Photoshop CMM History

- Photoshop 4 and earlier: all work done in screen colour space
- Photoshop 5 started to offer sophisticated colour management functions based on ICC profiles
- In PS 5, all images on screen were shown in the same colour space
- Photoshop 6, 7 and CS allow arbitrary colour spaces per open image