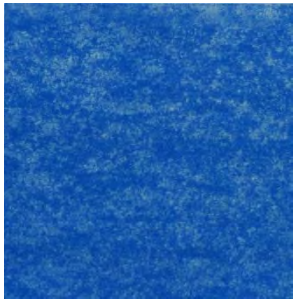
Physical evaluation of print quality

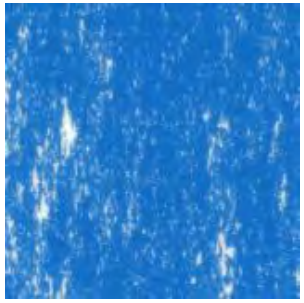
Li Yang
(li.yang@innventia.com)
Innventia, Sweden

INNVENTIA

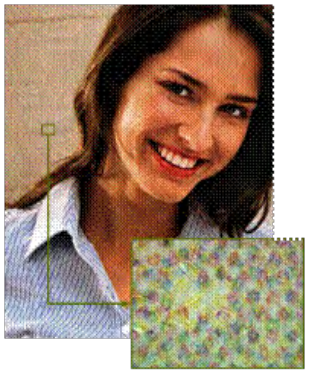
What is print quality ?



mottling



uncovered areas



missing dots

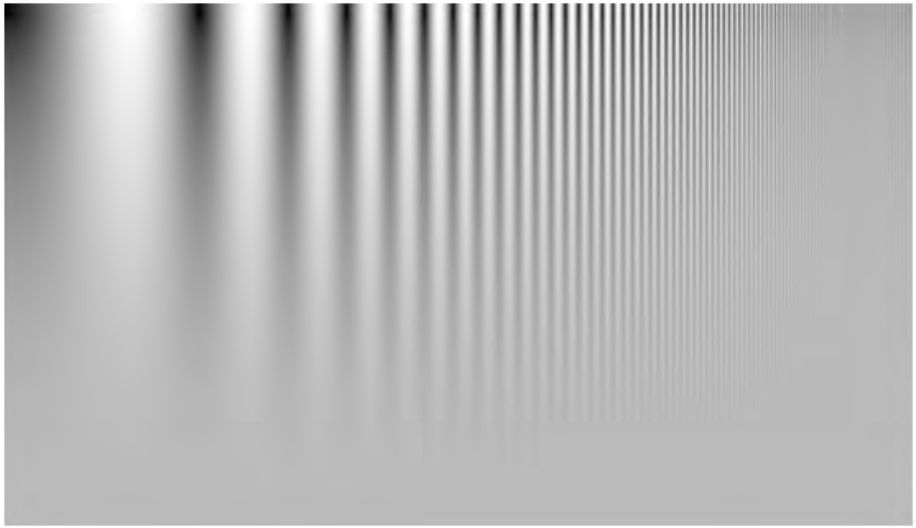
colour gamut

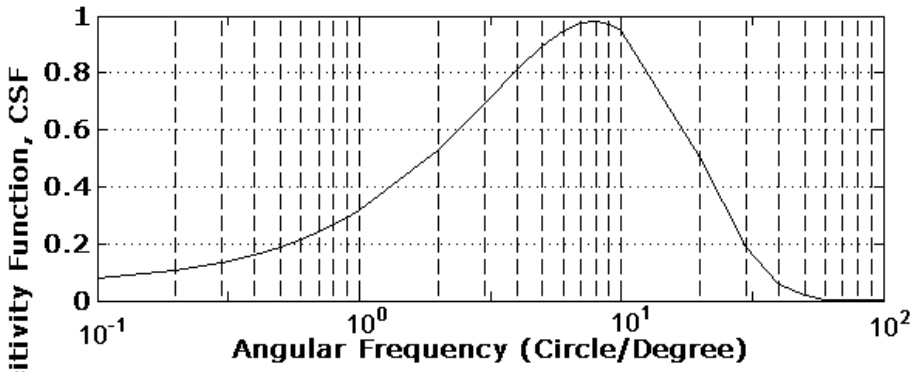
gloss and gloss variation

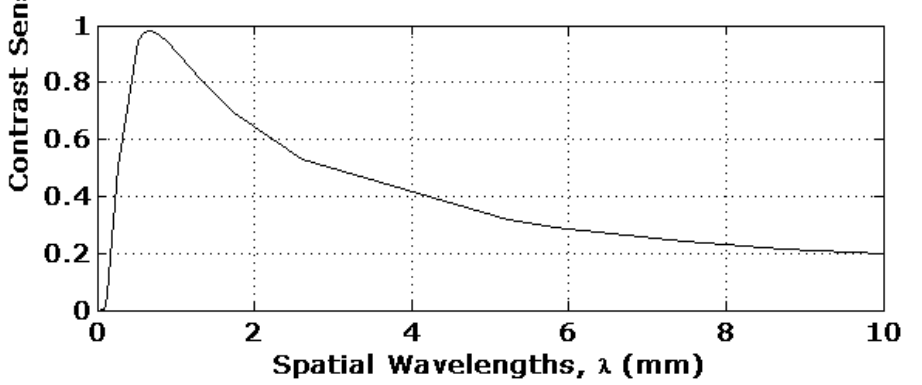
visual perception

Scope of the presentation

- Print quality is a complex concept
  - A print + a viewer.
  - Physical factors (3D ink placement)
    - Materials & printing process
  - Visual characteristics
    - Acuity, contrast sensitivity, etc.
- Physical evaluation methods

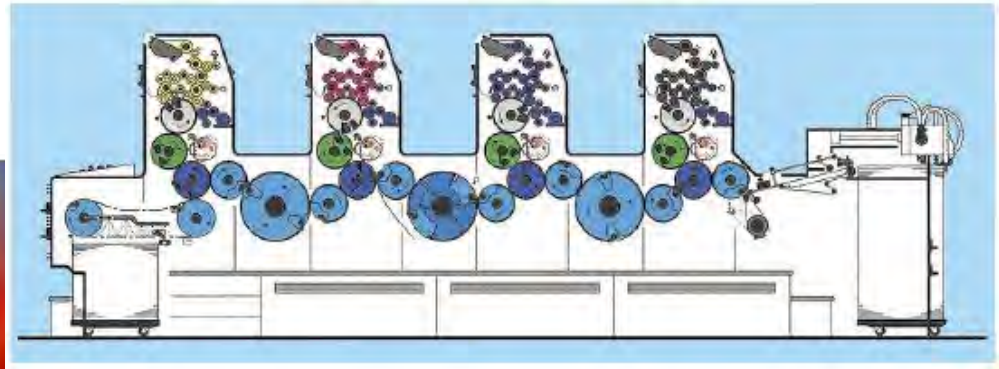


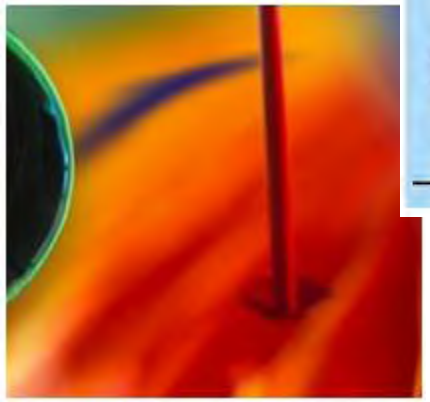


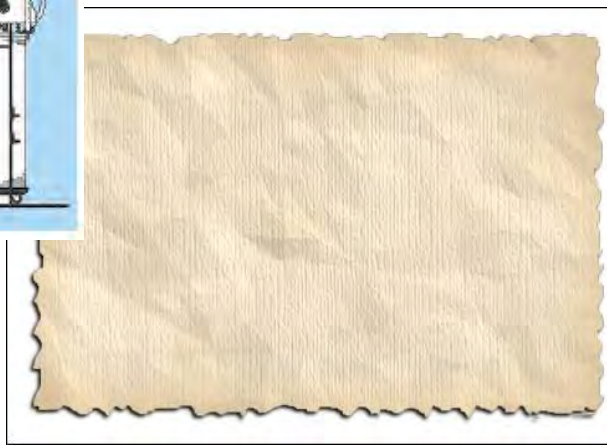


INNVENTIA

- Paper properties
- Ink properties
- Ink-paper interaction







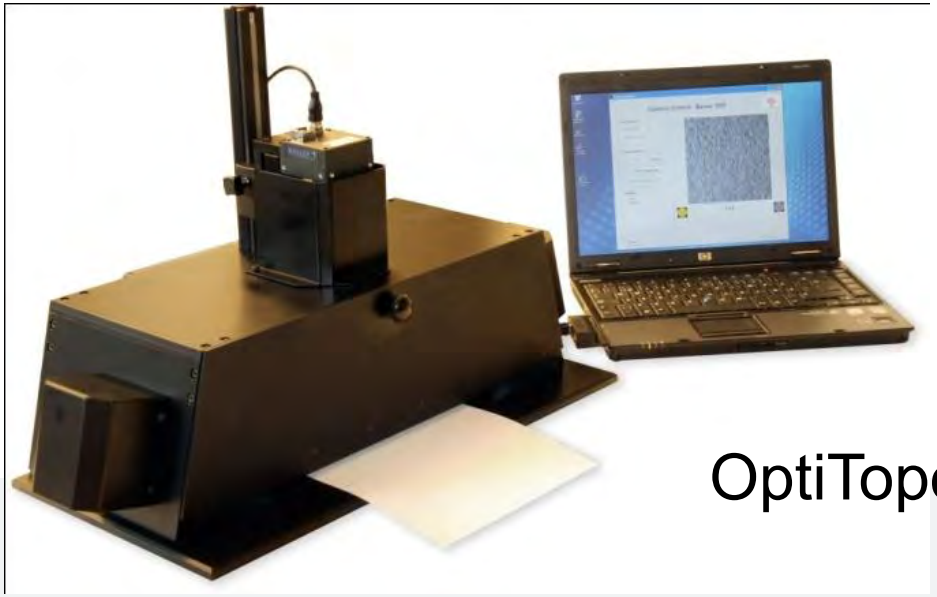
INNVENTIA

Physical factors

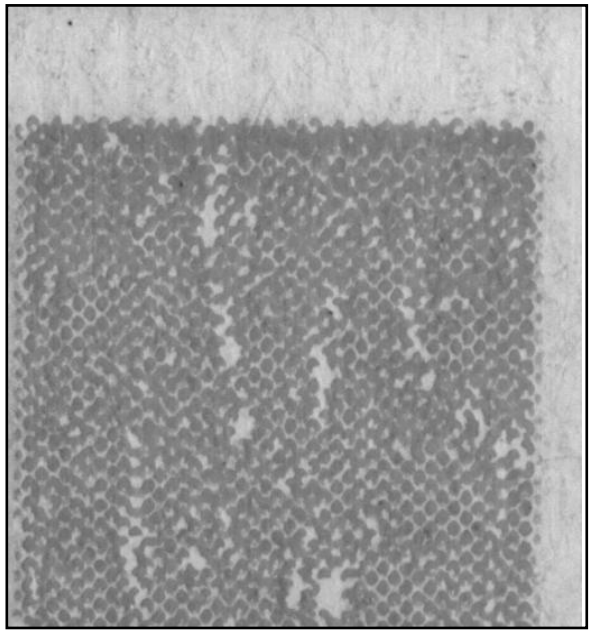
- Paper properties
  - Surface roughness
  - Porosity
  - Fluorescence
- Ink properties
  - Viscosity, ink tack, …
  - Ink transfer and ink setting
- Ink-paper interaction
  - Ink-spreading
  - Ink-penetration

Surface roughness

- Surface roughness affects ink-transfer.
- Low surface roughness ➔ high paper gloss and print gloss.
- To reduce surface roughness
  - Adding fillers
  - Calendering
  - Surface coating



