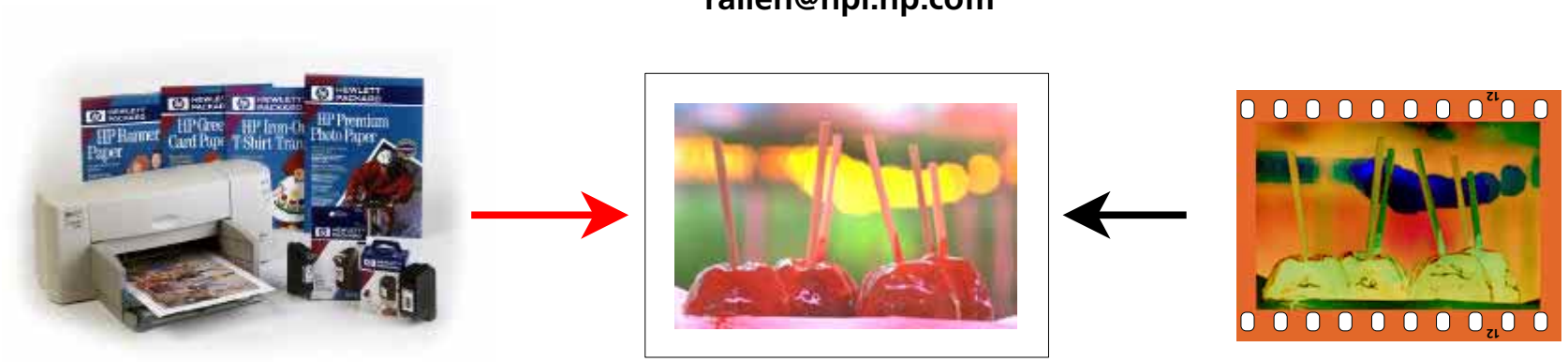
PHOTOGRAPHIC QUALITY IMAGING WITH HP THERMAL INK JET

Dr. Ross R. Allen,
Project Manager

Printing Technology Department
Hewlett-Packard Laboratories
Palo Alto, CA USA

rallen@hpl.hp.com



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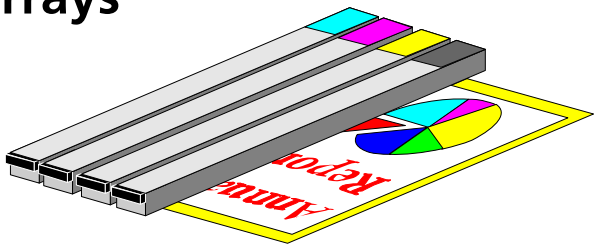
Ink Jet Printing

success factors for the next decade

- ✓ **Availability of (high-quality) digital source material provides opportunities for new color imaging markets**
  - **desktop film, negative, & slide scanners (35mm & APS)**
  - **digital photographic printing**
  - **Internet printing**
  - **digital proofing**
- ✓ **Traditional strengths of laser printers (media independence, throughput, low cost/page) are becoming less relevant in color imaging applications**
- ✓ **Unlike other printing technologies, ink jet offers low-cost, high-quality, high-throughput solutions from the desktop to large format**
- ✓ **Publish-on-demand of color documents and new applications may drive development of practical pagewide arrays**



Ink Jet Printing

HP's thermal ink jet

- invented in 1979 at Hewlett-Packard Laboratories
  (Canon invented "BubbleJet" at the same time)
- first product: HP ThinkJet Printer in 1984

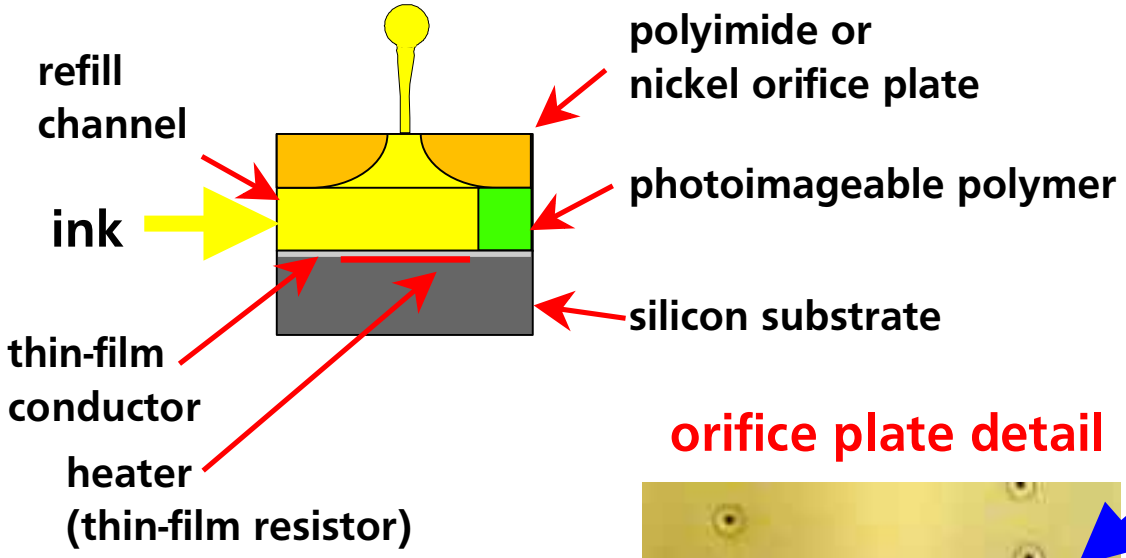
- high operating frequency
- high orifice density
- energetic drop ejection purges trapped gases
- integrated power & interconnect electronics

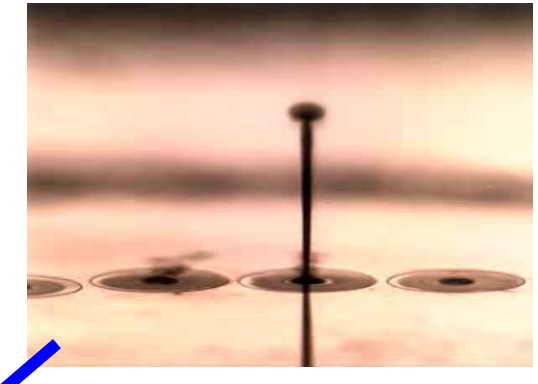
- inks & ink delivery systems for imaging solutions from the desktop to large format

...and, no moving parts except the ink itself

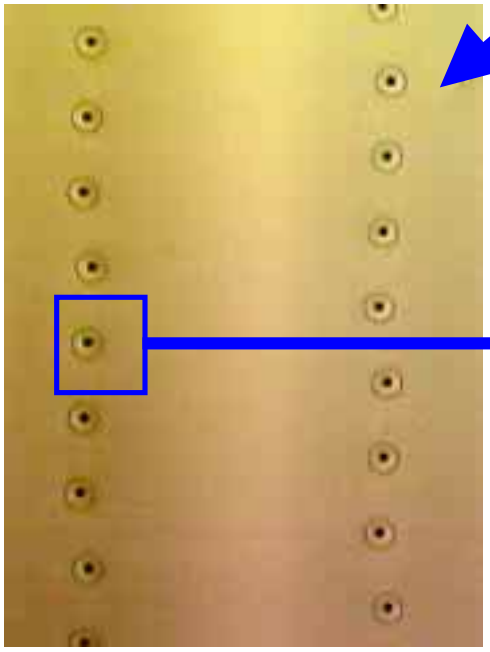
Thermal Ink Jet

printhead detail

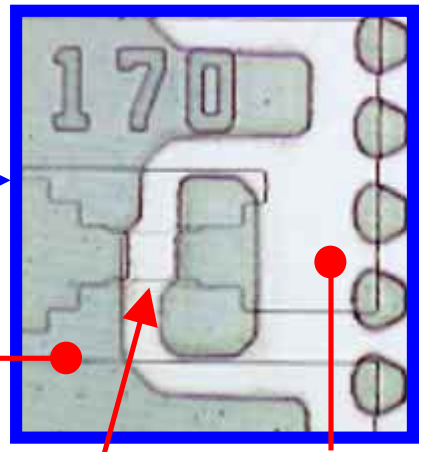




orifice plate detail



substrate detail
(DeskJet 720C)

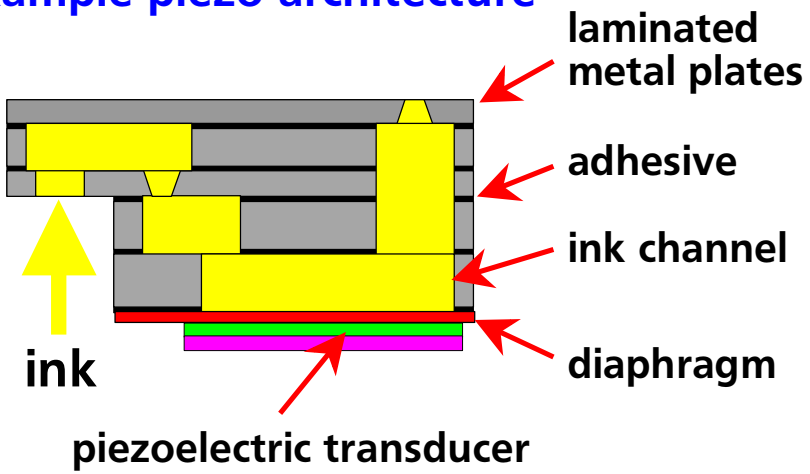


- staggered orifices compensate for firing order and allow accurate dot placement at high drop frequencies

Ink Jet Printing

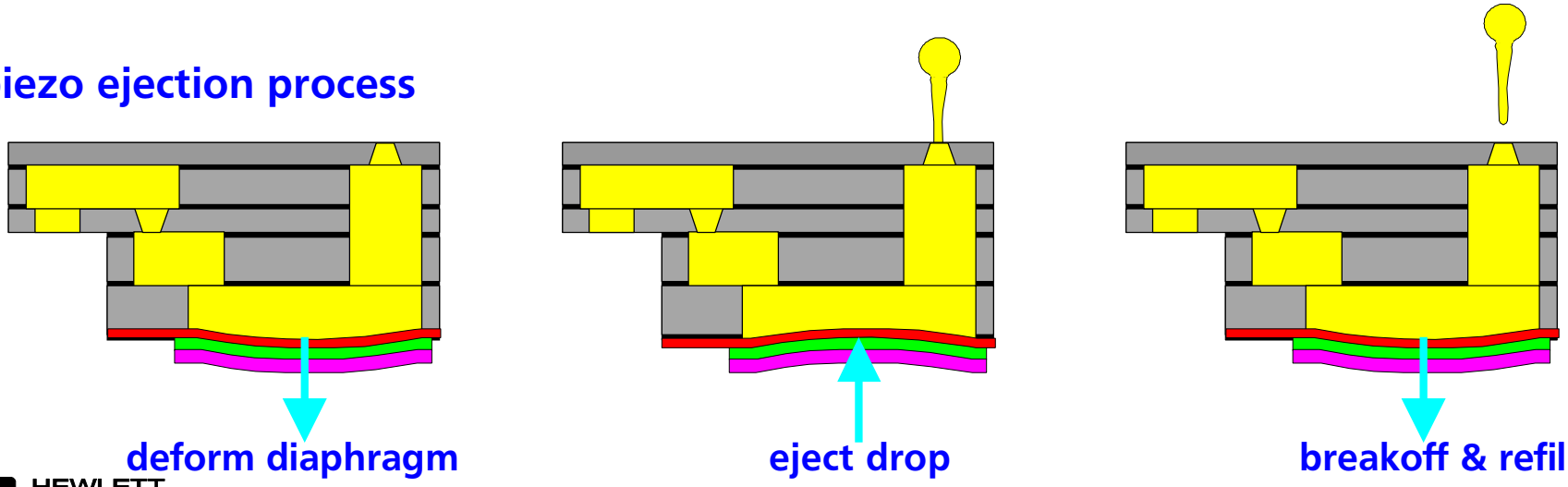
piezo ink jet

- example piezo architecture



- piezo is NOT a new technology!
- lower orifice density than TIJ
  - drive & interconnect electronics are not integrated with printhead structure
  - high chamber/drop volume ratio
- significant quantity of ink required for printhead maintenance
  - drop ejection process is less energetic than TIJ
- mechanical elements limit frequency
- exaggerated claims for life & ink versatility

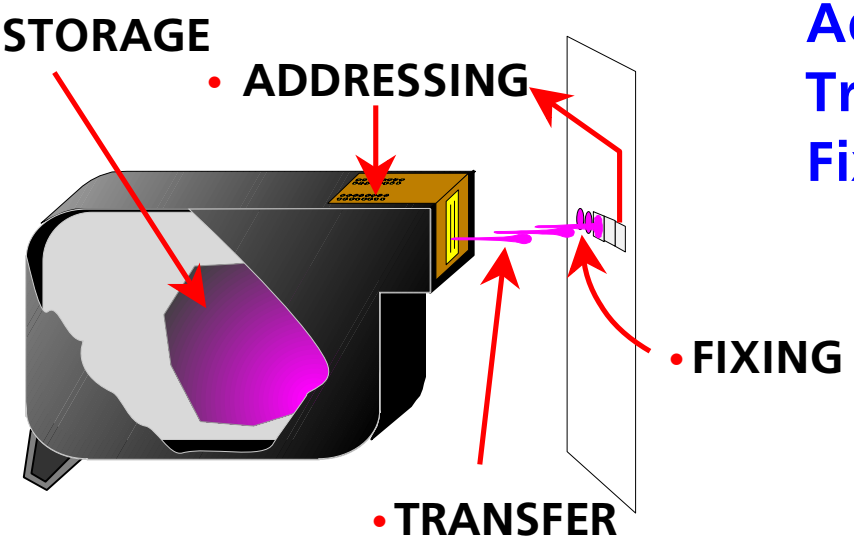
- piezo ejection process



Printing Process

elements of marking

Storage & Delivery of ink
Addressing of pixels
Transfer of ink to print medium
Fixing of ink on print medium



STORAGE

- usable quantity
- pressure regulation
- material compatibility

ADDRESSING

- resolution
- dots/pixel
- colors/pixel
- drop volume
- multiplexing

TRANSFER

- drop placement
- consistent drop volume

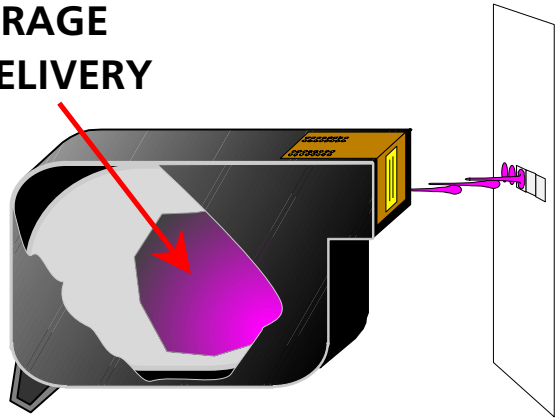
FIXING

- color
- spot density
- spot size
- spot shape
- color bleed
- ink chemistry
- media chemistry
- drying
- media types