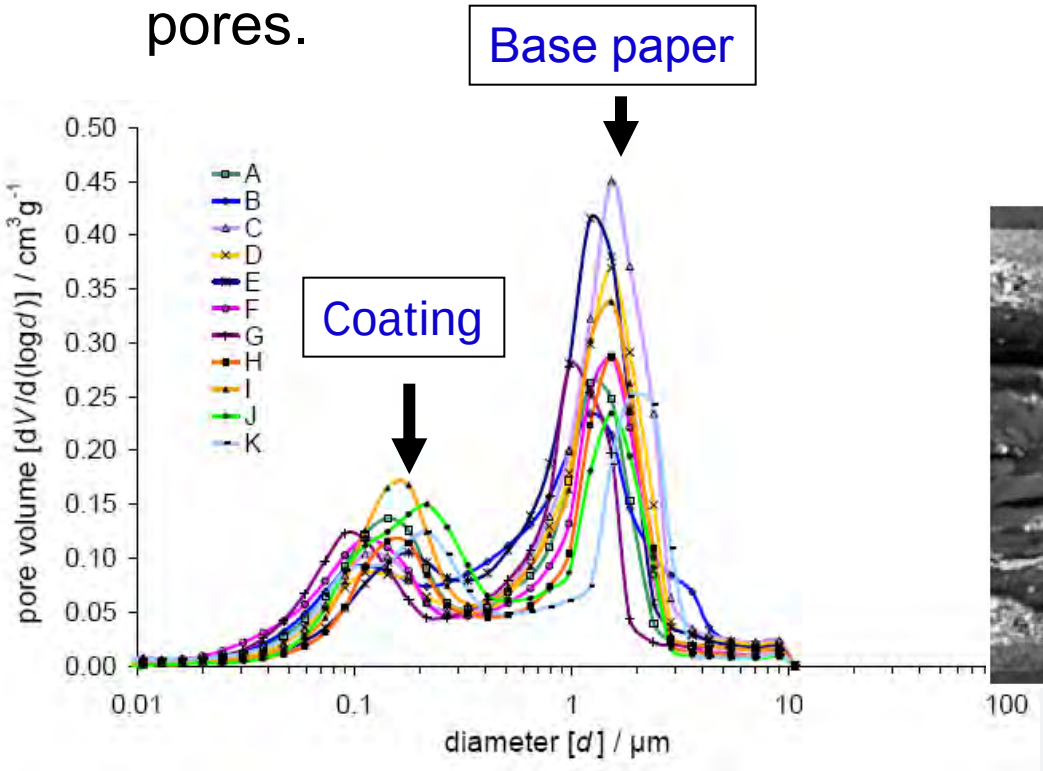
OptiTopo



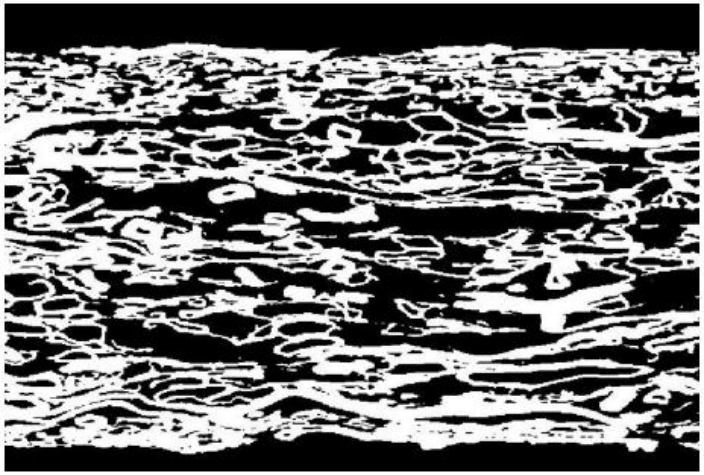
INNVENTIA

Porosity

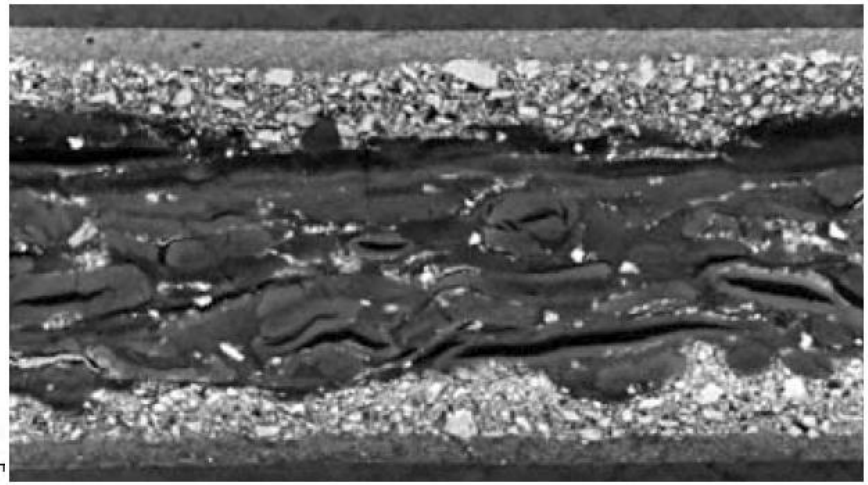
- Paper is a porous media
- The porous (pore-size) distribution governs ink absorption and ink setting.
- Adding fillers creates more small pores.



Cross section (uncoated)



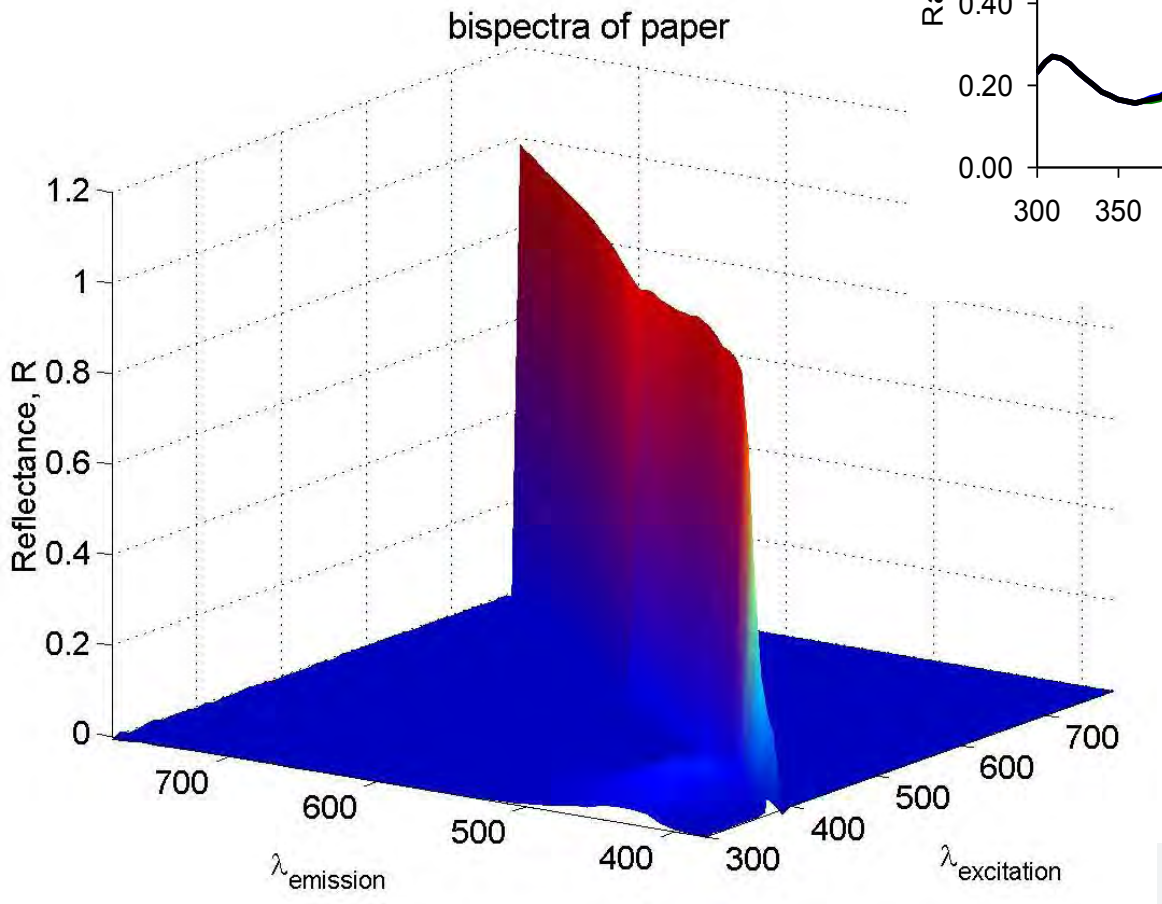
Cross section (coated)

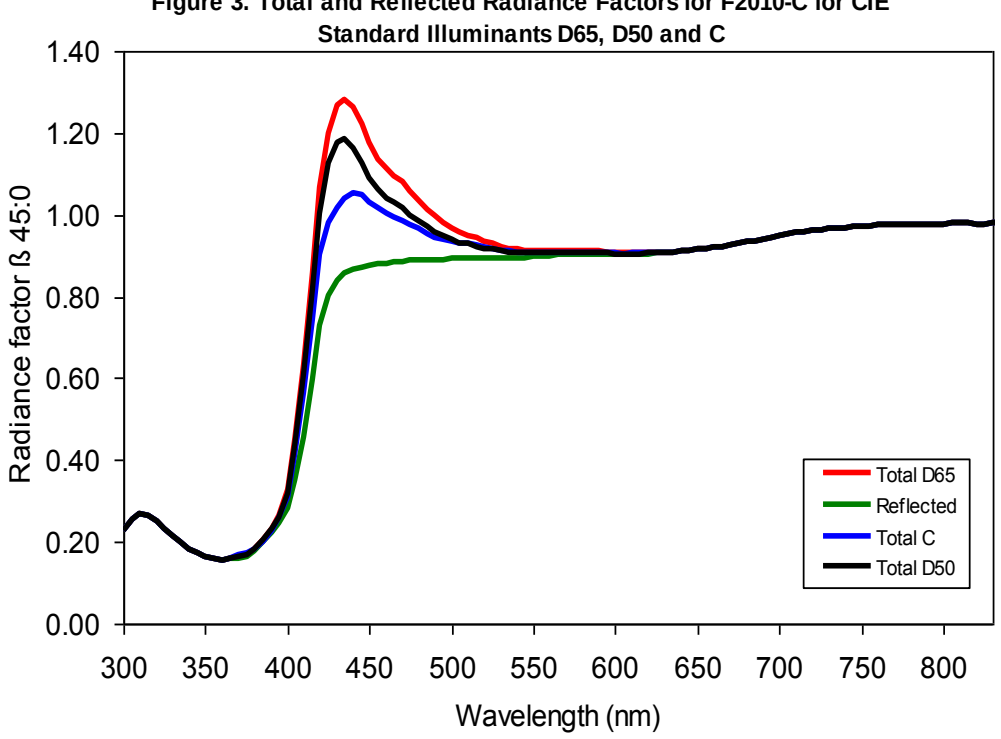


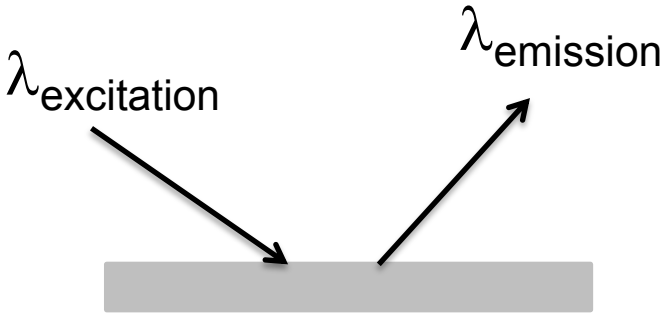
INNVENTIA

Fluorescence

- Paper shows different color under different illumination



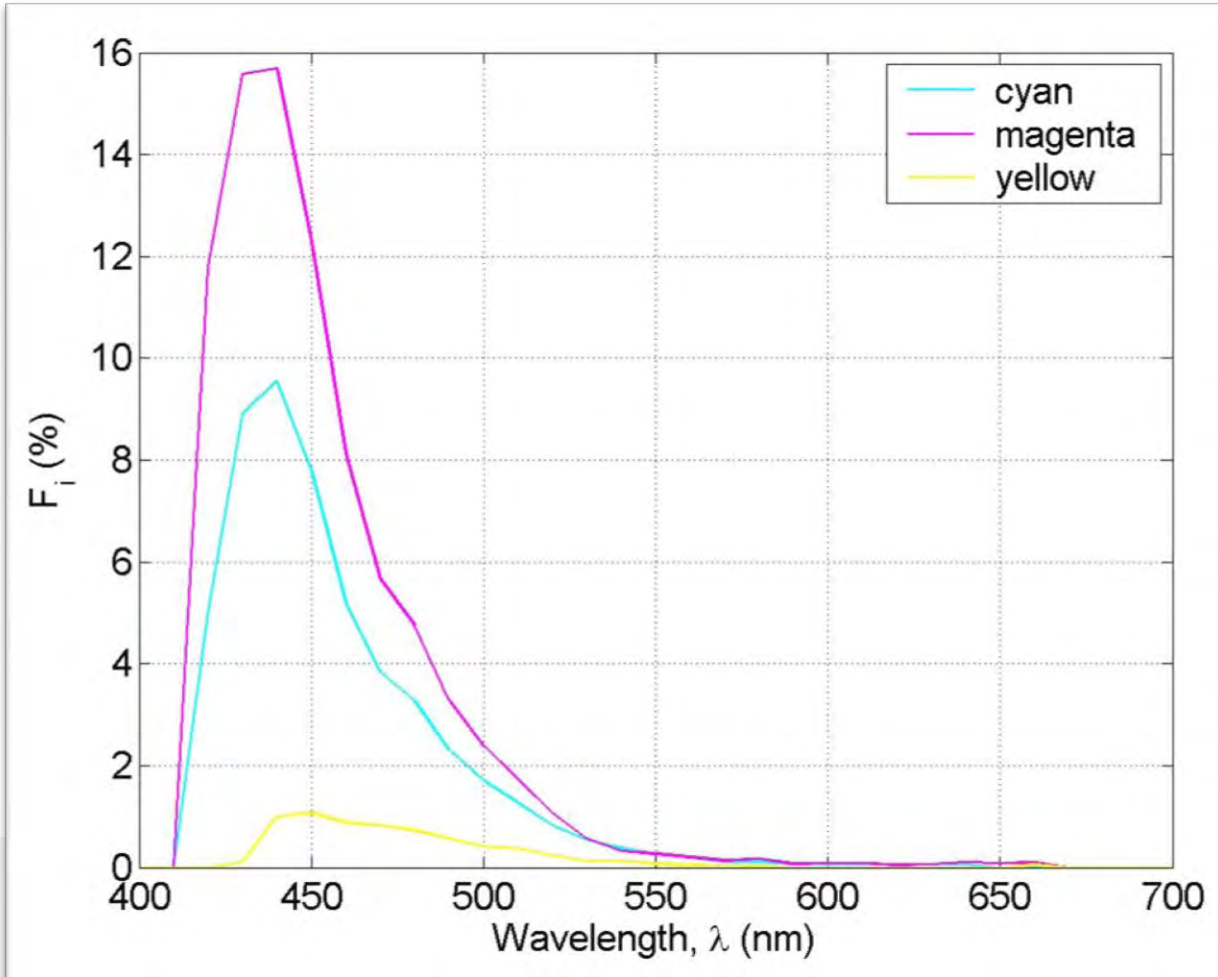




INNVENTIA

Fluorescence

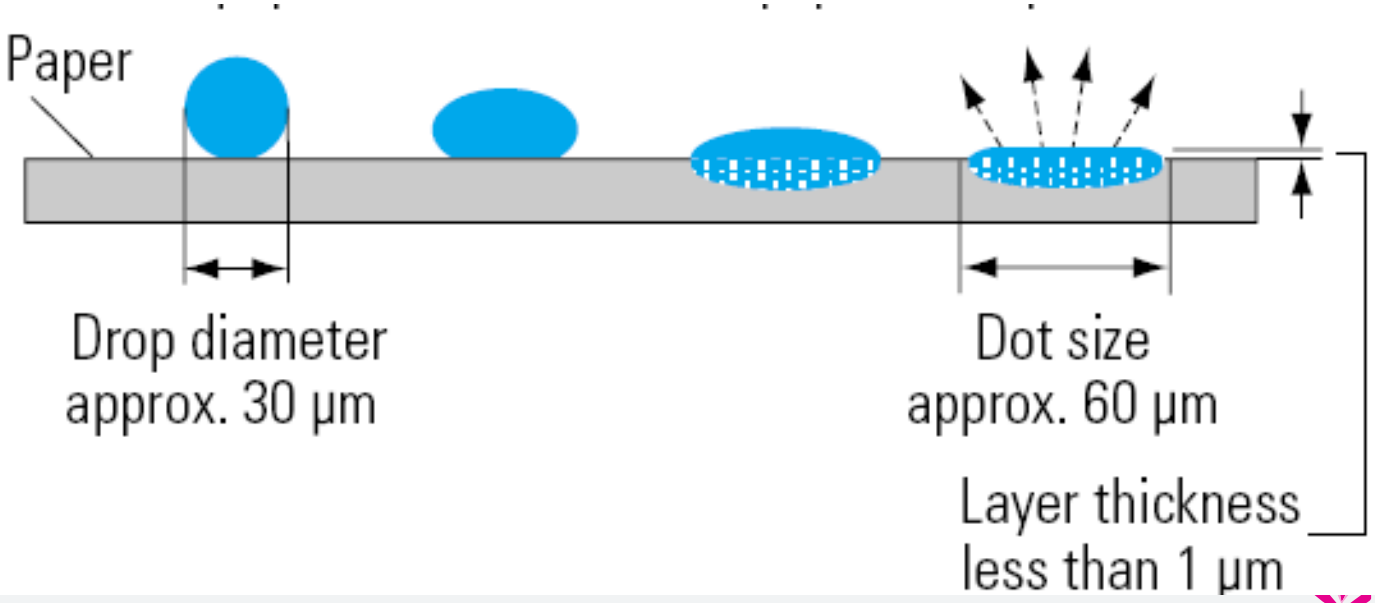
- Fluorescent contributions to the colors of the print solids
  - Illumination D_{65}



- Paper properties
  - Surface roughness
  - Porosity
  - Fluorescence
- Ink properties
  - Viscosity, ink tack, …
  - Ink transfer and ink setting
- Ink-paper interaction
  - Ink-spreading
  - Ink-penetration

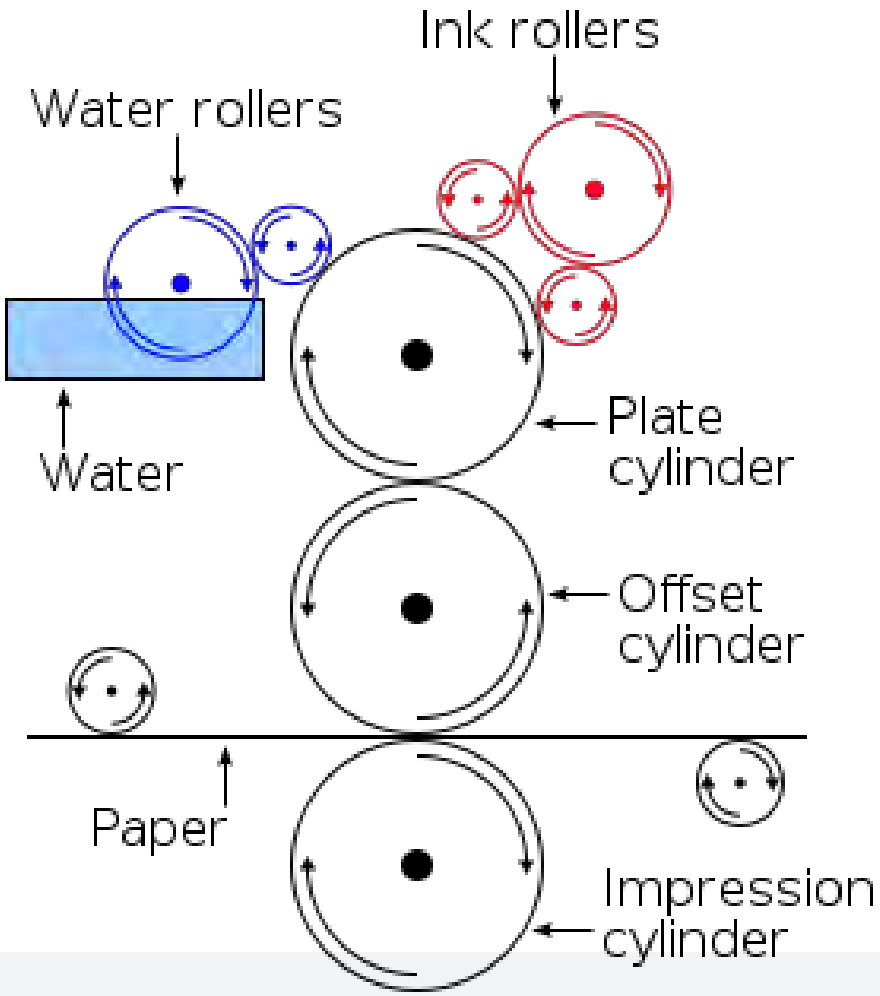
Ink properties

- The role of ink
  - Selectively absorbs light and creates color.
  - Ink flows on paper surf. and penetrates into paper.
- Important ink properties
  - Viscosity: ink spreading and penetration.
  - Ink tack: ink stickiness after printing, ink transfer and ink setting.