Ink Storage & Delivery

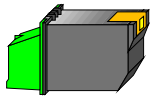
ink delivery system evolution

STORAGE
& DELIVERY

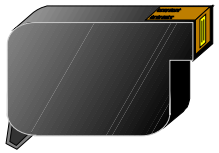


1985	4ml	Bladder.....	ThinkJet
1987	17ml	Foam.....	DeskJet
1992	40ml	Hi-Capacity....	DeskJet 500 & DesignJet 600
1993	42ml	Spring-Bag....	DeskJet 1200C & DesignJet 650C
1997	410ml	Ink Kit.....	DesignJet 2000CP
1998	Modular Ink Delivery System	.....	HP 2000C

Modular Ink
Delivery System



Disposable
Printheads



High-Capacity
Disposable
Printheads

DesignJet Replaceable
Printheads & Cartridges

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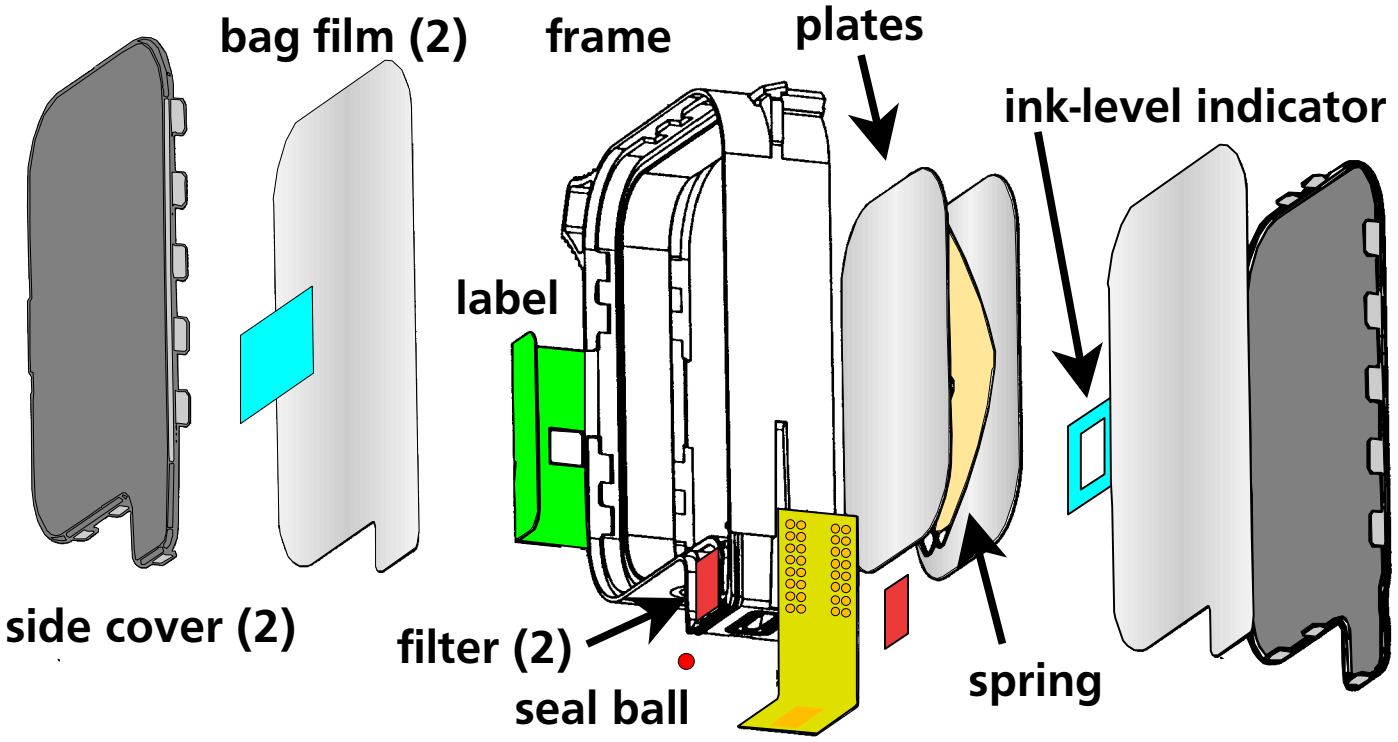
Ink Storage & Delivery

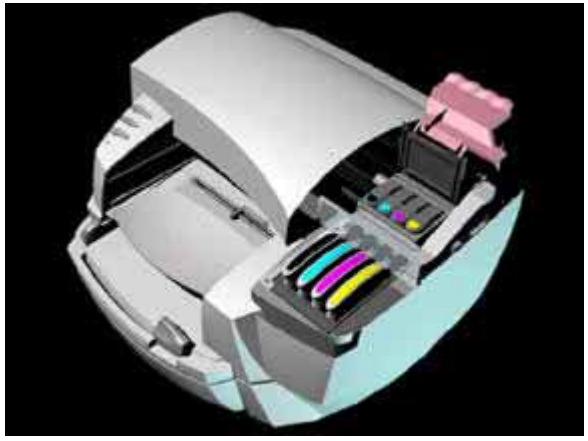
inside a print cartridge



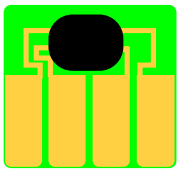
Ink Storage & Delivery

Modular Ink Delivery System

- introduced on the HP2000C
- printheads separated from ink cartridge
  - 4 high-capacity ink cartridges
    - CMY: 28ml
      - K: 26.6ml & 65ml
  - 4 long-life printheads
    - CMY: ~24000 pages
      - K:~12000 pages
- unique pressurization system maintains constant supply of ink to printheads through flexible tubes

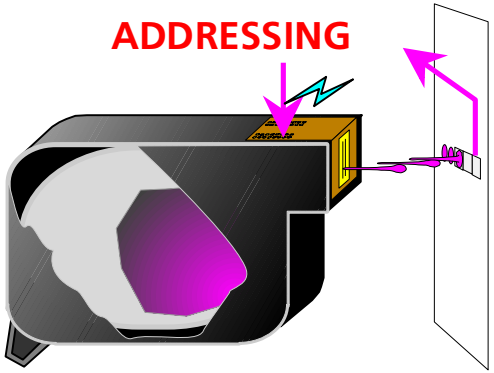


- "smart chip" in printhead & ink cartridge
  - uniquely identifies each component
  - monitors ink use
  - monitors printhead operation
  - signals low ink, ink out, printhead end-of-life



- only components that are no longer usable are replaced

Addressing

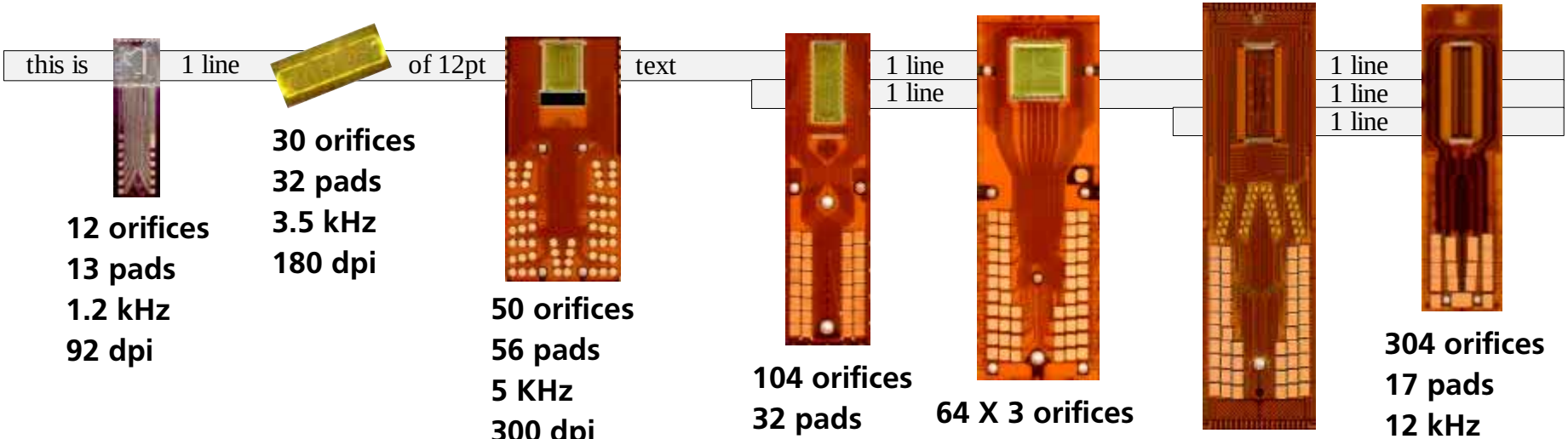


HP TIJ generations

- each scan line requires a drop generator
- more lines per scan = higher throughput
- multiplexed addressing
  - ✓ active logic & drivers on the TIJ silicon substrate
  - ✓ high orifice density in a compact package
  - ✓ fewer electrical connections for reliability & low cost

Direct Addressing → **Multiplexed Addressing**

ThinkJet (1985)	PaintJet (1987)	DeskJet (1987)	DeskJet 1200C (1993)	DeskJet 850C (1995)	DeskJet 850C (1995)	HP 2000C (1998)
12 orifices 13 pads 1.2 kHz 92 dpi	30 orifices 32 pads 3.5 kHz 180 dpi	50 orifices 56 pads 5 KHz 300 dpi	104 orifices 32 pads 8 kHz 300 dpi	64 X 3 orifices 52 pads 6 kHz 300 dpi	300 orifices 32 pads 8 kHz 600 dpi	304 orifices 17 pads 12 kHz 600 dpi



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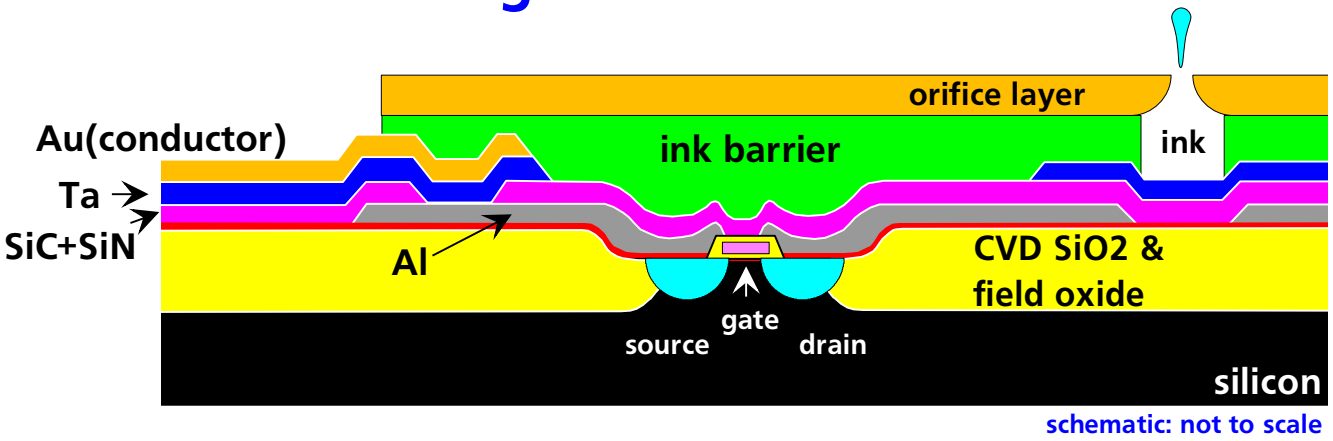
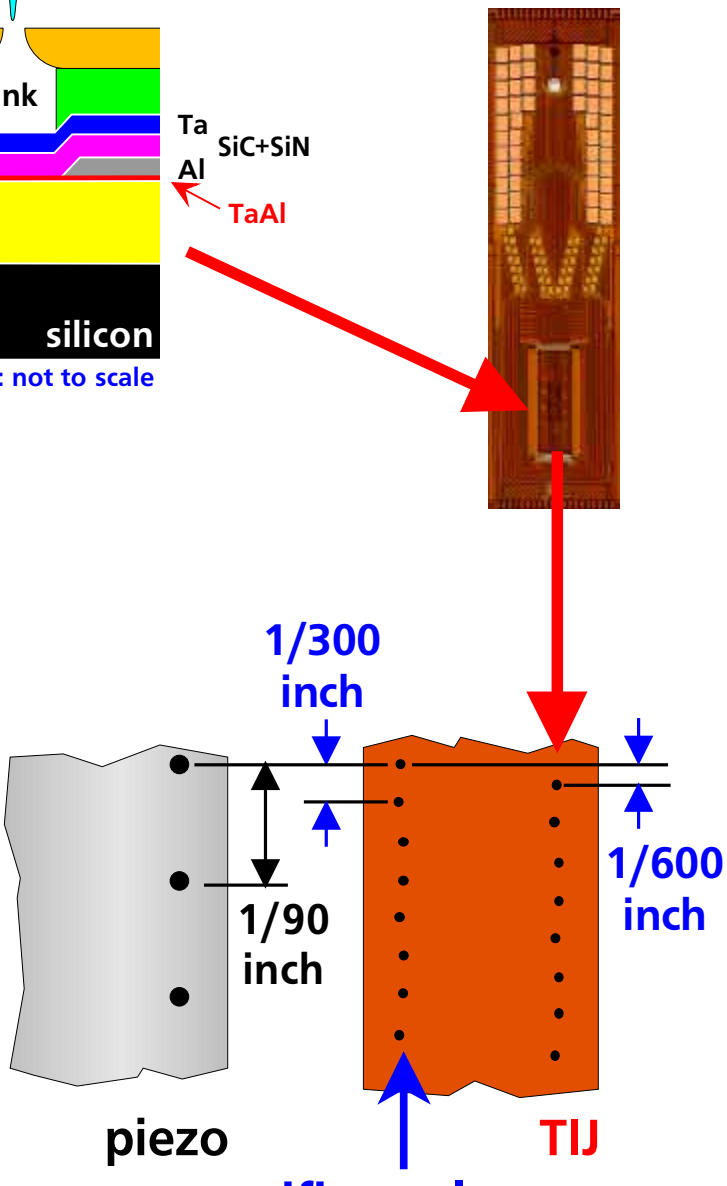
addr1f