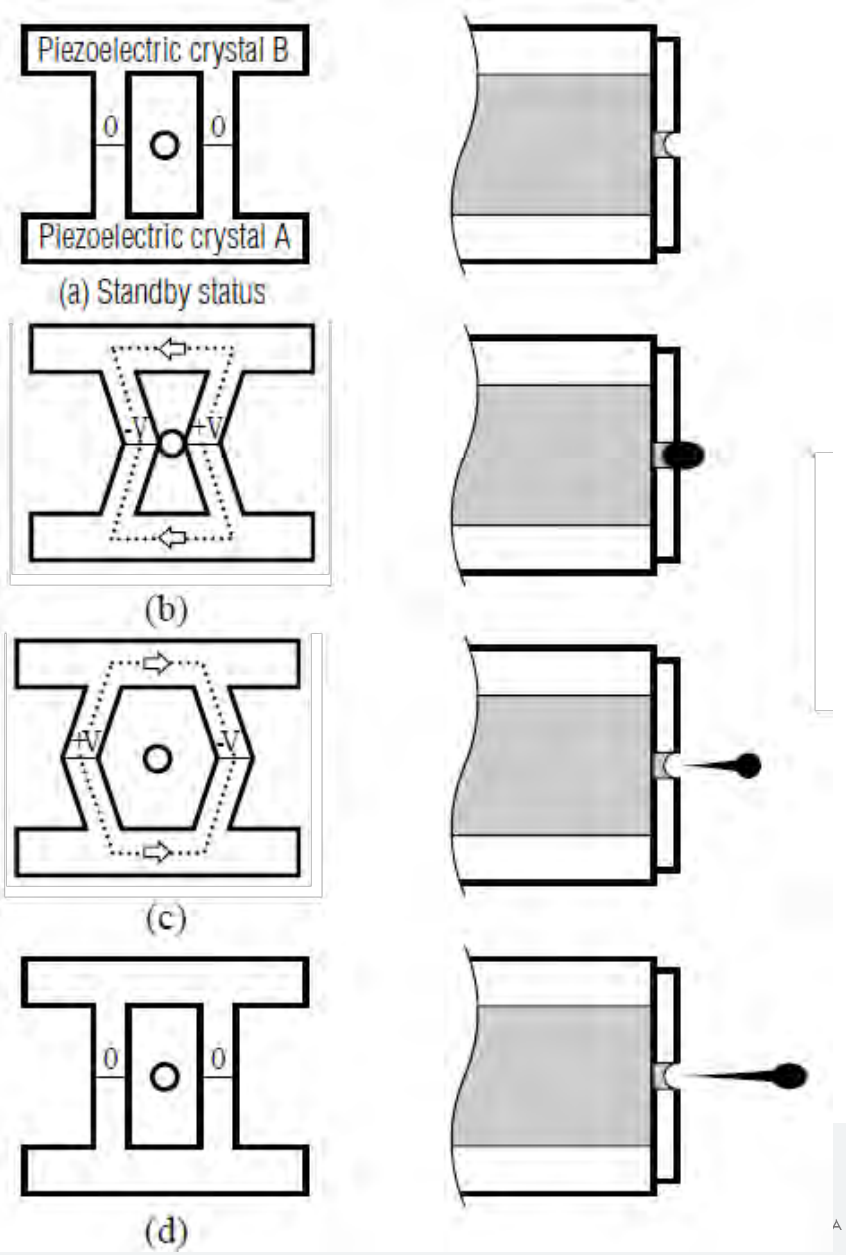


Ink transfer

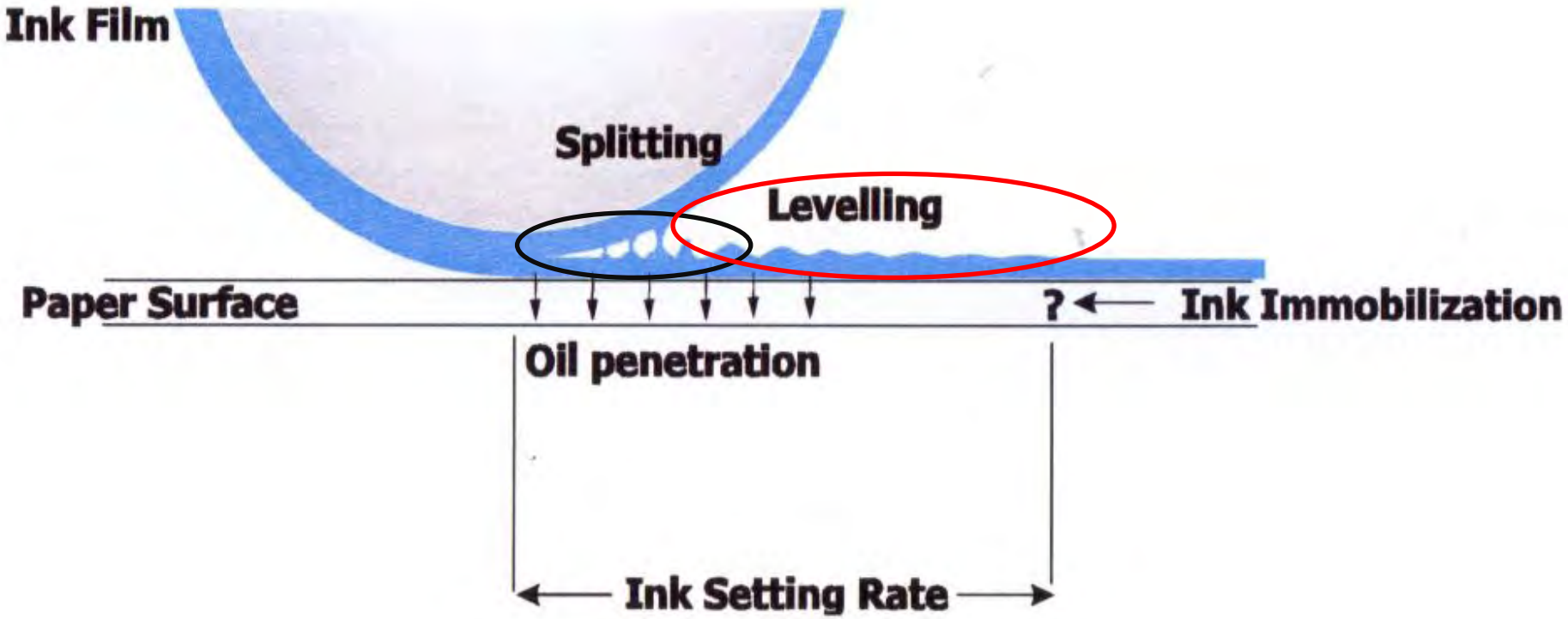
- Mechanical contact/pressure



- Non mechanical contact



Ink transfer and ink setting



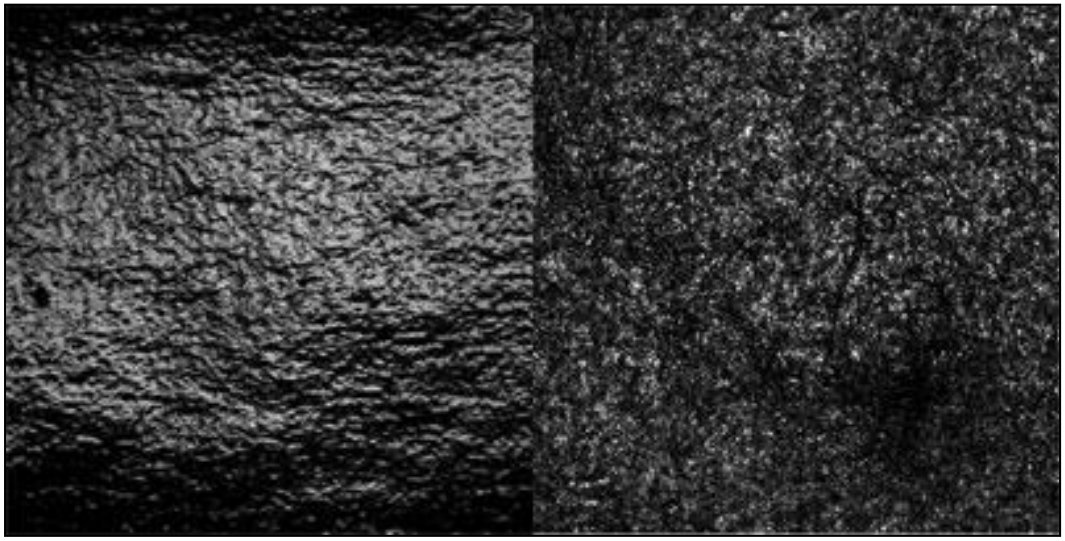
Ink sequence: cascading order of ink tack, K,C,M,Y

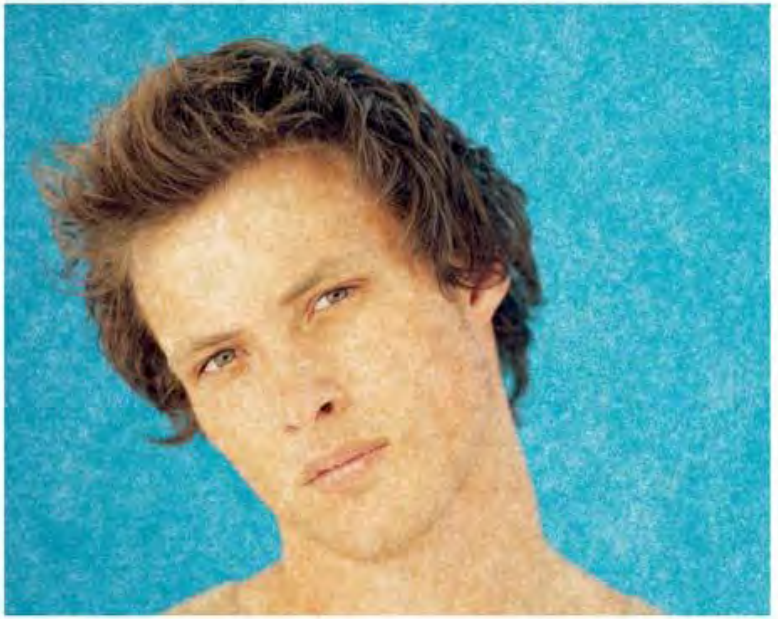
Ink transfer and ink setting

- Ink transfer determines the initial size of the ink dots
- Important source of physical dot gain and print mottle

Some examples of print mottle

Uneven print gloss





Uneven print density

- Paper properties
  - Surface roughness
  - Porosity
  - fluorescence
- Ink properties
  - Viscosity, ink tack, …
  - Ink transfer and ink setting
- Ink-paper interaction
  - Ink-spreading
  - Ink-penetration

Ink-paper interaction

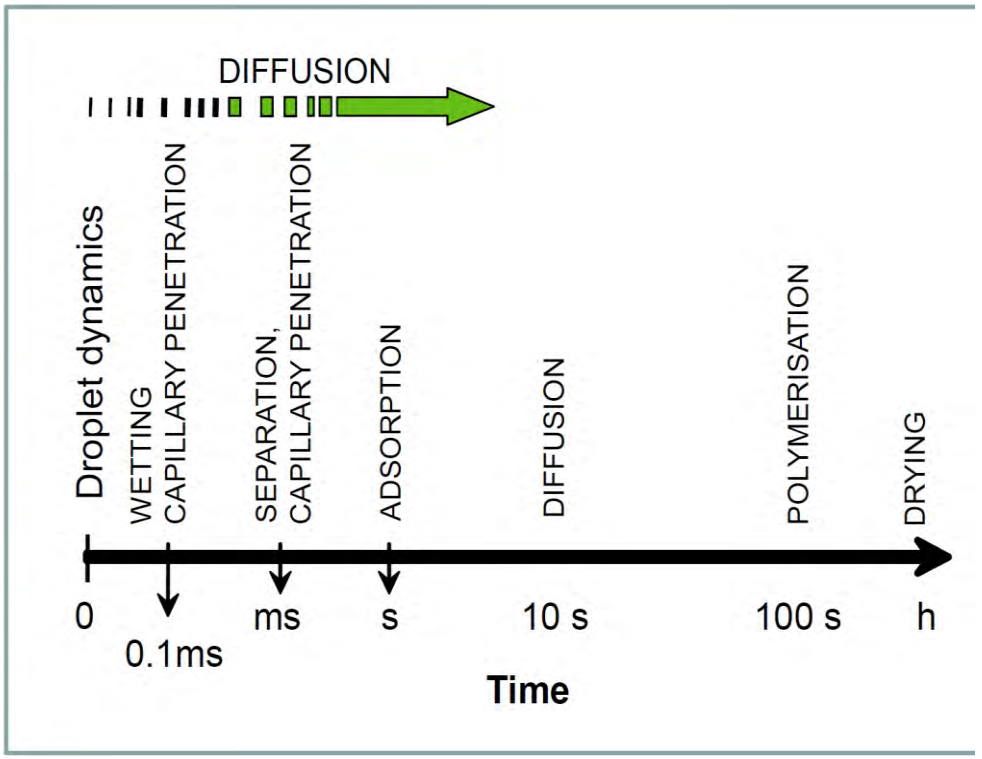
Physical processes

- Ink spreading
- Ink penetration
- Carrier/pigment separation
- Diffusion
- …

Chemical processes

- Adsorption
- Polymerisation
- …

Inkjet droplet on coated grade



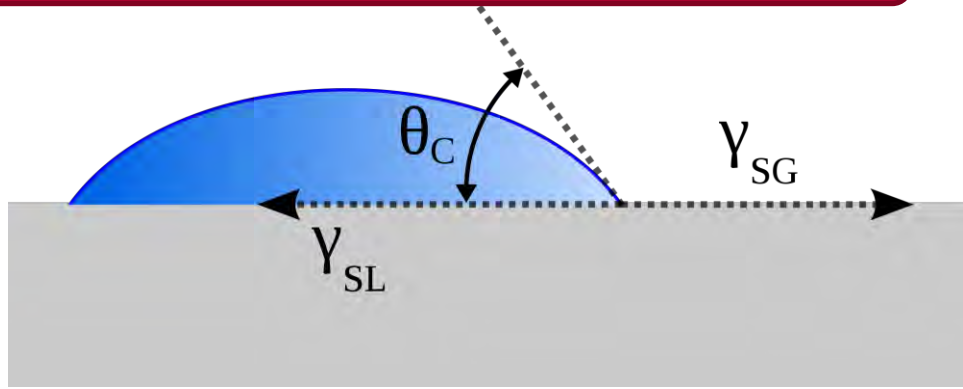
Can be altered by calendering, coating, sizing, …

Ink spreading

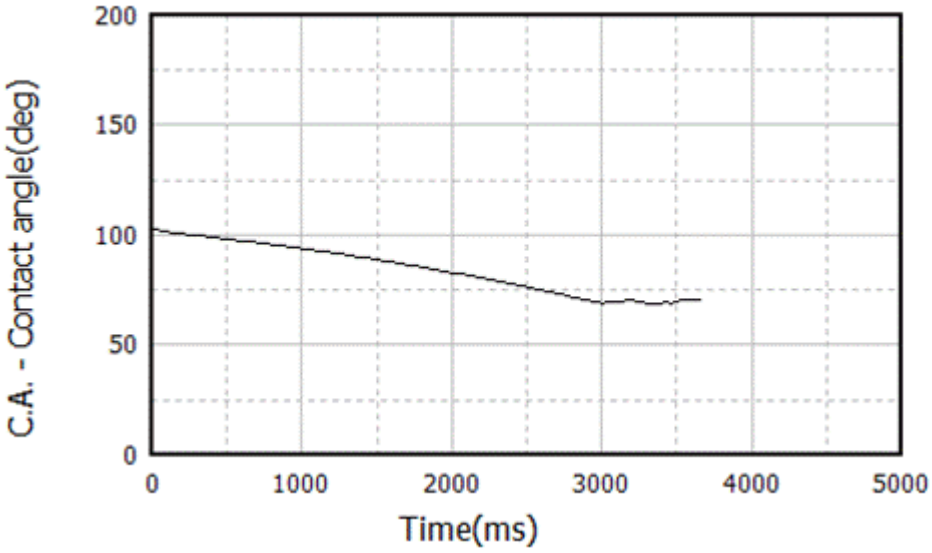
- *Cause physical dot gain*

- Affecting factors
  - Surface tension of the ink
  - Surface energy of the paper
  - Surface roughness
  - …

- Rough description for print
  - Paper surface is not flat
  - Paper sucks
  - Vaporization
  - Non-equilibrum state
  - …



$$\cos\theta_c = \frac{\gamma_{sg} - \gamma_{sl}}{\gamma_{lg}}$$

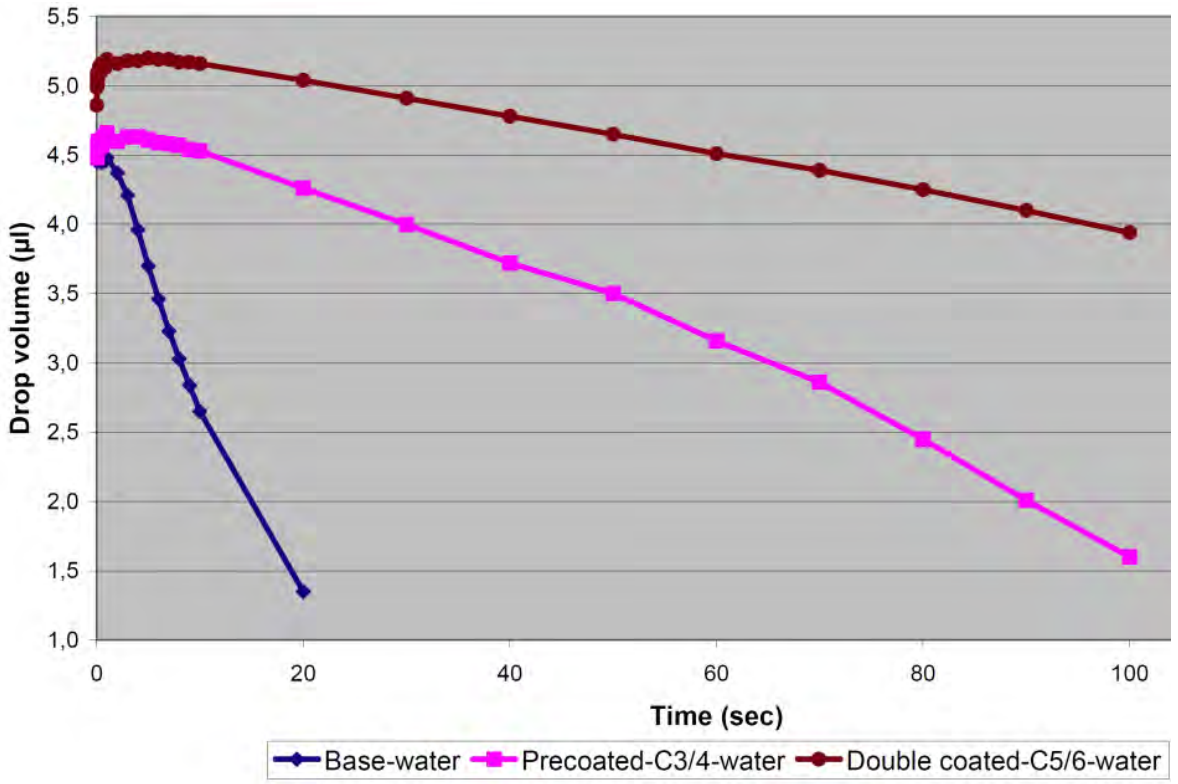


Ink penetration

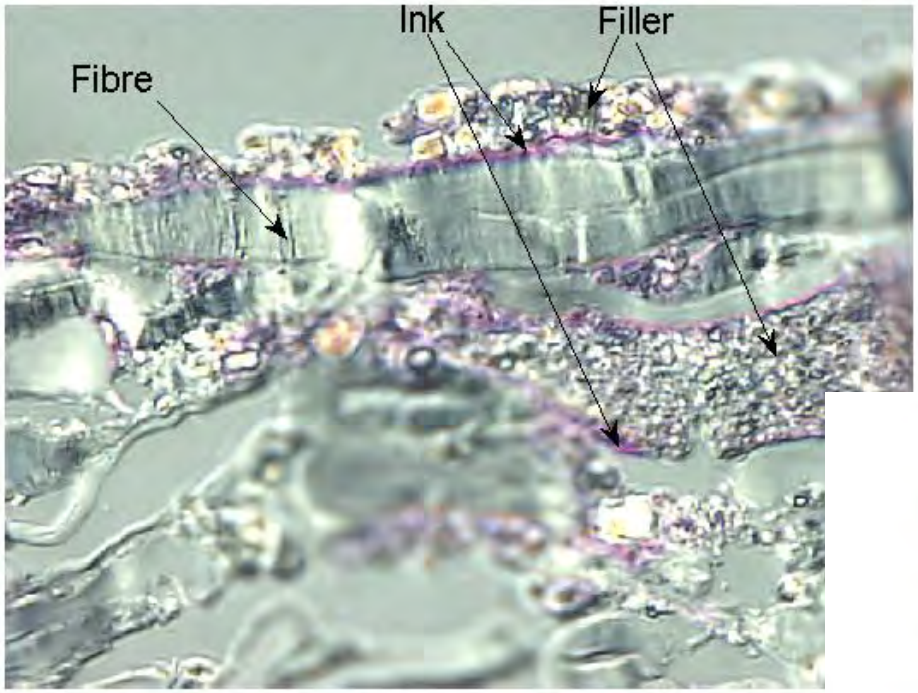
- Ink fills the surface pores and is sucked into paper's pores.
- Darcy Law

$$\frac{dV}{dt} = -\frac{KA\Delta P}{\eta L}$$

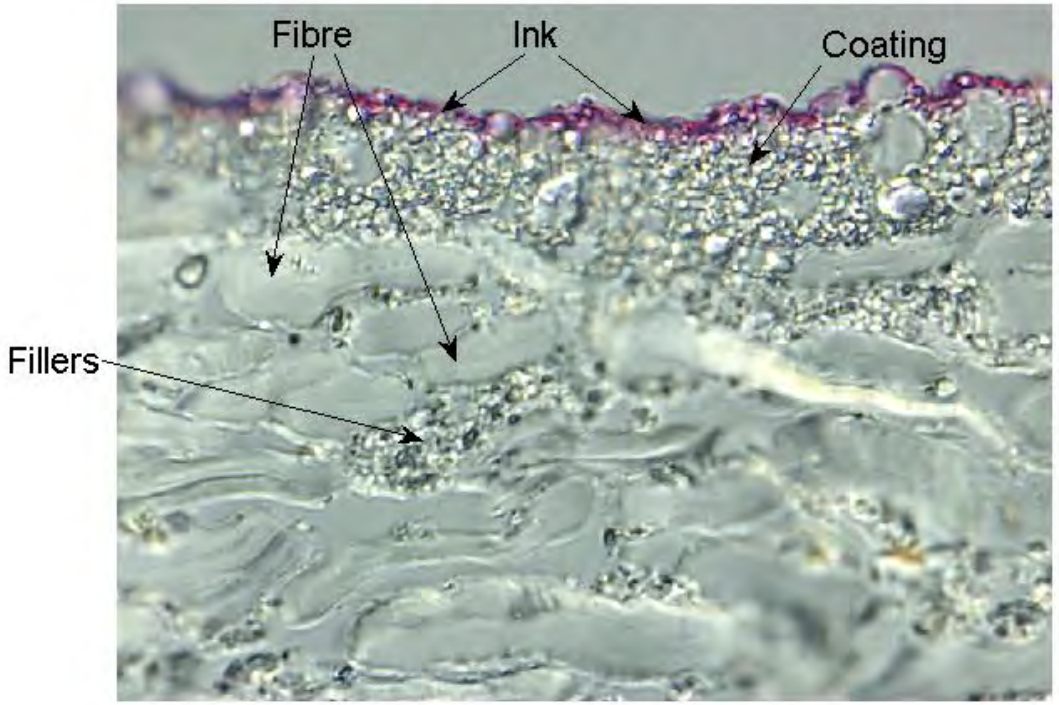
- Paper's properties
  - Permeability, K
  - Capillary pressure, ΔP
- Ink properties
  - Viscosity, η



Ink penetration



Can be altered by coating, sizing, …



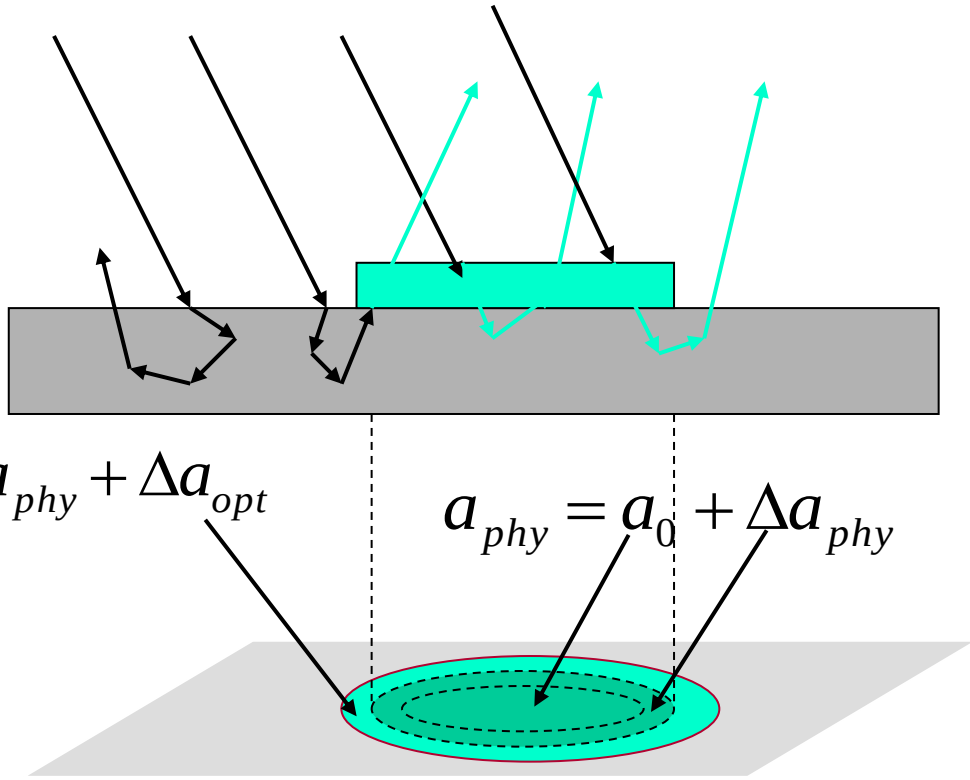
INNVENTIA

Physical evaluation methods

- Determination of physical dot gain
  - Resulting from ink-transfer and ink-spreading
- Quantitative determination of ink penetration
  - Resulting from ink-setting process

Determination of dot gain

- Physical dot gain
  - Caused by ink-transferring and ink-setting
- Optical dot gain
  - Caused by lateral light scattering



$$a_{eff} = a_{phy} + \Delta a_{opt}$$

$$a_{phy} = a_0 + \Delta a_{phy}$$

- To separate physical and optical dot gain needs tools
  - Model based methods
  - Imaging processing-based methods