Addressing

integrated electronics & orifice density



schematic: not to scale

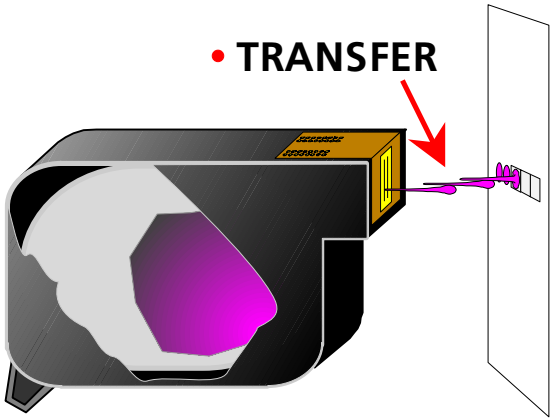


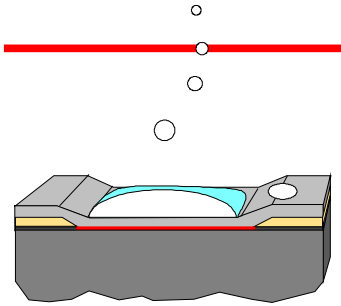
- TIJ silicon & drop generator structure
  - ✓ power electronics, orifice addressing, & drop generators on a single chip
  - ✓ high orifice packing density for high throughput (fewer passes needed)

- TIJ orifices spaced 300/inch in a single column
  - ✓600 dpi printhead uses two offset columns
  - ✗ current piezo ink jets: only 90 orifices/inch
- feasible: more than 600 TIJ orifices/inch in a single column

Transfer

a key process for quality, reliability & throughput





nucleation processes

consistent drop volume & placement

lower drop volume

smaller features

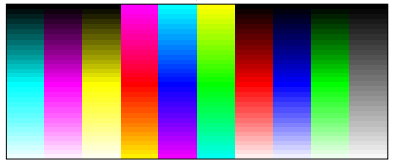
advances in TIJ materials & processes

Best Text Quality

smaller dots

halftone pixels

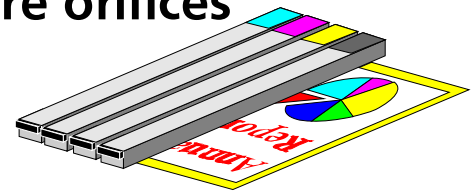
Photographic Image Quality



Maintain & Enhance Throughput

higher drop rates

more orifices



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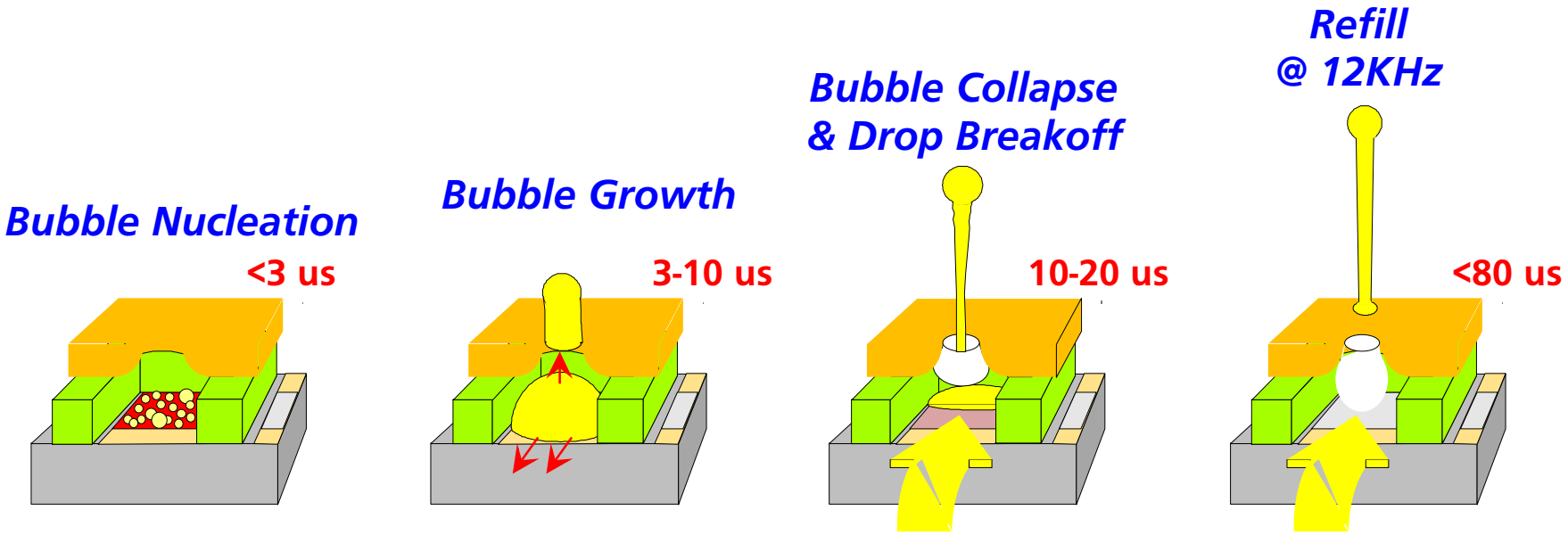
xfera

Transfer

TIJ drop ejection process

- the TIJ drive bubble is the result of a superheated vapor explosion in a film of ink over the heater resistor < 0.1 um thick
- most of the ink is not heated at all: heat penetrates < 1 micrometer
- TIJ cannot "boil" the ink - physically, *boiling cannot occur* when the ink is heated at 100 million °C per second for less than 3 microseconds!



Rapid Heating 100 °C/usec produces vapor explosion in ink

Drop formation & bubble expansion

Bubble collapse begins refill

Orifice meniscus settles; refill completes

...no moving parts except the ink itself

Elements of Bubble Nucleation

understanding nucleation is necessary to deliver consistency in drop ejection

Near the *Institute of Thermophysics*
Novosibirsk, Siberia, Russia

Liquid Composition

Liquid Density

Liquid Viscosity

Surface Tension

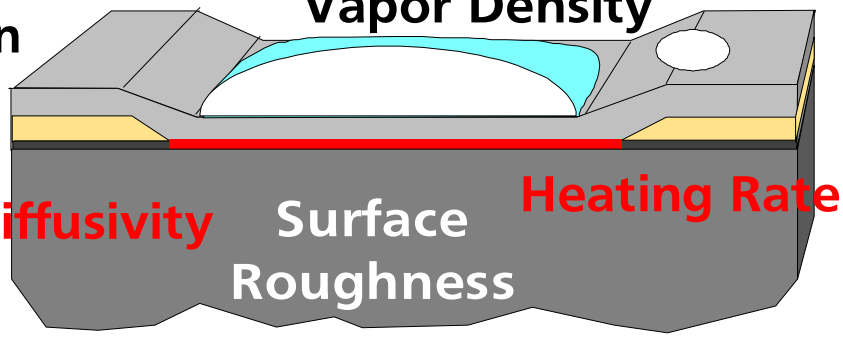
Superheat Limit

Vapor Enthalpy

Temperature Distribution

Vapor Density

Static Bubbles



Thermal Diffusivity

Surface Roughness

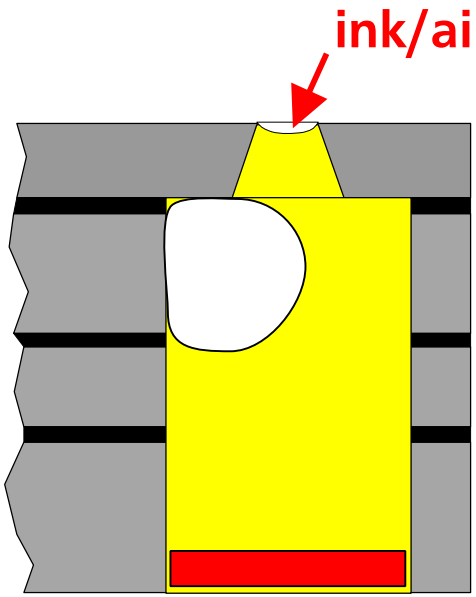
Heating Rate

- HP supports fundamental research on the physics of bubble nucleation

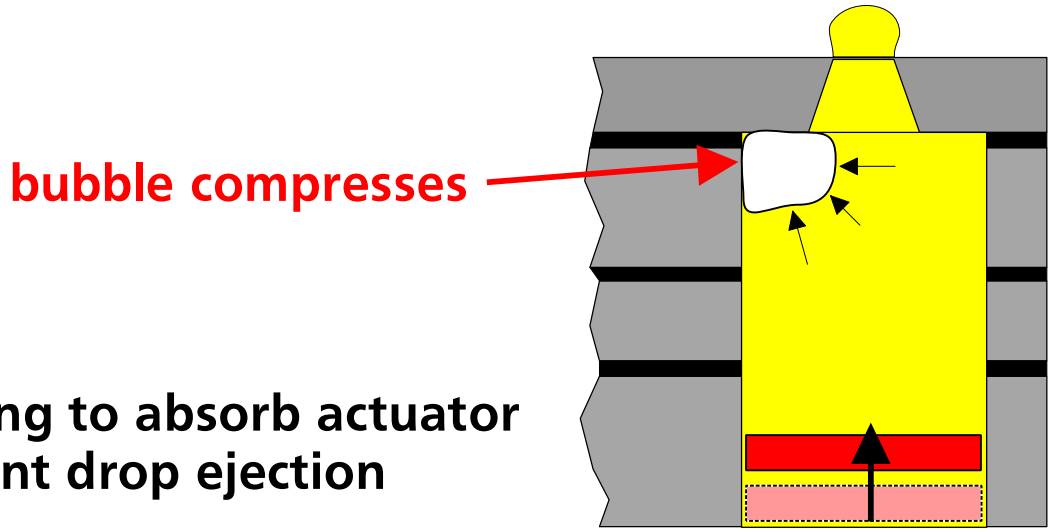
Transfer

trapped air bubbles

- trapped air bubbles are a major cause of failure to eject droplets
- bubbles nucleate at sharp edges, rough surfaces, and on particles suspended in the ink
- bubbles can appear anywhere in the ink delivery system



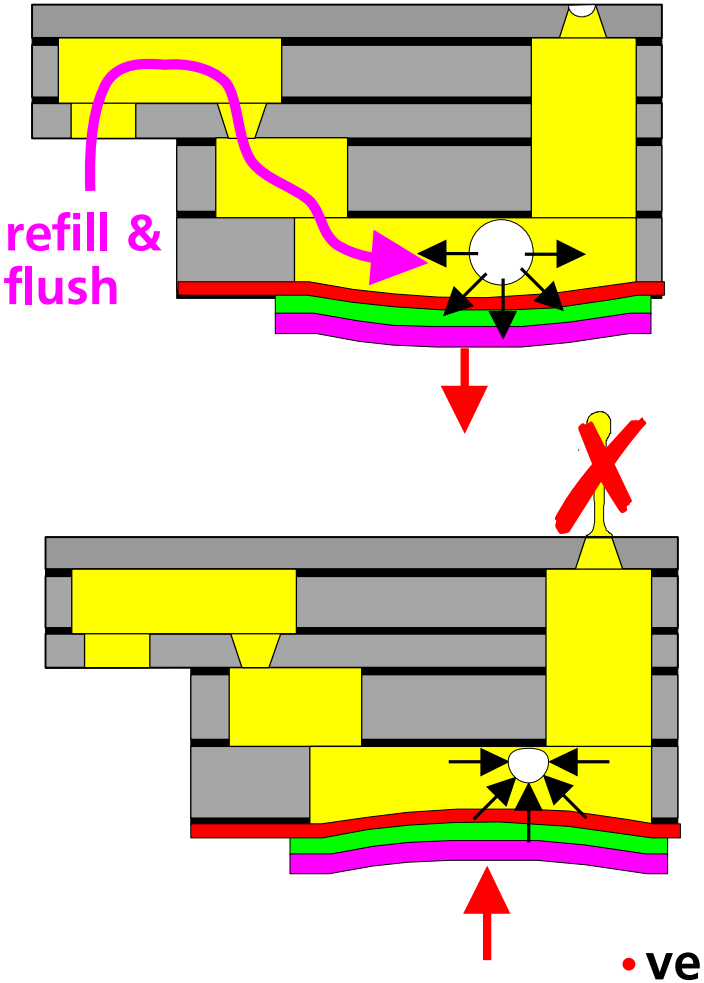
- ink is exposed to air at the orifice
- the ink in the drop generator becomes fully saturated with air over time



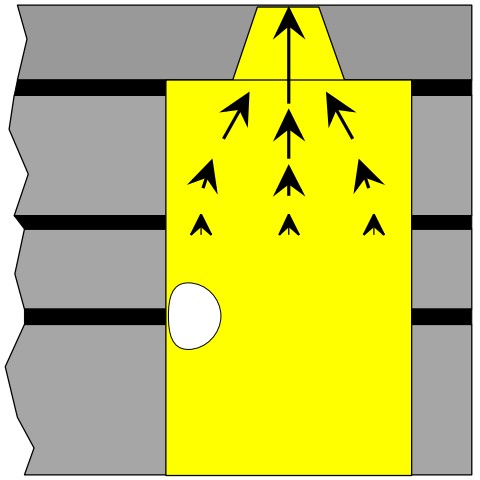
- bubbles act like a spring to absorb actuator energy: this can prevent drop ejection

Transfer

piezo & air bubbles

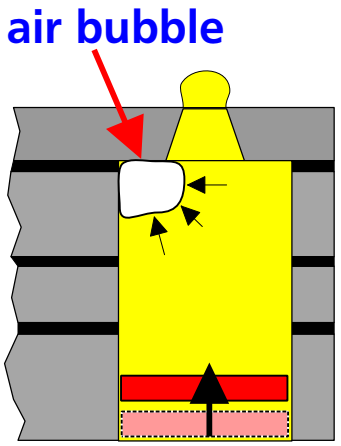


- intake stroke of diaphragm creates a low pressure that contributes to trapped bubble formation & growth
- *a special flush cycle* is required to pump sufficient ink through the printhead to flush trapped air bubbles
- small motion of piezo diaphragm pressurizes ink inside a large chamber
  - air bubbles absorb the energy of the diaphragm stroke



- very low fluid velocities *except* near orifice are ineffective at flushing trapped bubbles during normal operation