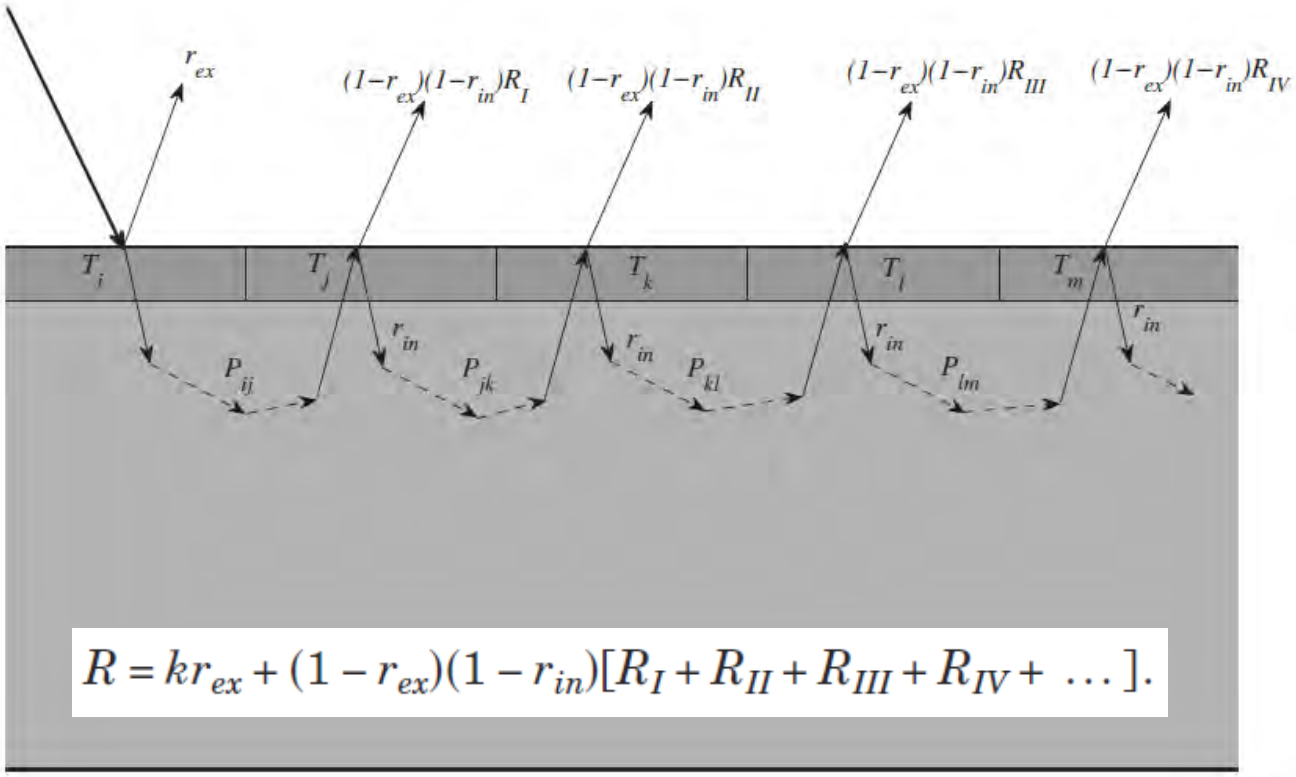
There are two types of methods for determination of dot gain

- Methods based on physical model
  - Reflectance model
  - Transmittance model

- Methods based on image processing
  - Histogram thresholding
  - Line scan
  - …

Methods based on physical model

- All the major physical phenomena have to be propriate accounted.
  - Light diffusion
  - Inter-facial reflections
  - Fluorescence
  - ..



$$R = kr_{ex} + (1 - r_{ex})(1 - r_{in})[R_I + R_{II} + R_{III} + R_{IV} + \ldots].$$

$$R_I = \sum_{i=0}^{N-1} \sigma_i \left(\sum_{j=0}^{N-1} T_i P_{ij} T_j \right) = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \sigma_i T_i P_{ij} T_j,$$

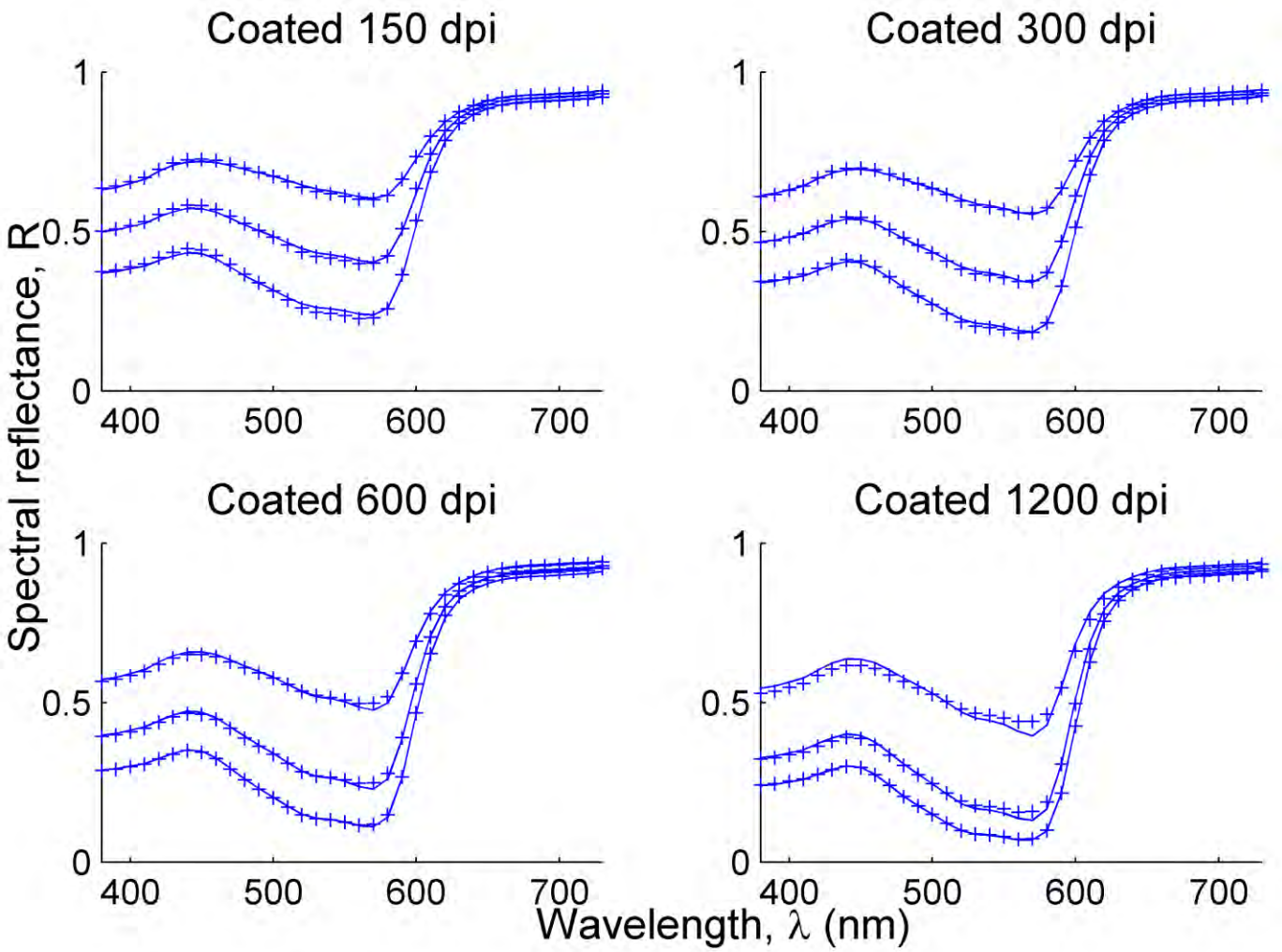
$$R_{II} = \sum_{i=0}^{N-1} \sigma_i \left(\sum_{j=0}^{N-1} T_i P_{ij} T_j \right) \left(r_{in} \sum_{k=0}^{N-1} T_j P_{jk} T_k \right)$$

$$= r_{in} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \sum_{k=0}^{N-1} \sigma_i T_i T_j^2 T_k P_{ij} P_{jk},$$

Spectral estimations – Magenta,

$\Delta E_{\max} = 2.1$

σ_0 = 20, 40, 60%,

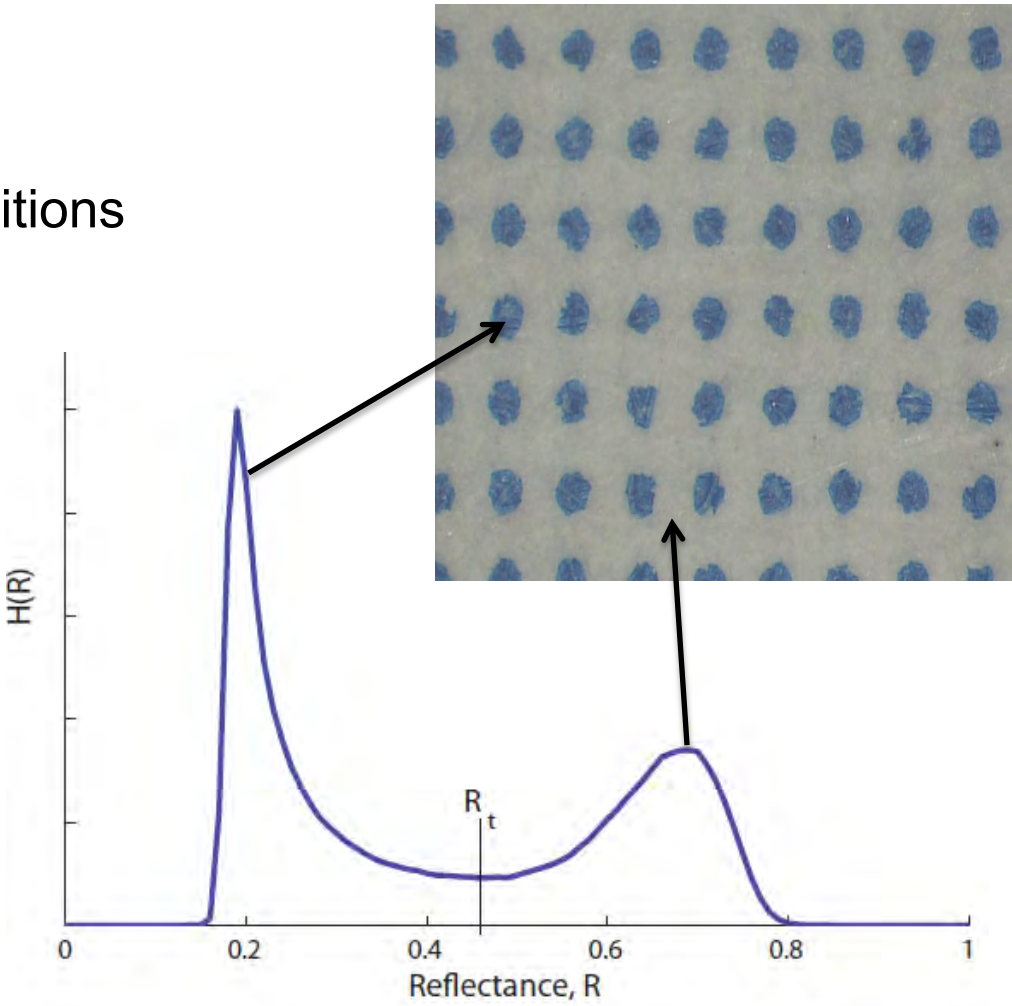


INNVENTIA

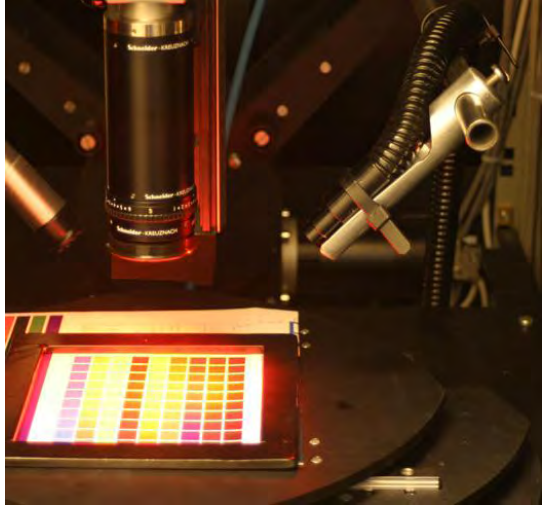
Microscopic imaging:
Histogram analysis

- Chose the thresholding
  - The average of the peak positions
  - *or*
  - $R=R_t$ when $\frac{dH(R)}{dR}=0$

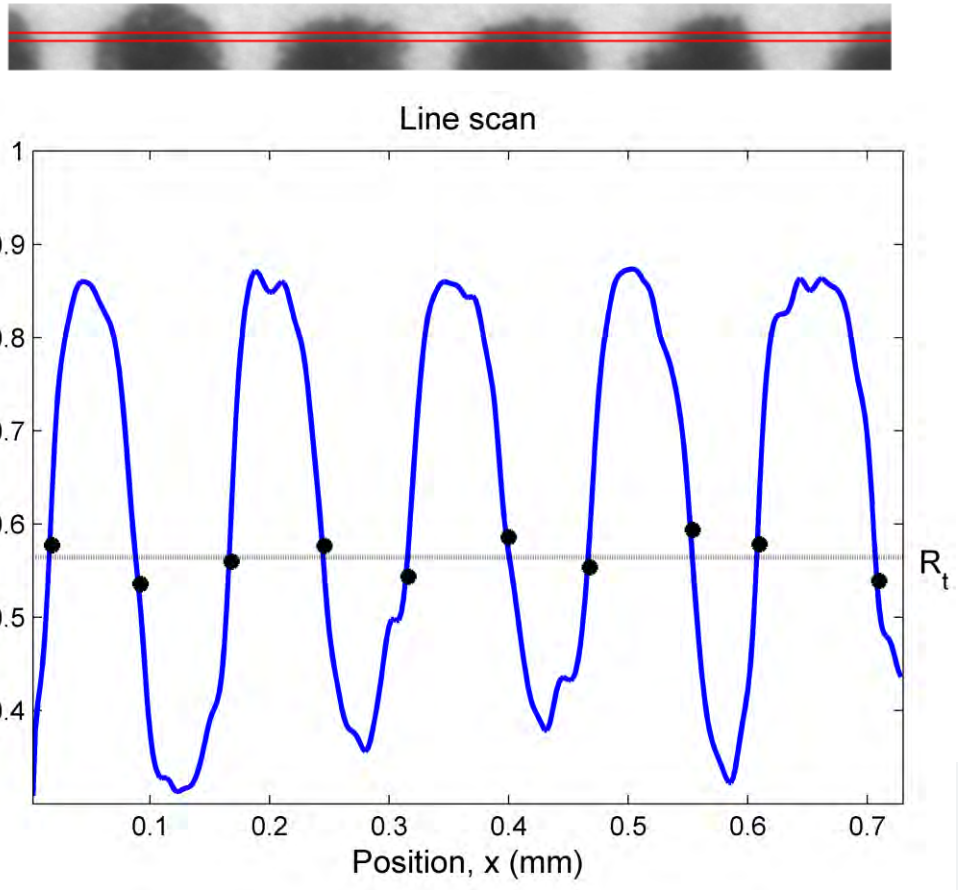
$$a=\frac{\int_0^{R_t} H(R)dr}{\int_0^1 H(R)dr}$$



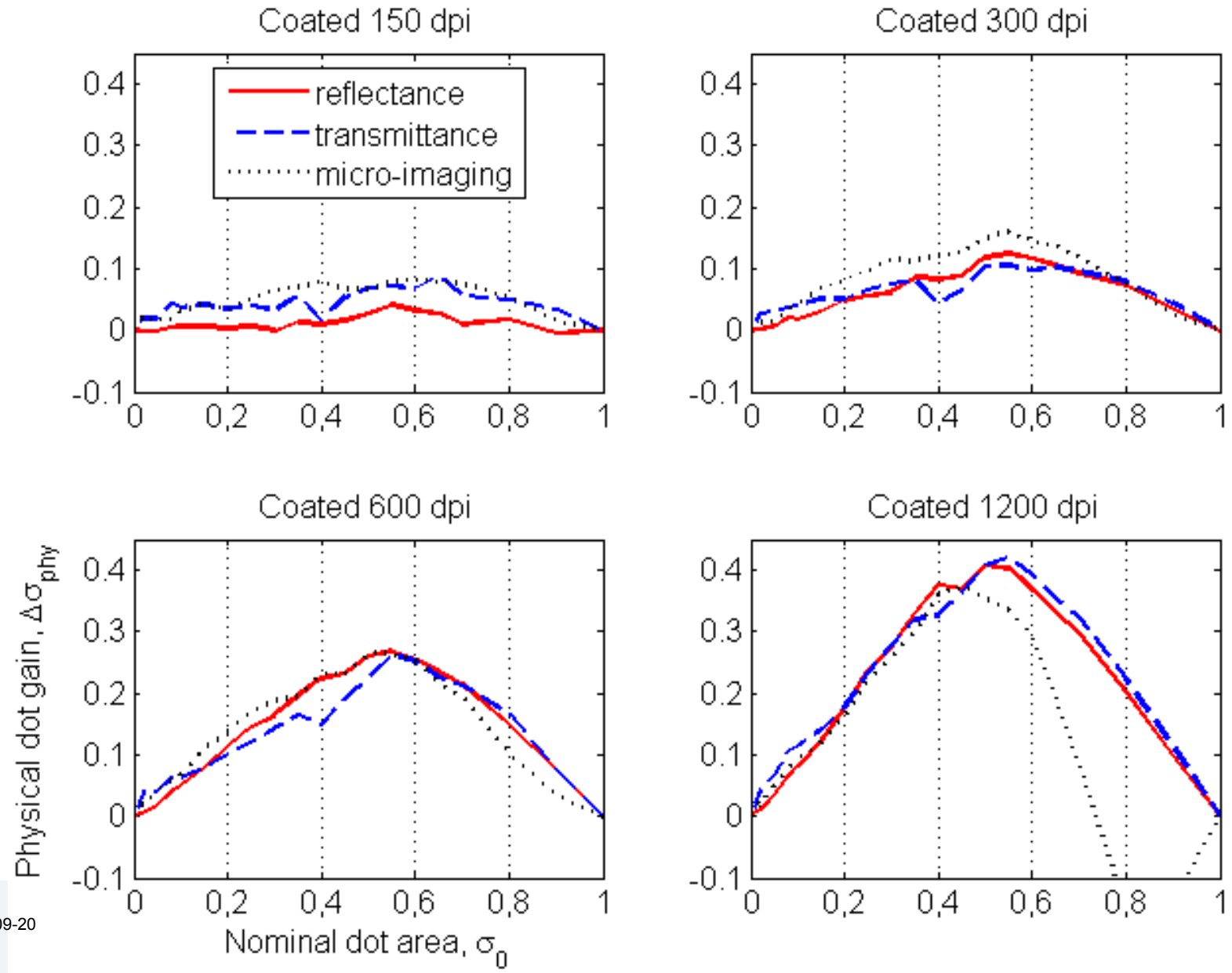
Microscopic imaging:
Line scan



- Line scans across halftone dots
- Threshold, R_t : boundary between dot and paper
  - Find maximum rate of change: dR/dx
- Sufficiently accurate for light and middle tones; unreliable for dark tones