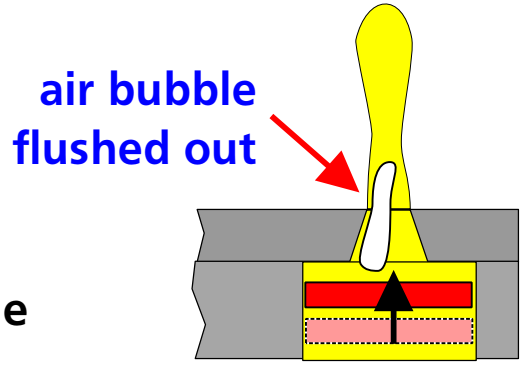
Transfer



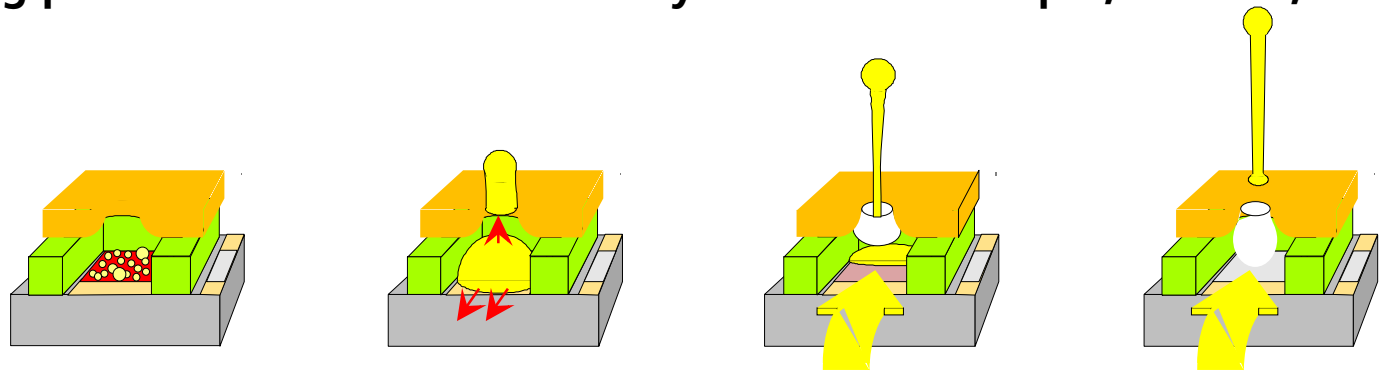
TIJ & air bubbles: robust from the beginning

- In 1978, scientists at HP Laboratories investigating new printing technologies recognized that trapped air bubbles were a major source of unreliability in piezo ink jet

- Their solution: find a way to place the energy source right at the orifice
  - ✓ a small chamber with a large-displacement "pump" is less sensitive to air bubbles
  - ✓ bubbles are flushed out on every drop ejection cycle



- These ideas (and a coffee percolator) led directly to HP's invention of TIJ
- TIJ uses heat to make a tiny, fast pump from a bubble of ink vapor
- TIJ: no moving parts but the ink itself for a system that is simple, reliable, & fast



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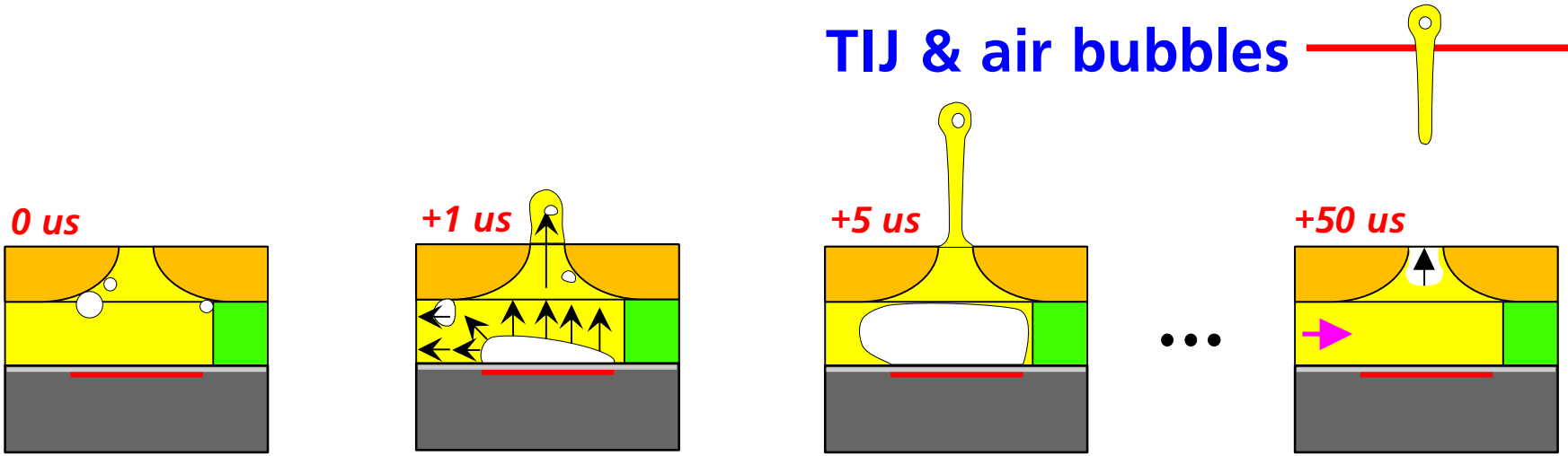
gas2

Transfer

TIJ & air bubbles



- the TIJ ejection process is very energetic: the vapor bubble acts like a piston to drive ink and air bubbles out of the orifice
  - ✓ high velocities are created throughout the entire drop generator chamber
  - ✓ no ink-wasting flush cycles are required
  - ✓ reliable drop ejection

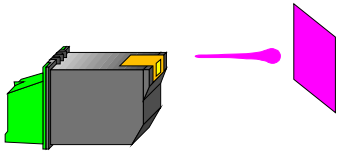
- air bubbles flushed on *every cycle*

- **TIJ is the only drop-on-demand ink jet technology to provide the high-displacement energy source close to the orifice needed to flush air bubbles on every drop ejection cycle**

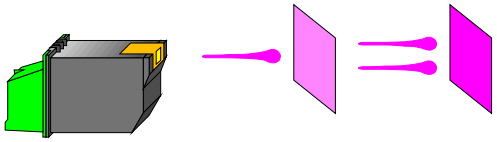
Transfer

smaller drops: a key enabler for photographic image quality

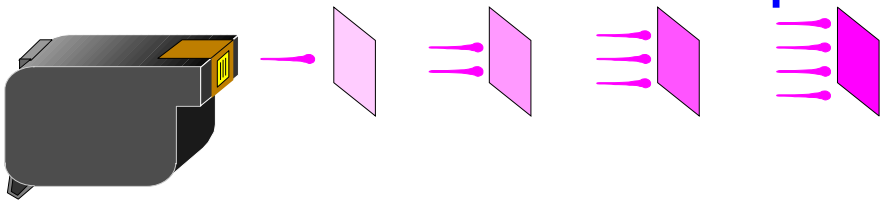
- '91 DeskJet 550C CMY: 85pl



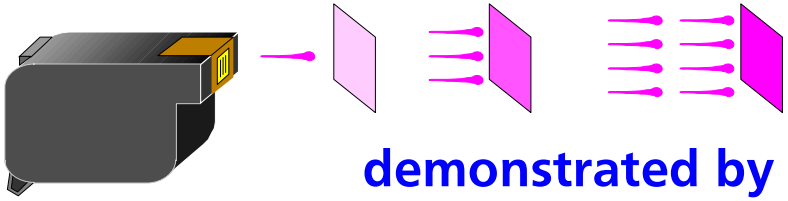
- '96 DeskJet 690C cmK: 35pl



- '97 PhotoSmart cCmMYK: 27pl

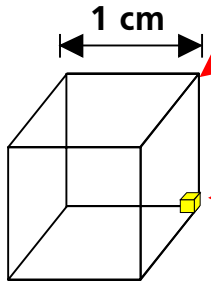


- '98 PhotoREt II on the HP2000C CMY: 8pl



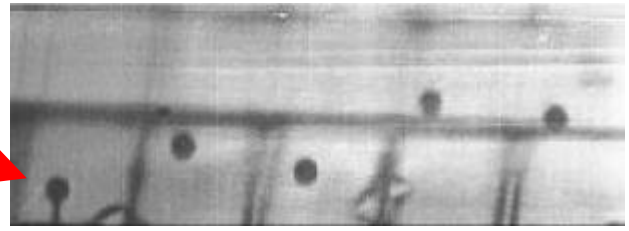
A picoliter is
1/1,000,000,000,000 liter

1 cm cube holds
1/1,000 liter (1 ml)



1 mm cube holds
1/1,000,000 liter (1 μl)
-or-
1,000,000 picoliters

demonstrated by HP R&D:
2pl drops for virtually
continuous-tone printing
in a single pixel



Transfer

marking throughput

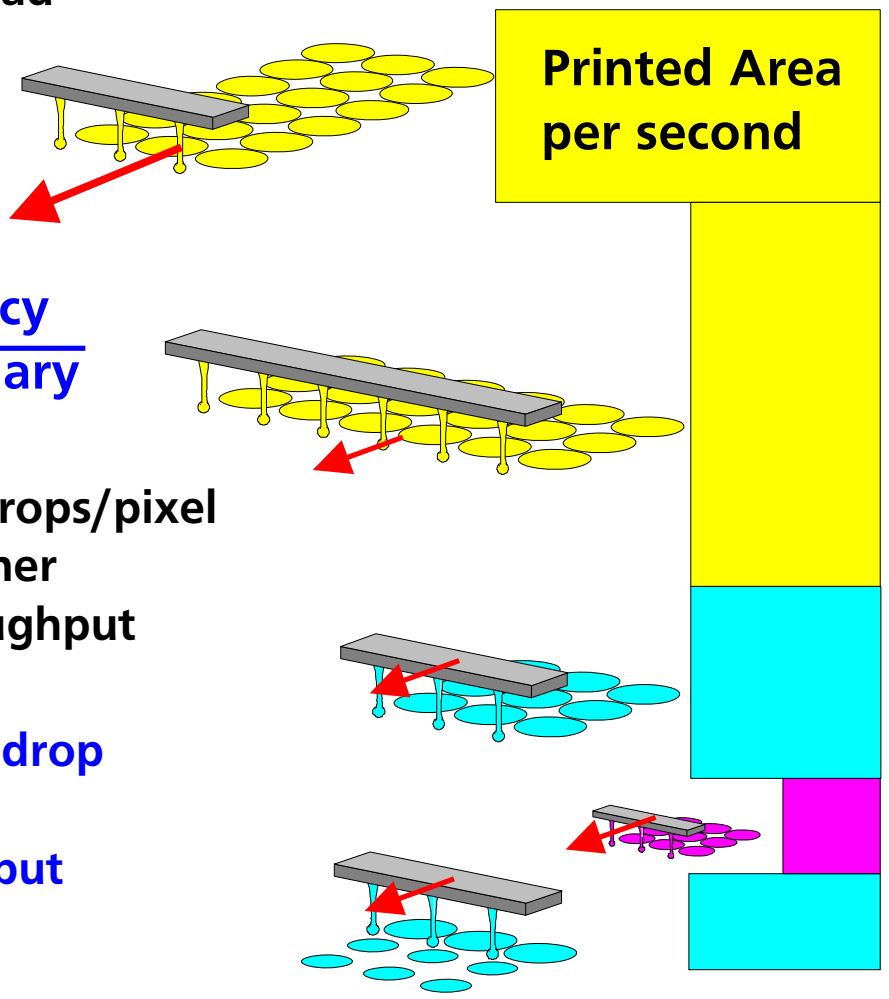
- marking throughput is the area per second a printhead can print 100% density of a specified primary color

- marking throughput is

$$\frac{\#\ \text{orifices} \cdot \text{drop frequency}}{\text{resolution}^2 \cdot \#\ \text{passes/primary}}$$

- higher resolution and more drops/pixel require more orifices and higher frequencies to maintain throughput

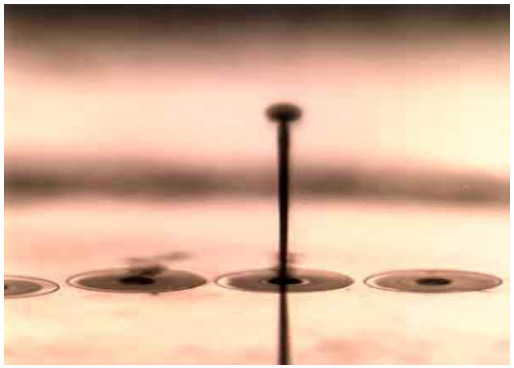
✓high orifice density and high drop frequency make TIJ the ideal technology for high throughput *and* high image quality

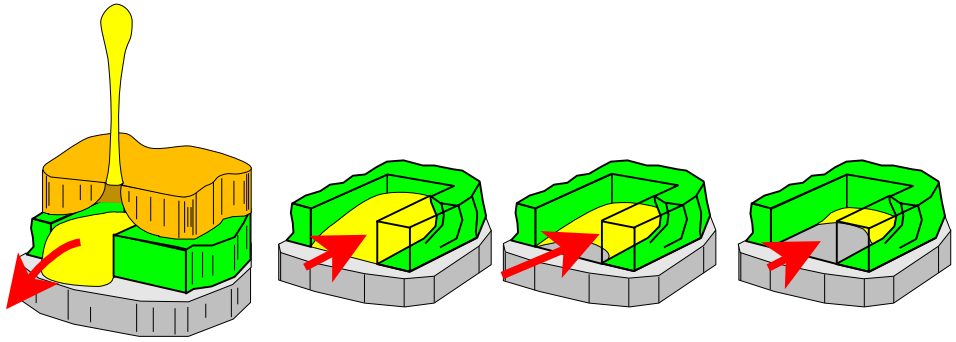


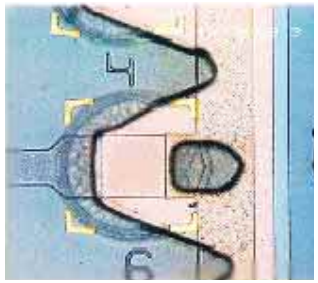
orifices	KHz	dpi	passes
3	8	300	1
6	4	300	1
3	4	300	1
3	4	600	1
3	4	600	2

Transfer

HP's technology base



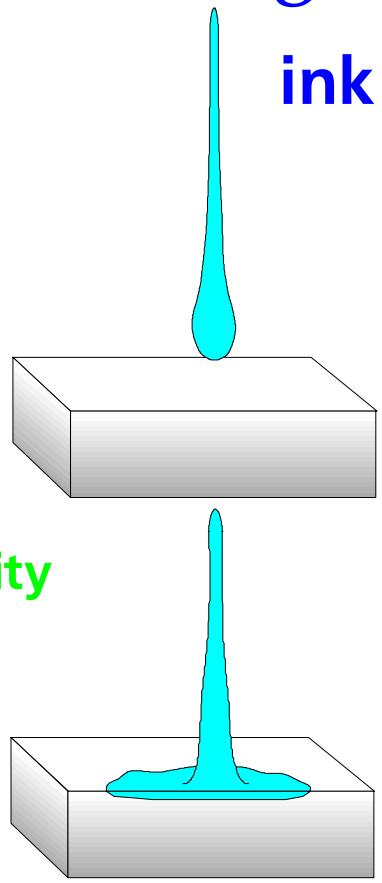




- a two decade investment in analytical & experimental studies of bubble formation & drop ejection
- a fundamental understanding of the relationship between TIJ design & printing performance
- the most advanced fluidic architectures for drop-on-demand ink jet
- a scientific & engineering base to support evolving performance requirements in digital imaging

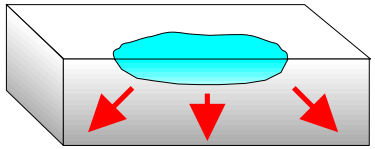
Fixing

ink technologies

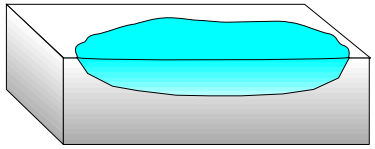


• liquid ink

+ high durability
+ simple ink supply & service station
+ high color saturation
+ photographic image quality
+ versatility
+ low-cost
- dry time
- media interaction



• spread
• penetration



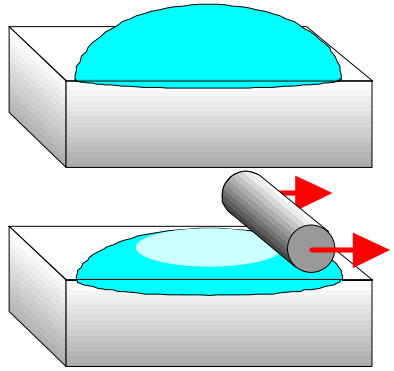
• evaporation
• chemical reaction

• solid ink

- poor abrasion resistance
- complex ink supply & service station
- higher system cost
- thick colorant layer
- image quality
+ quick dry
+ media independence
+ waterfast

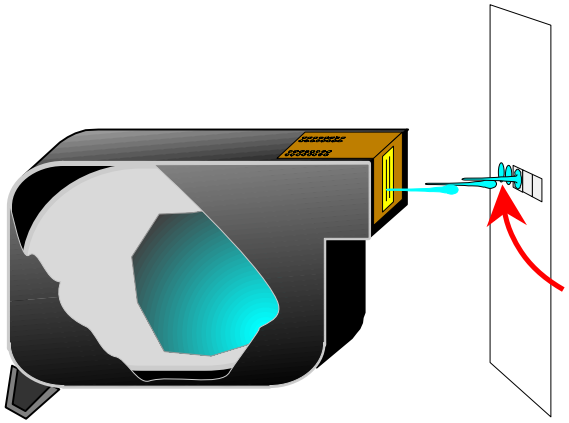
• spread
• little penetration
• phase-change

• post-treatment
reflow or
pressure roller



Fixing

Ink has complex physical & chemical interactions with paper



- FIXING

- stable, solvated colorant

- wetting
- kinematic spread

- cellulose hydration
- diffusion
- solubility changes
- solvent separation

- surface capillary flow
- multi-colorant interface

- solvent loss
- interdiffusion

drying

cockle

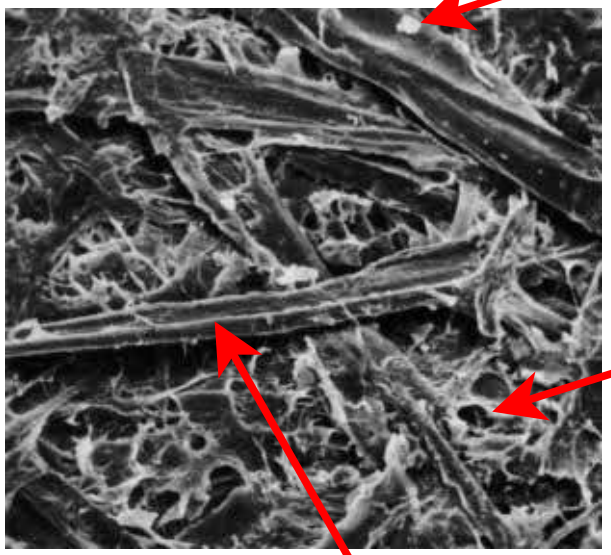
feathering
color bleed

spot-size,
optical density,
strike-through

Fixing

paper is a complex chemical system

microscopic view of paper surface



~100 um

filler (acidic) clay, TiO_2, silica; (basic) $CaCO_3$
- increases stiffness
- affects porosity
- absorbs water
- increases brightness & opacity

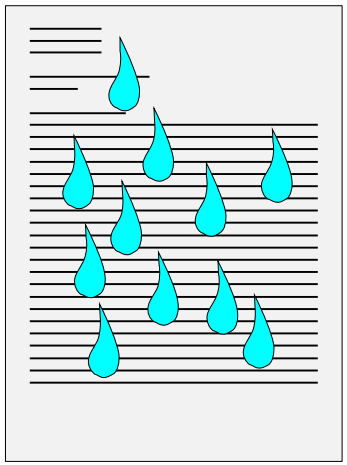
sizing starches, PVA
- improves strength
- affects wettability
- holds colorant at surface
- improves smoothness

cellulose fiber
strength

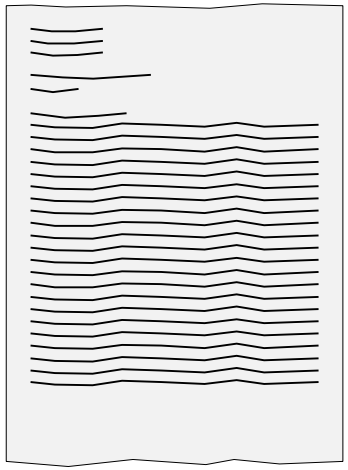
- HP analyzes over 300 papers worldwide to develop & test inks for plain-paper
- HP develops special media & inks *as a system* for optimal imaging performance

Fixing

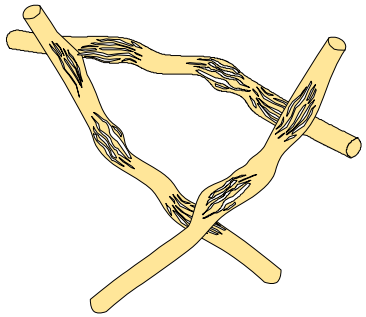
cockle

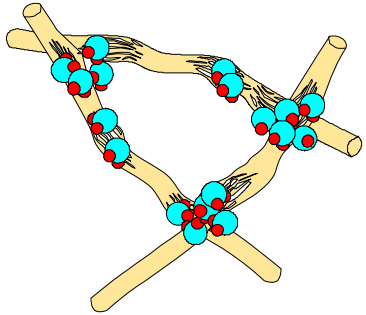


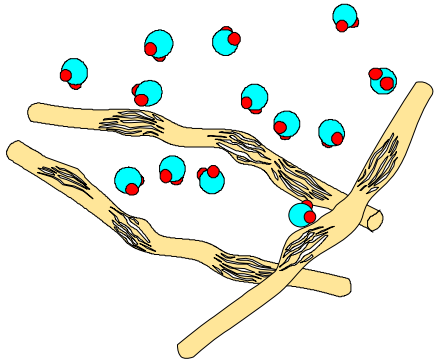
applying water-based inks
to plain (uncoated) paper
can produce wrinkles in the
surface called "cockle."



- cockle occurs as cellulose fibers swell and shift:
  hydrogen bonds within and between fibers
  are disrupted by water molecules





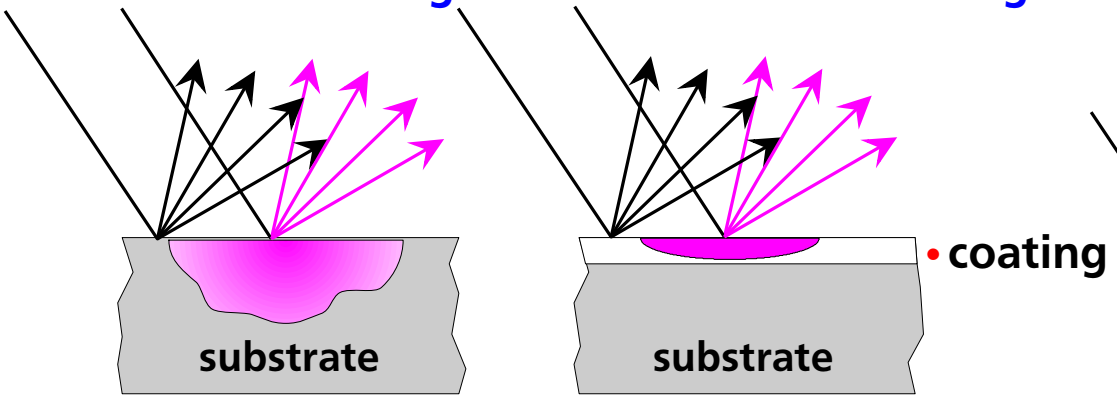


- cockle is suppressed with
  - ✓ multipass print modes
  - ✓ ink chemistry

Ink Jet Ink & Media

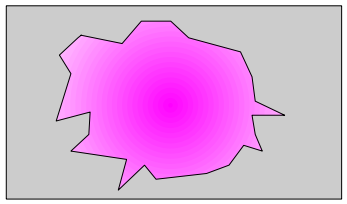
plain & special media

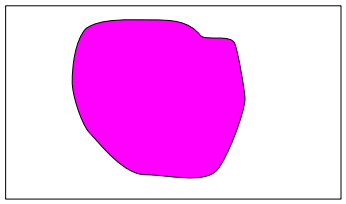
- diffuse reflection from matte surface desaturates image
- specular reflection from glossy surface gives saturated colors & shadows



plain paper

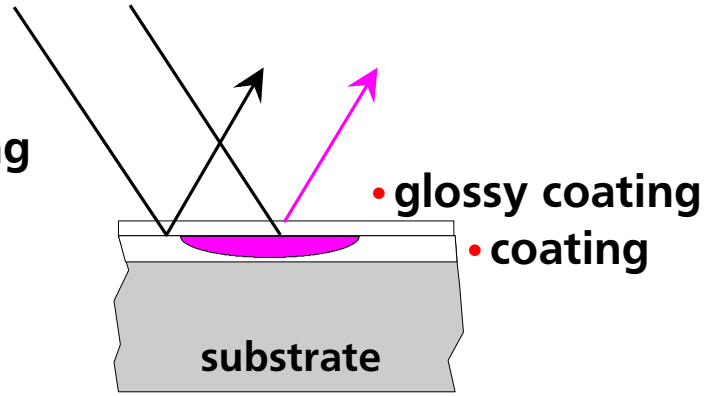
coated paper





- dull surface color
- uncontrolled dot spread & penetration*

- whiter surface
- controlled dot spread & penetration



glossy paper

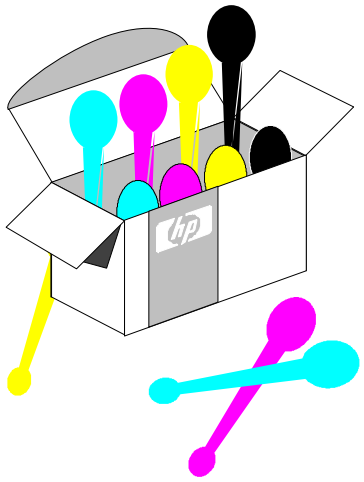
- photographic-quality images require glossy media with a bright white background

***HP PhotoREt II plain-paper advantage:**

many small drops per pixel enables tuning dot characteristics to the selected media → control of dot spread & penetration = color accuracy

Fixing

objectives in TIJ ink design



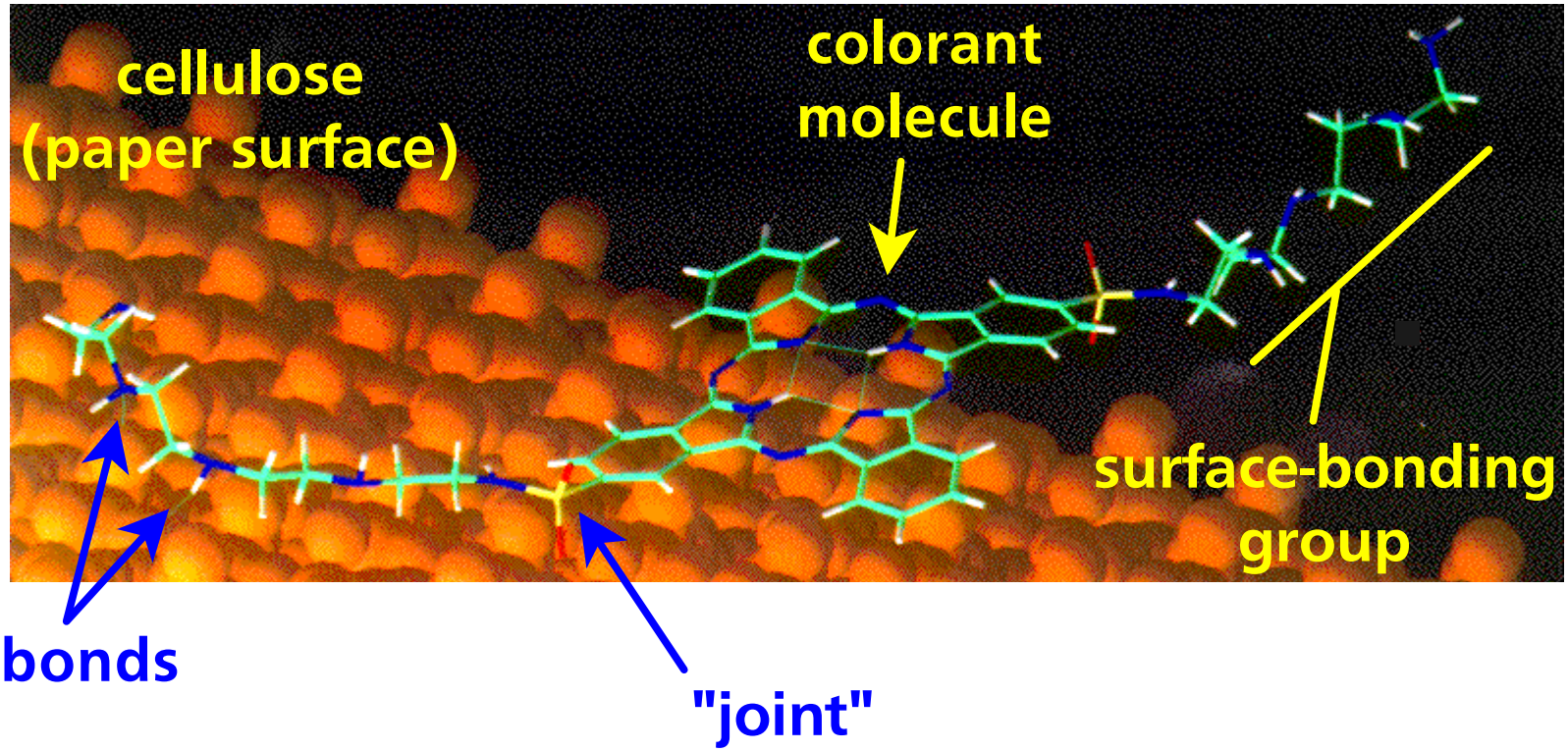
- **Improve the fixing mechanism for better, more consistent quality**
  - ✓ eliminate paper cockle
  - ✓ eliminate color bleed
  - ✓ achieve consistent spot-size & edge sharpness
  - ✓ maximize water- & lightfastness
  - ✓ improve color gamut & optical density
  - ✓ produce best rendering of neutral tones