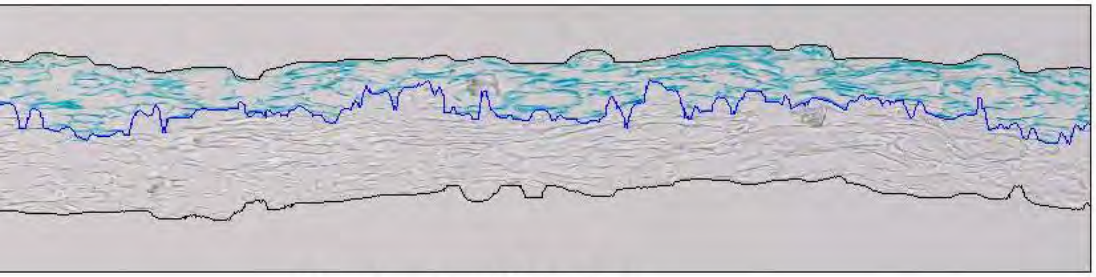


Physical dot gain of offset prints

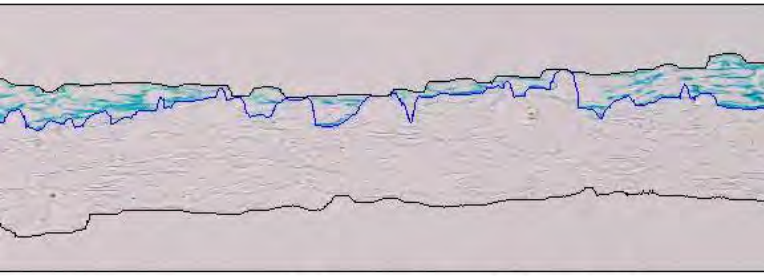


NNVENTIA

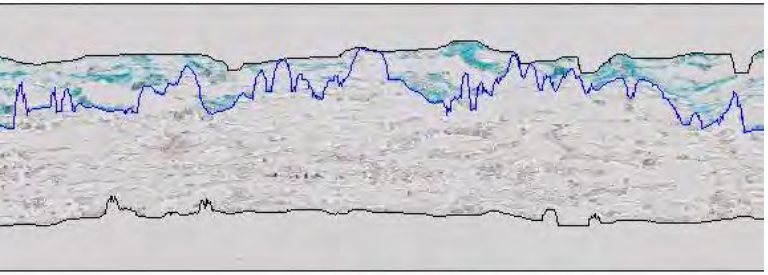
Determination of ink-penetration



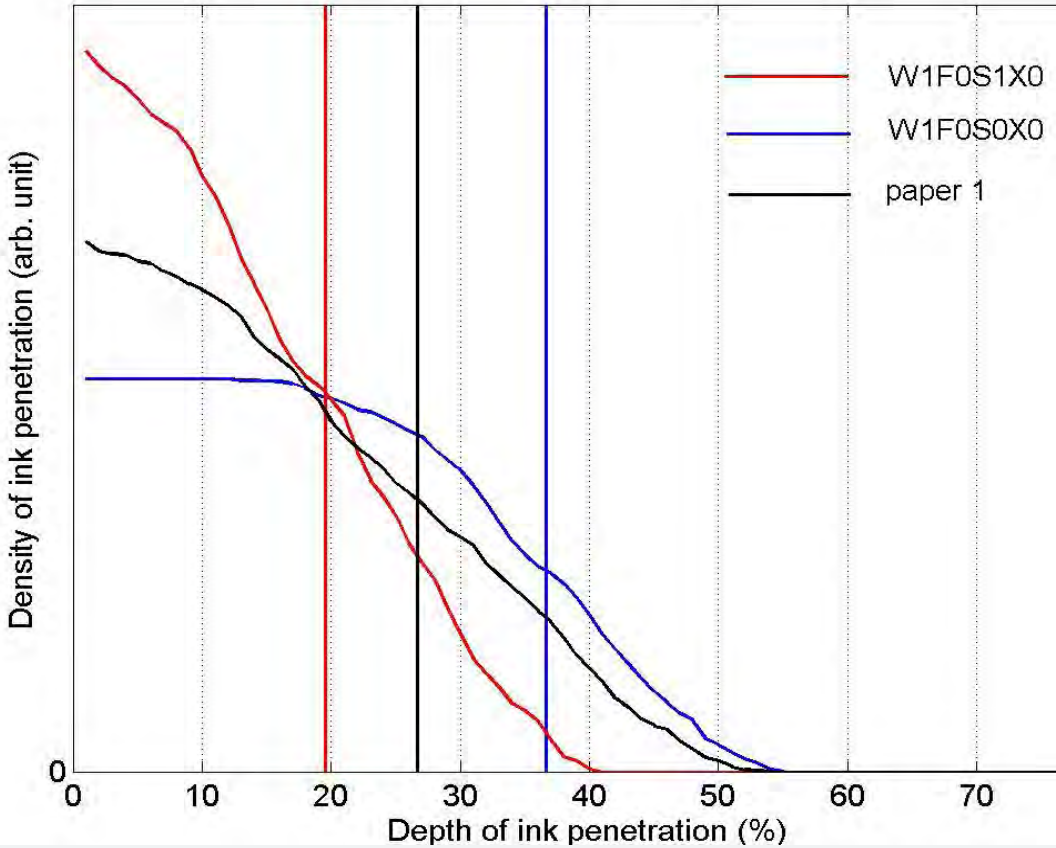
(a) substrate: $W_1F_0S_0X_0$



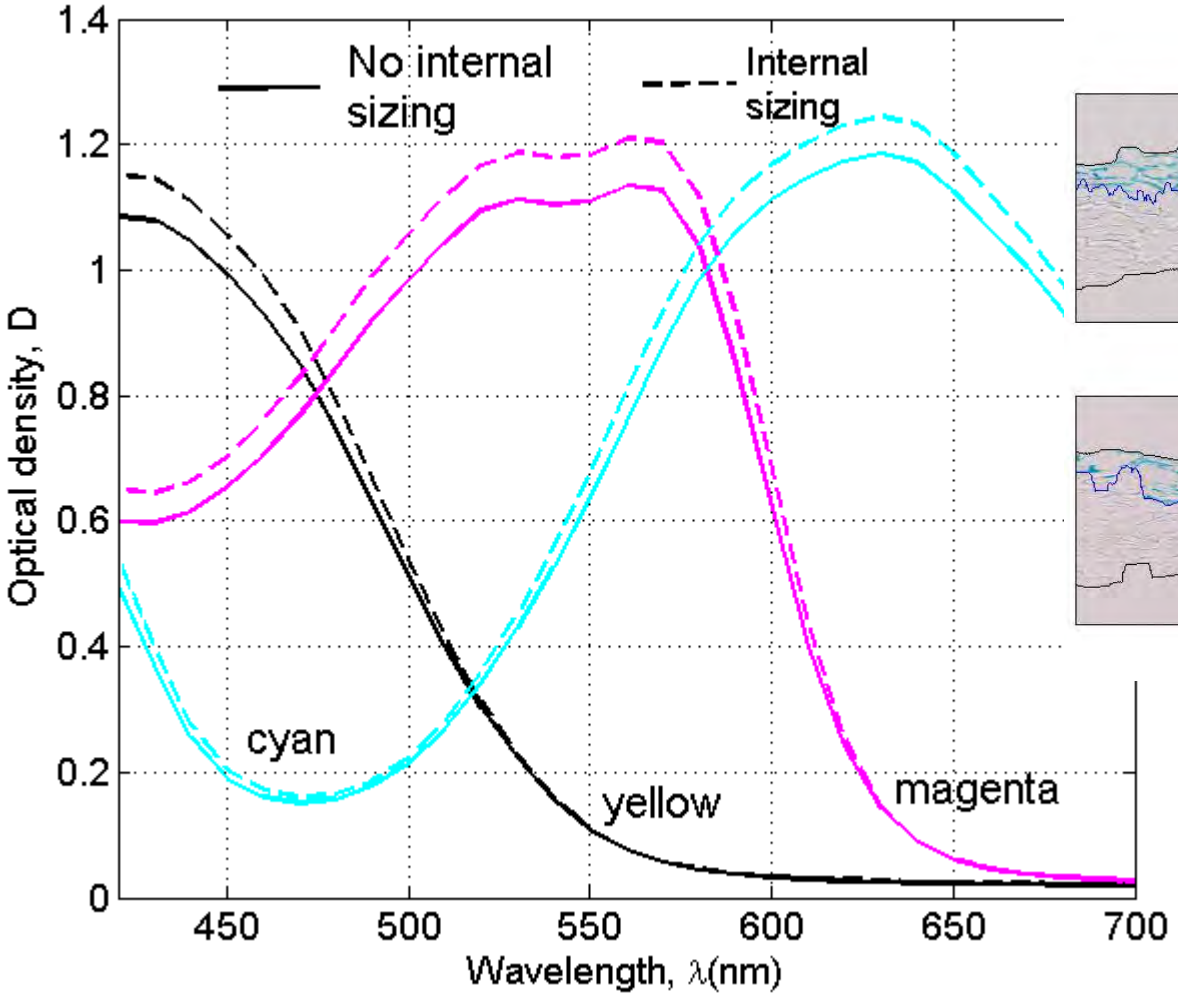
(b) substrate: $W_1F_0S_1X_0$

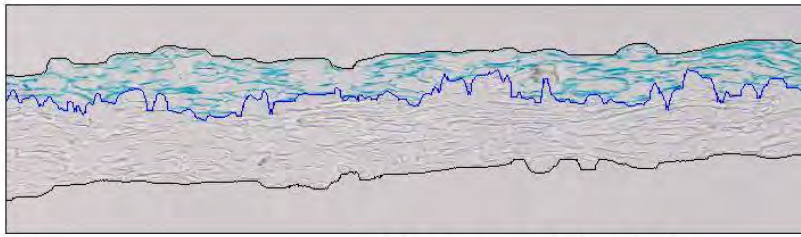


(c) substrate: paper 1

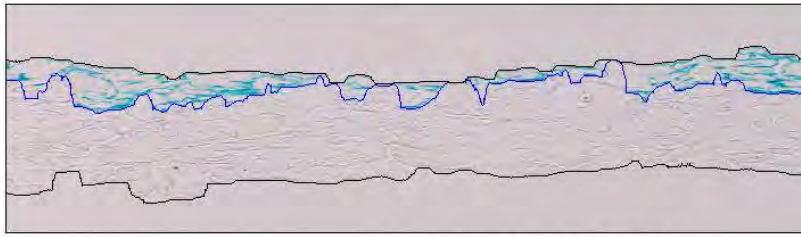


Effect of ink-penetration on printed color





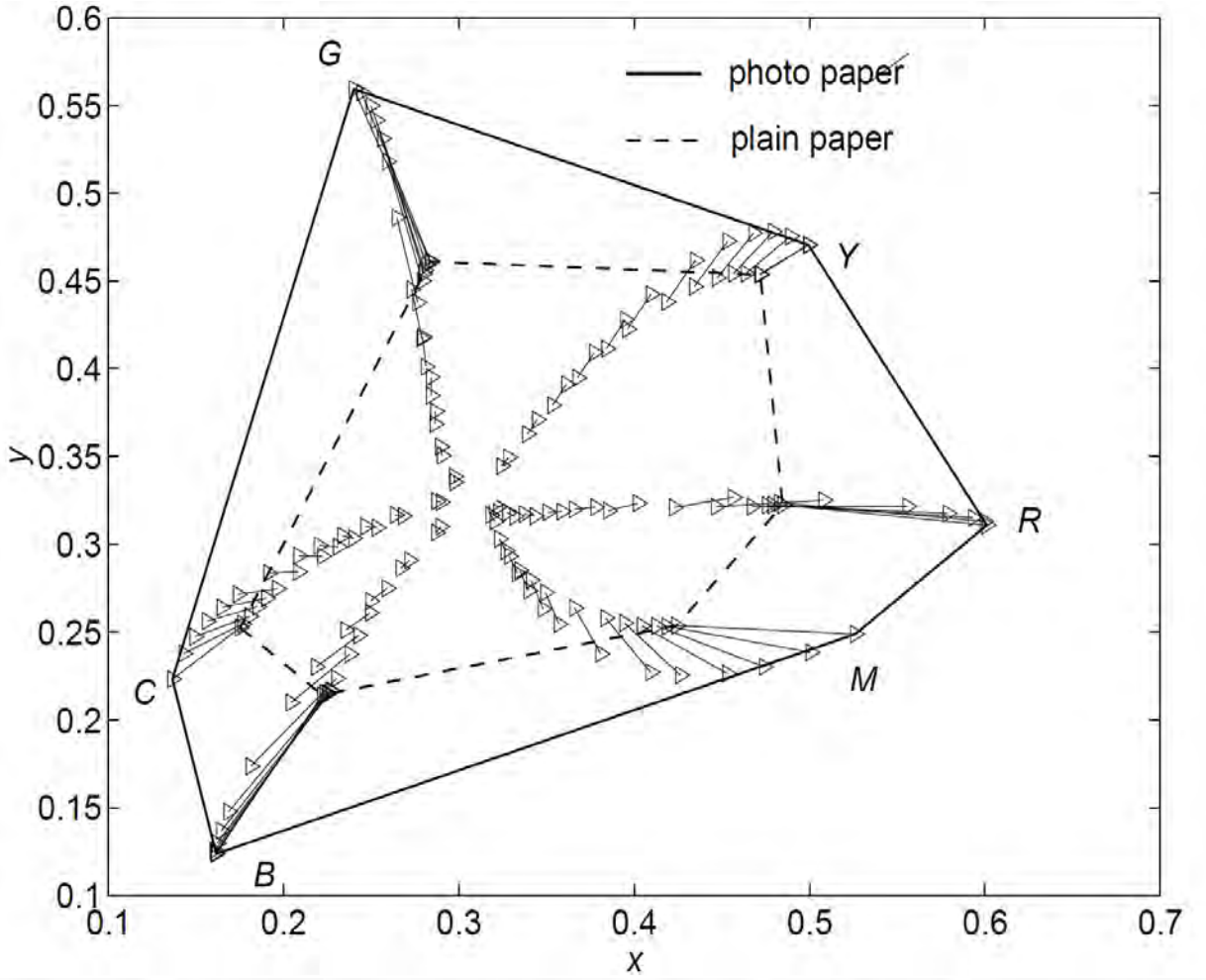
(a) substrate: $W_1F_0S_0X_0$



(b) substrate: $W_1F_0S_1X_0$

INNVENTIA

Color gamut of prints on two commercial papers (similar color before printing)

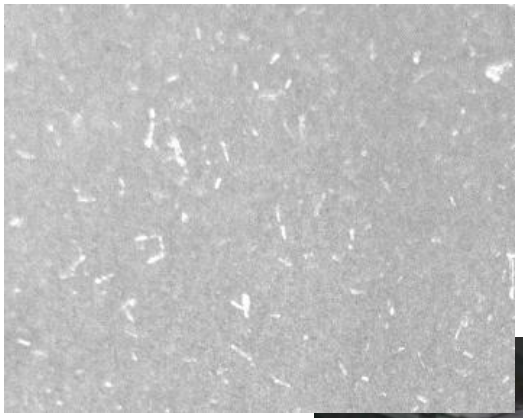


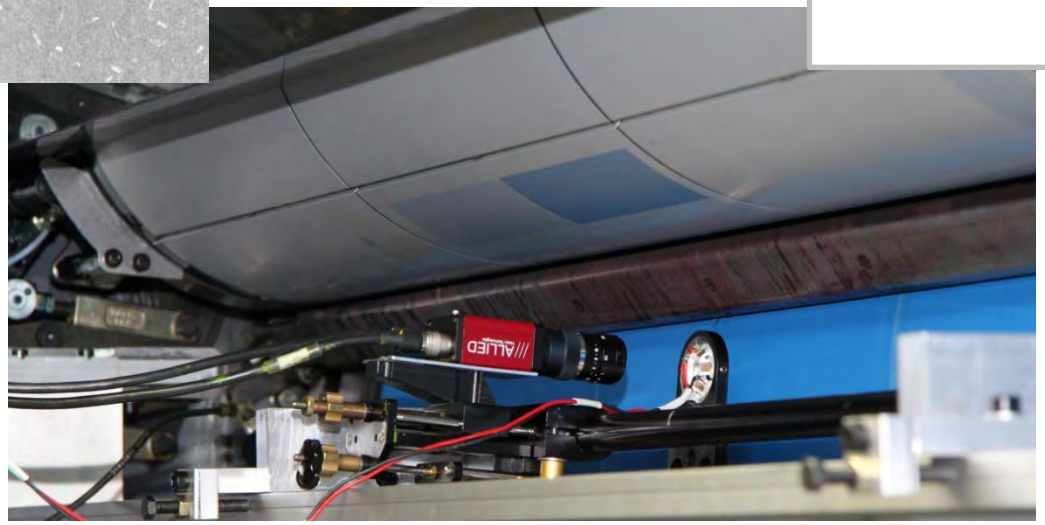
color	paper white	cyan	magenta	yellow	black	red	green	blue
ΔE	1.32	12.37	19.30	23.67	13.44	24.92	22.59	20.75

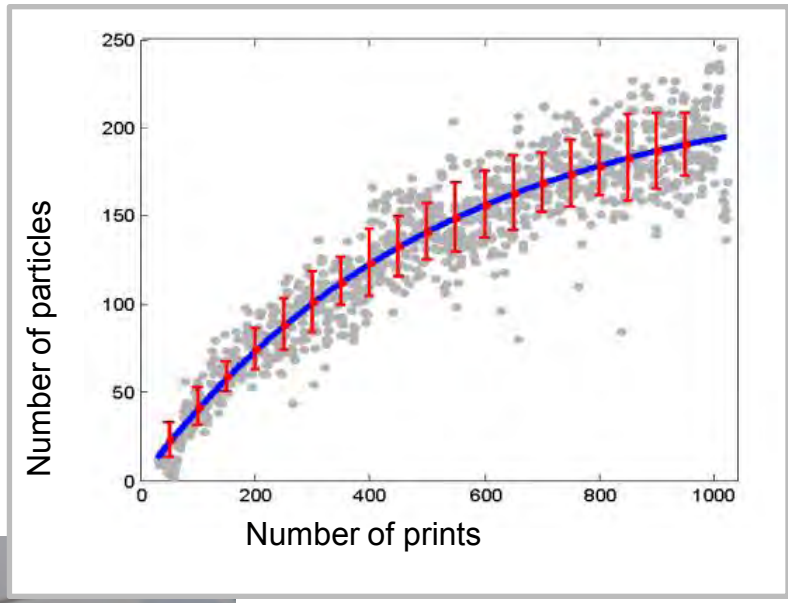
INNVENTIA

Dynamic ink-paper interaction

- Online Linting Measurement (OLM)







Summary

- Quality of print is affected by the materials' properties.
- Printing processes particularly ink transfer, ink spreading and ink penetration are important for print quality
- Paper making and paper properties have great impact on these processes and print quality
- Methods have been developed for determining these physical phenomena and their effects on print quality.