- **Extend the limits of water-based ink technology**
  - ✓ develop inks with advanced molecular structures allowing use of water-insoluable colorants
  - ✓ water is a safe solvent for use world-wide
    - ✗ volatile organic solvents are subject to environmental health & safety regulations in the home & office

Fixing

advanced ink research

Computer simulations observe behavior of prototype molecules at the paper surface



600 dpi Print Cartridge

a versatile platform for desktop & large format printing

- The 600 dpi cartridge for the DeskJet 700/800-series & DesignJet 2000/3000-series sets new performance levels for throughput, quality, & user convenience

- orifices in plastic flexcircuit
- integrated logic & drivers

- ✓ 300 orifices
- ✓ 52 pads
- ✓ 21pl (DesignJet) or 35pl (DeskJet)
- ✓ 12KHz
- ✓ pigment black ink
- ✓ high-capacity ink supply (700/800)
- ✓ large capacity ink supply (2000/3000)
- ✓ automatic out-of-ink sensing

Color Print Cartridge

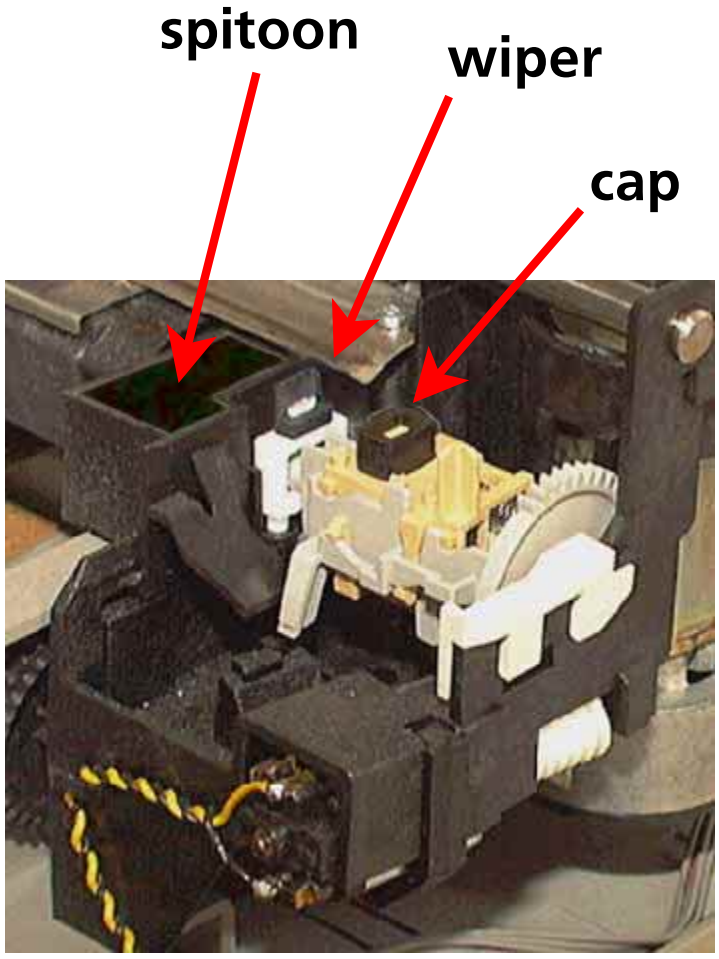
- The 3-color cartridge for the DeskJet 800-series & PhotoRET II printers sets the standard for performance & image quality with small drop halftone printing

- integrated control logic & drivers

- ✓ 192 orifices: 64 C + 64 M + 64 Y
- ✓ 52 pads
- ✓ 32 pl @ 300 dpi (800-series)
- ✓ 10pl (PhotoRET II)
- ✓ 6KHz (800-series)
- ✓ 12 KHz (PhotoRET II)
- ✓ CMY inks with large color gamut

Ink Jet Printing

printhead servicing



The service station provides functions essential to system reliability

- **orifice capping**
  - reduce evaporation of volatile components
  - minimize crusting & viscous plugs
- **orifice plate wiping**
  - remove paper dust & ink spray
- **drop ejection**
  - purge gases & allow a "wet wipe"
  - refresh ink for consistent physical properties
  - verify operation, volume, energy calibration
- **waste ink disposal**

Print Quality

HP develops printers, ink, & media together as a complete printing system solution

- print & image quality
- reliability
- durability
- throughput

printers

- halftone printing
- image processing
- print modes
- color maps

- media handling & reliability
- media recognition
- environmental performance

ink

- spot size & saturation
- optical density
- color bleed
- feathering
- edge sharpness

- color gamut
- optical density
- drytime
- fastness
- curl

media

- surface gloss
- uniformity
- bright & white
- opacity
- flexibility/stiffness

Photographic Image Quality

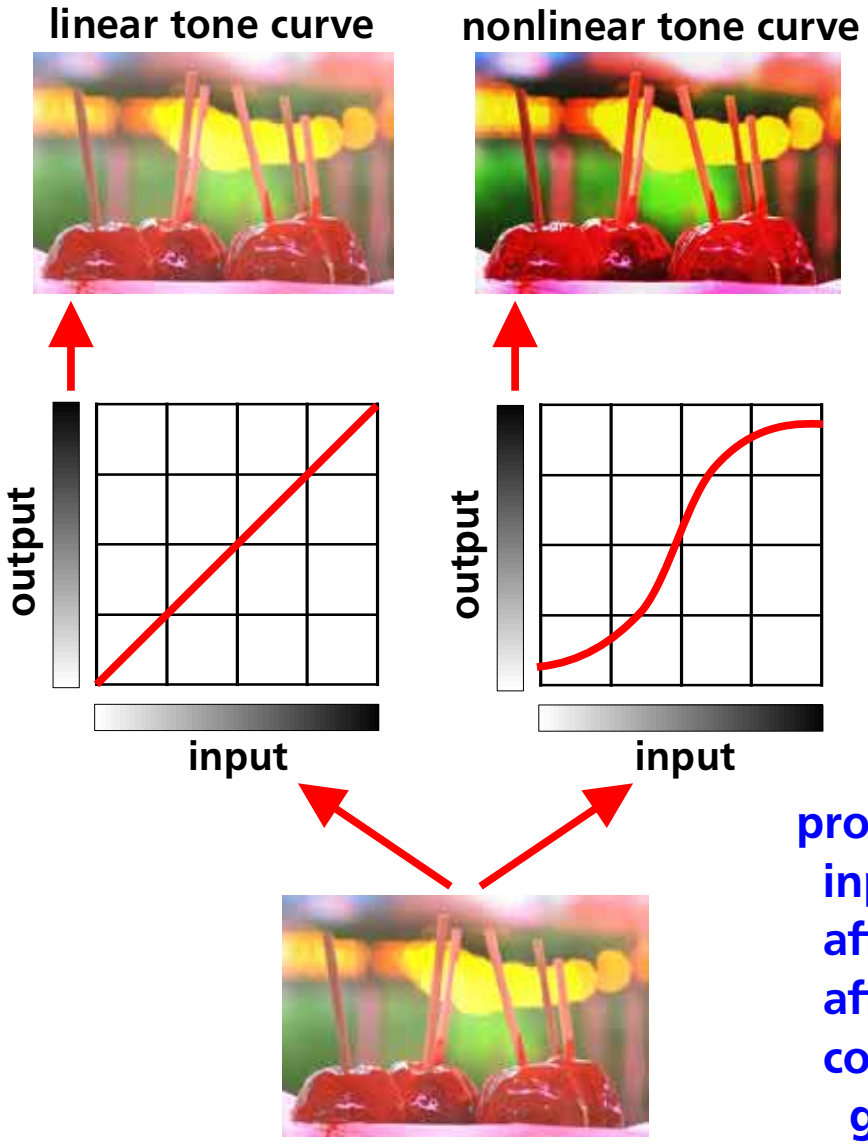
a proposal

Photographic image quality is achieved in a digital imaging system when...

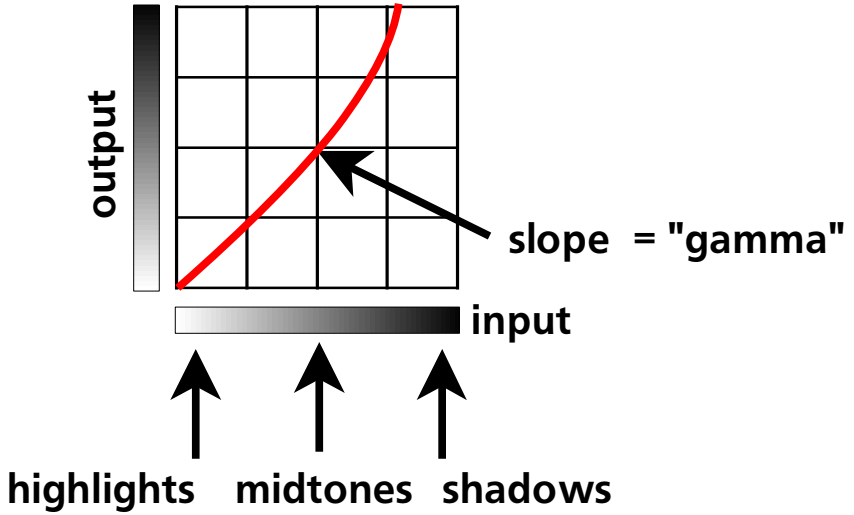
- ✔ **image quality attributes are measured considering characteristics of human visual response:**
  - *objective measures* of the eye as an optical instrument
  - *subjective measures* of what is pleasing to the viewer
  - employ traditional measures of image quality:
    - tone reproduction, color balance, sharpness & detail, graininess
- ✔ ***for the intended application*, measured qualities of the digital image meet or exceed those for a color photographic print from a negative**
  - e.g., compare with 35mm photography on prints up to 8" X 10"
  - e.g., recognize that retail photofinishing falls short of optimal quality
- ✔ **the digital imaging process introduces no objectional artifacts**
  - banding, color misregistration, etc.
- ✔ *You either can't tell the difference or prefer the digital print*
  - measurements never completely specify the quality of subjective experience

Image Quality

traditional criteria for image reproduction



- tone reproduction



proper tone reproduction is essential
- input-output relation for light intensity
- affects image contrast ("dull/misty" vs. "gaudy")
- affects highlight & shadow detail
- compensates for viewing environment:
  - gamma = 1 (reflection print)
  - = 1.25 - 1.5 (projection films)

Image Quality

traditional criteria for image reproduction

undersaturated

too green

too cyan

too yellow

too red

too blue

too magenta

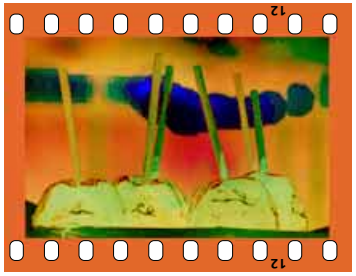
oversaturated

- **color balance & pleasing reproduction**

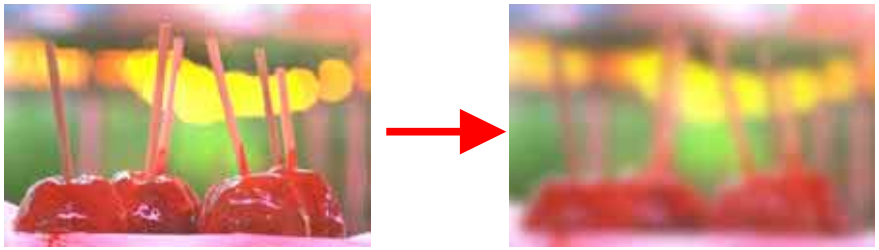
correct color balance:
  no objectionable color casts
correct white-point
adequate color saturation
memory colors:
  faithful reproduction
  pleasing enhancement

Image Quality

traditional criteria for image reproduction



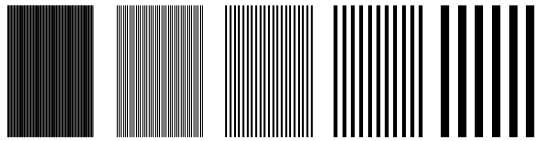
- Resolving Power: lines/mm
  RMS Granularity



unsharp

grainier

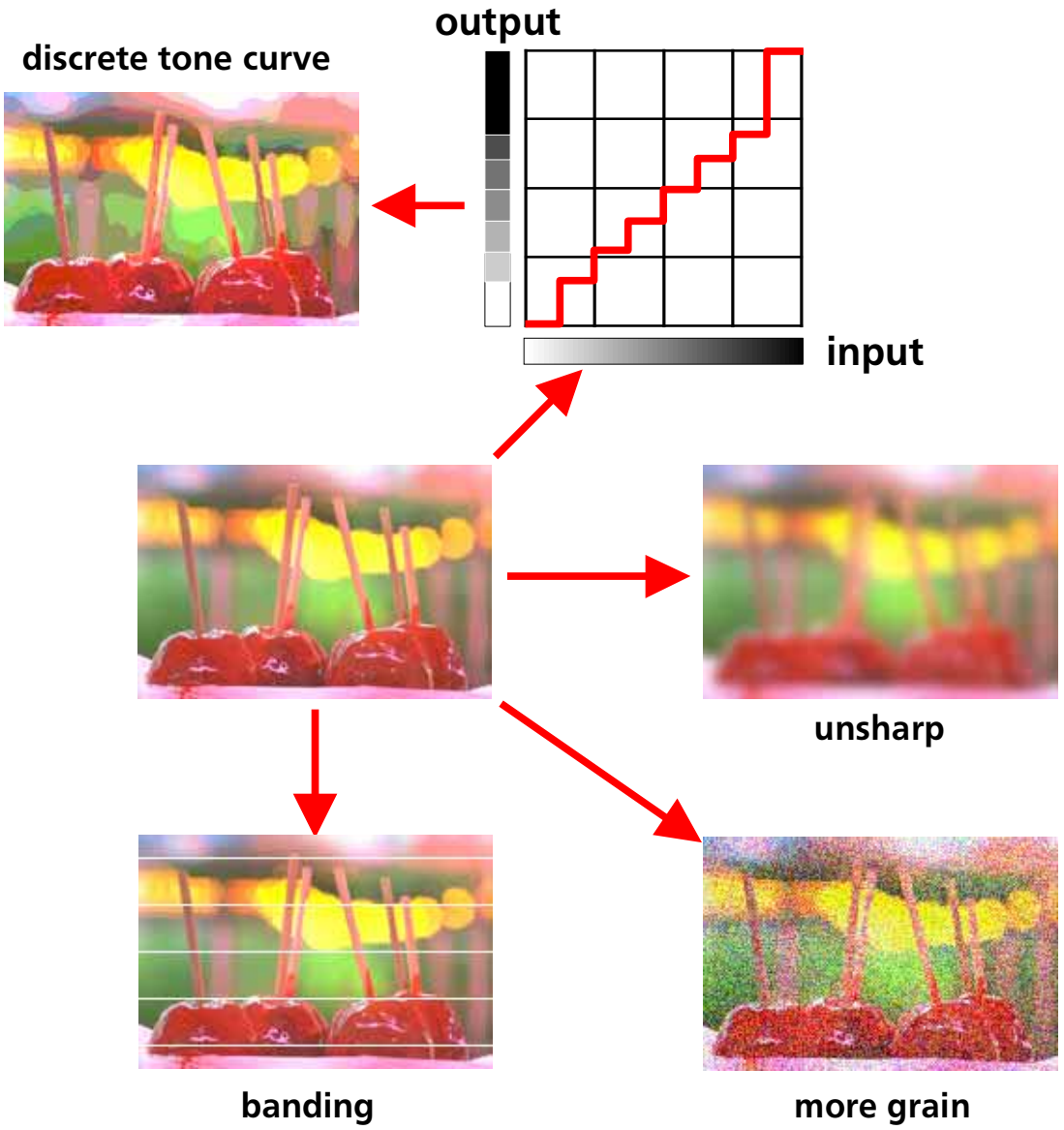
- **sharpness & detail**
  - edge contrast preserved
  - fine image features preserved
  - most sharpness & detail in gray channel
  - requires accurate color-plane registration
  - measure: MTF (lines/mm) at normal viewing distance



- **graininess**
  - undesirable image "noise" depends on:
    - physical size & distribution of pixel-forming marks
    - magnification of recording medium
    - optical density of measured region

Digital Image Quality

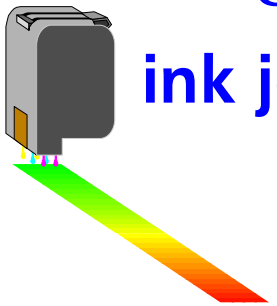
digital image reproduction



- **tone reproduction**
  - discrete output states
  - color & B/W tone breaks
  - highlight & shadow details
- **sharpness & detail**
  - dot edge sharpness
  - dot placement accuracy
  - black printer for gray channel
- **color balance & pleasing reproduction**
  - addressible colors & gamut
  - colorants:
    - selective absorption
    - saturation (low gray-content)
- **print engine artifacts**
  - (technology-specific)
- **graininess**
  - dot size & optical density
  - pixel resolution
  - halftone levels
  - dither patterns

Digital Image Quality

ink jet digital imaging



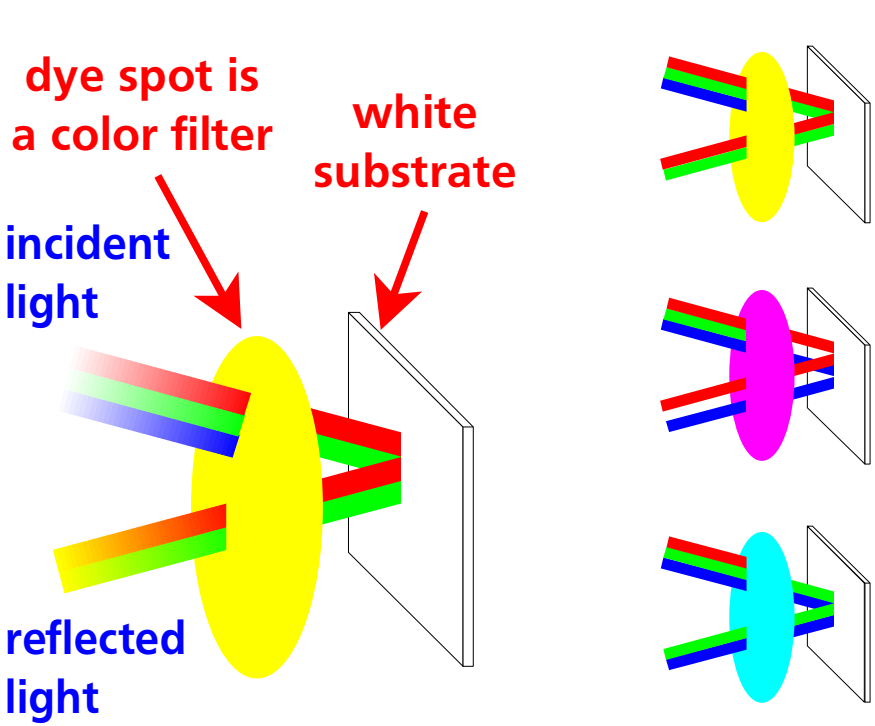
- **tone reproduction**
  - **preserve highlight & shadow detail...**
    - ✔ small dots producing many directly-printable neutral levels
  - **color & neutral tone breaks minimized with...**
    - ✔ 10's of directly printable colors (C-REt & PhotoREt)
    - ✔ >250 directly printable colors (PhotoREt II)
    - ✔ sophisticated halftoning algorithms

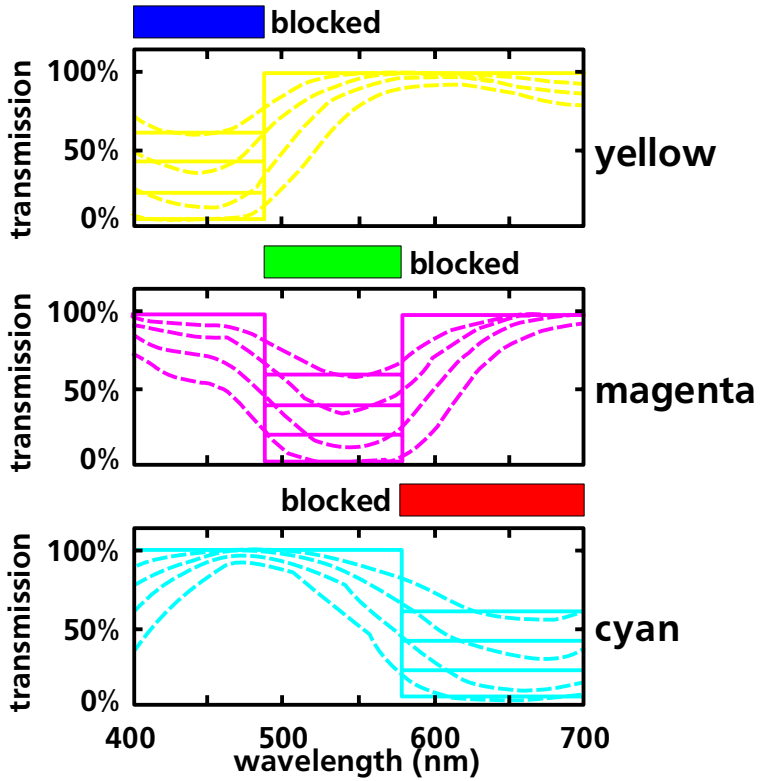
- **sharpness & detail**
  - ✔ precisely controlled dot size
  - ✔ TIJ inks producing high edge sharpness
  - ✔ separate black printer for high edge sharpness
  - ✔ printhead & mechanism designed for accurate dot placement

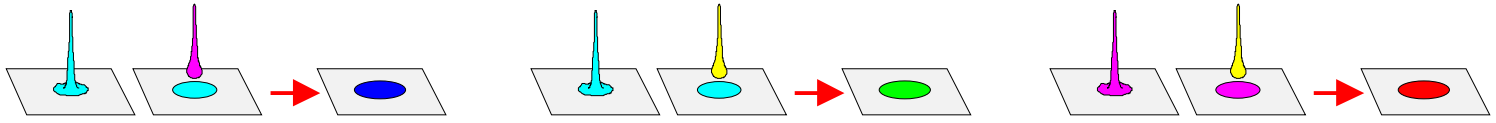
Basic Color Science

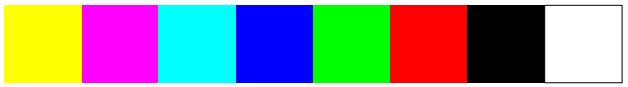
subtractive primaries work by absorbing red, green, or blue wavelengths of incident light

block dyes & real dyes @ several concentrations







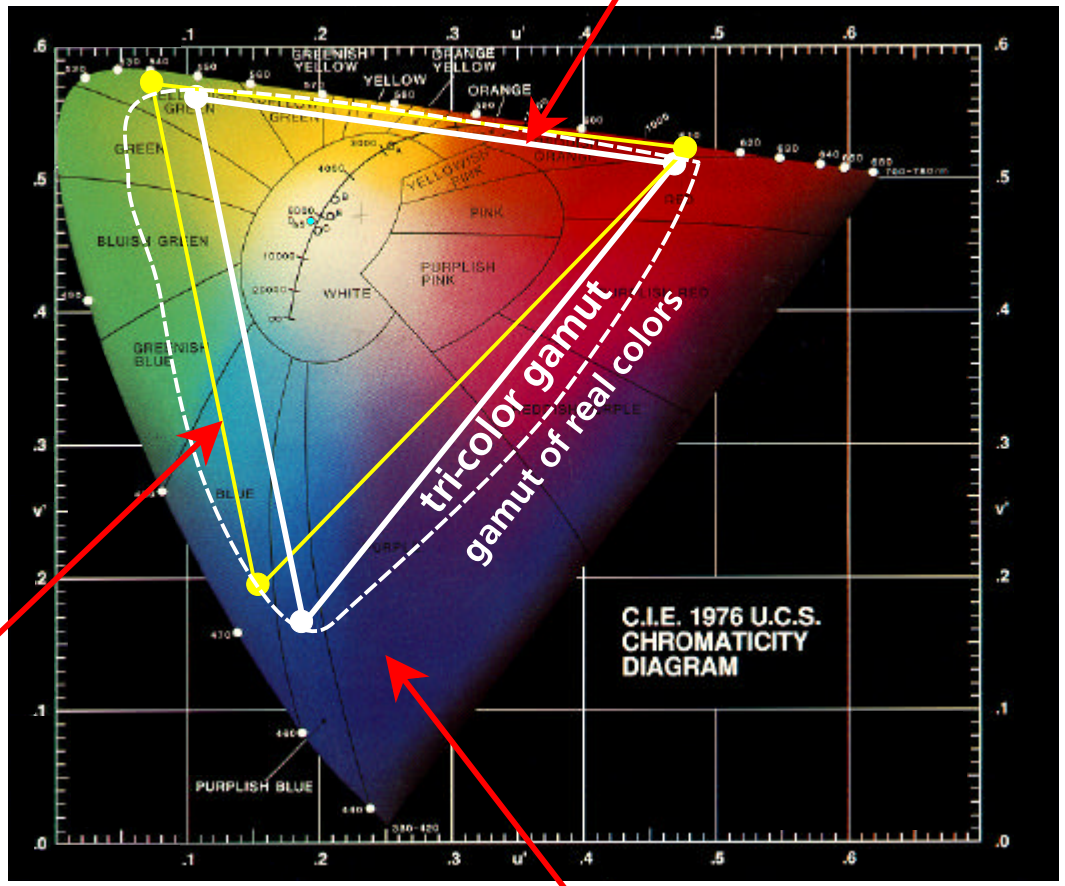


Basic Color Science

color gamuts

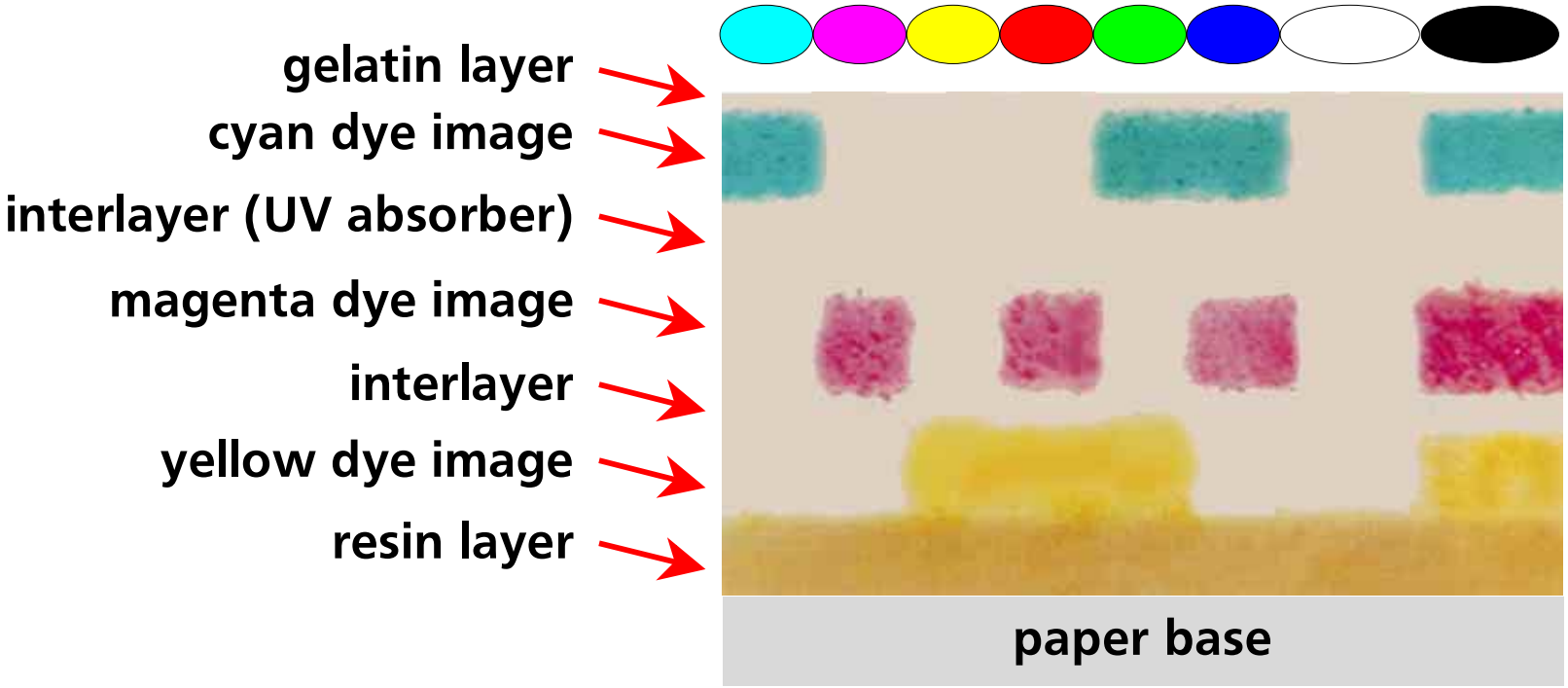
chromaticity diagram: a coordinate space for describing colors

color gamut: the range over a color space that a printing (or display) technology can reproduce



Photographic Materials

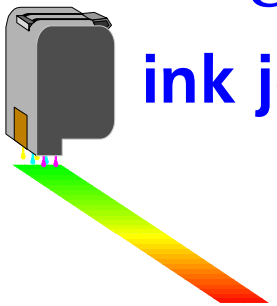
cross-section of a color paper



- color-coupling chemistry forms cyan, magenta, & yellow dyes
- a subtractive, 3-color process: black = C + M + Y
- color dyes selected for color gamut *AND* neutral tones
- deeper layers have less sharpness due to interlayer scattering

Digital Image Quality

ink jet digital imaging



- color balance & pleasing reproduction

highly selective light absorption...

- ✔ TIJ dyes can be "pure" colors
- ✔ low gray content gives high color saturation
- ✔ advanced black-generation algorithms (in HP's RealLife Imaging System)

addressible colors & gamut

- ✔ TIJ inks can achieve better saturation & color gamut than photographic dyes
- ✔ TIJ uses 4 or 6 primary colors vs. 3 in photography
- ✔ dot optical density is controlled with dye load

color fidelity

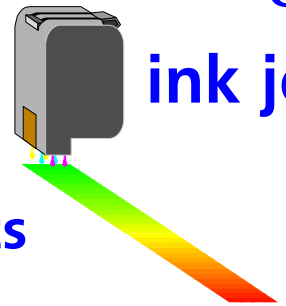
- ✔ white-point correction & accurate memory colors

excess gray content

saturated

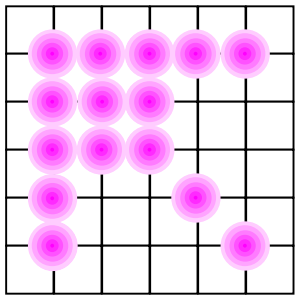
Digital Image Quality

ink jet digital imaging



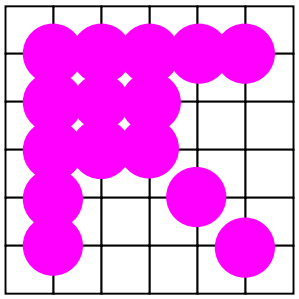
- print engine artifacts

low dot density



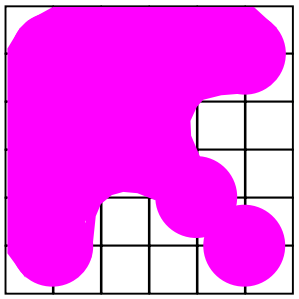
gray text & washed-out color

dots too small



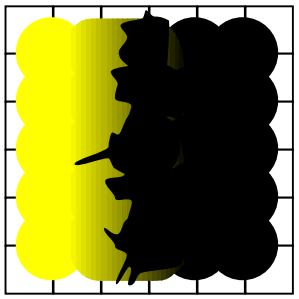
open lines & area fills

dots too big



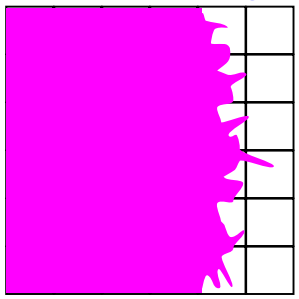
blooming & cockle

color bleed



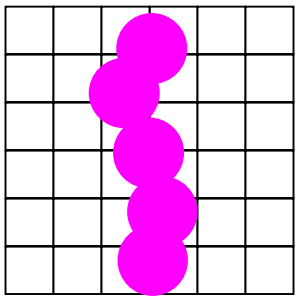
poor color/ ragged edges

poor shape, feathering



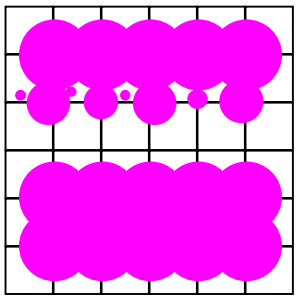
ragged edges

poor dot placement



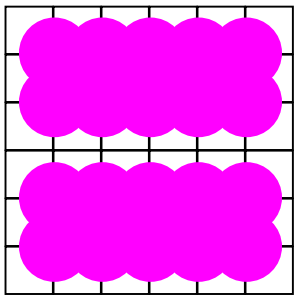
uneven edges & lines

missing or weak dots



banding

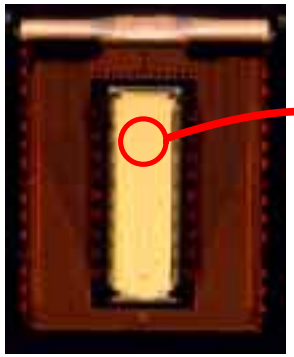
paper feed errors



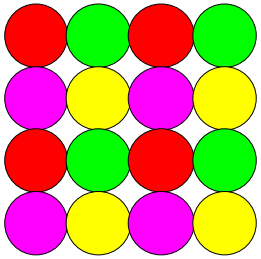
banding

Insuring Image Quality

multipass printing hides artifacts



scrambling the dots...



neighbor dots are printed by different orifices on different passes

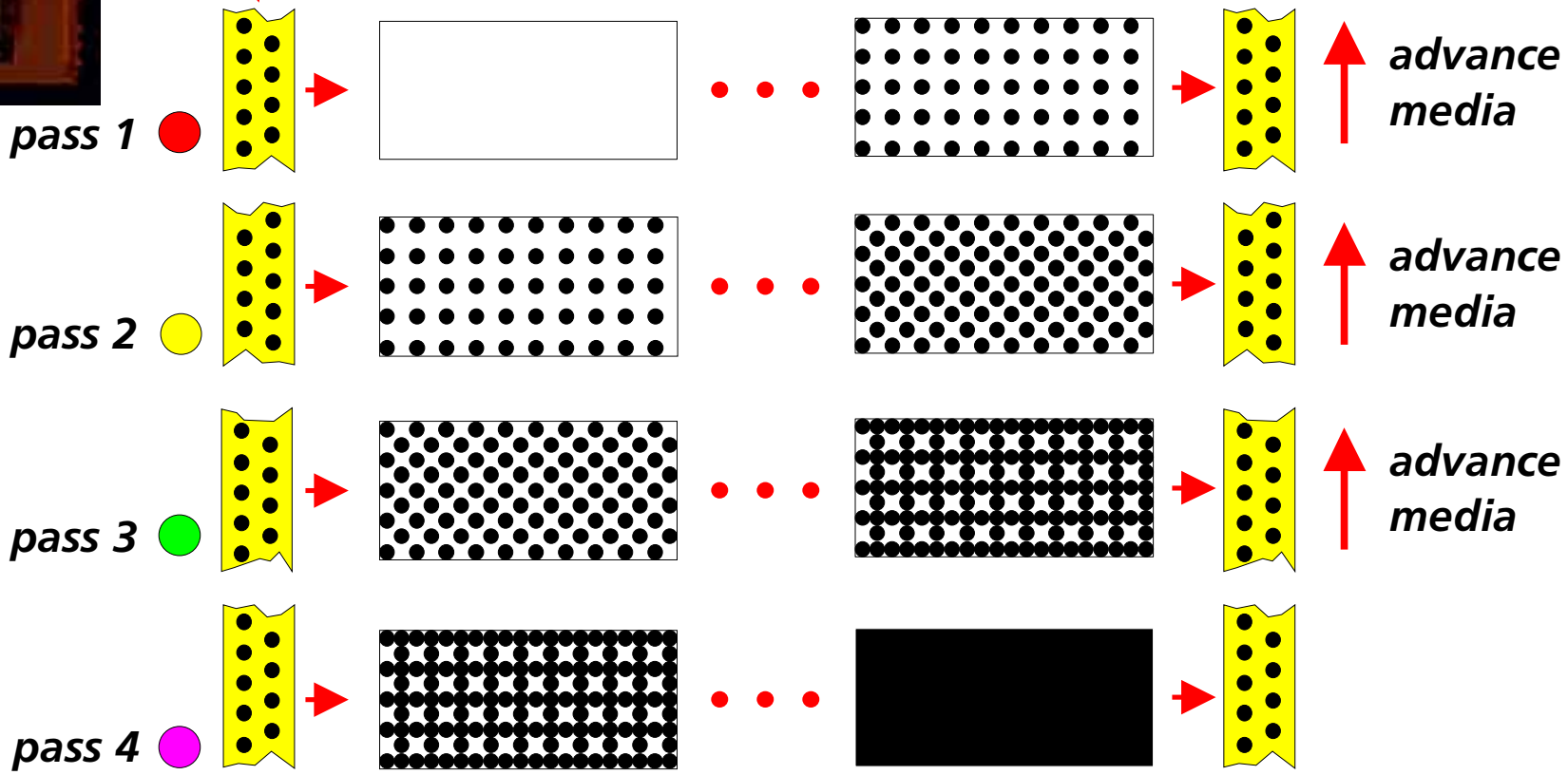


Image Quality

- **graininess**

  image "noise" particularly visible in regions of uniform reflectance where printing process artifacts are not hidden by image detail

  in music reproduction, this is similar to electronic process noise ("hiss") heard during quiet passages

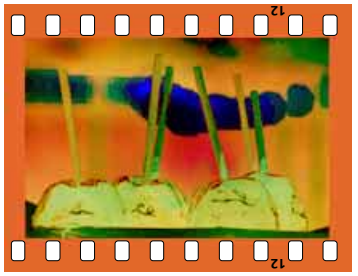
- ***Granularity* is a *measure* of visible variations in image reflectance produced by the printing process**
- **Granularity correlates closely with the subjective quality of *graininess***

Granularity

graininess in photographic images

The Kodak Granularity Scale:

- a subjective measure based on psychophysical studies
- measured for film exposed & developed to a mean optical density of 1.0 (i.e., 10% reflectance)
- based on 12X enlargement of negative emulsions: photographic graininess increases with enlargement
- Used as a standard for grading photographic emulsions for nearly 50 years



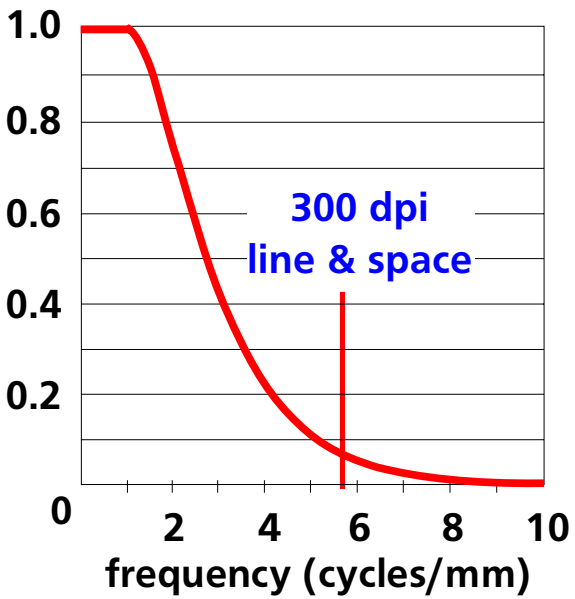
>60	off-scale
45 - 55	Very coarse
33 - 42	Coarse
26 - 30	Moderately coarse
21 - 24	Medium
16 - 20	Fine
11 - 15	Very fine
6 - 10	Extremely fine
<5	Microfine

most color negative films with ISO < 400

Granularity

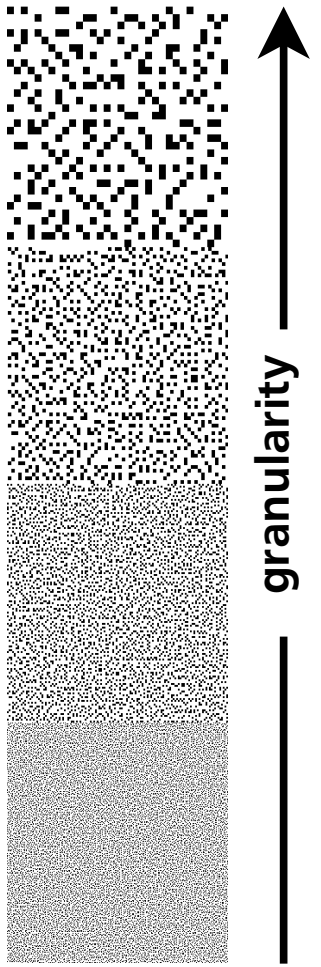
graininess in digital images

- In a digital imaging system, granularity relates image quality to
  - the printing resolution ("dpi")
  - the number of halftone levels
  - the method of error diffusion ("dither")
  - the reflectance of ink used at each halftone level



The human eye is less sensitive to high spatial frequencies

Dither patterns containing more high spatial frequencies make halftones appear *less* grainy



15% gray

the difference between patches is how the dots are grouped

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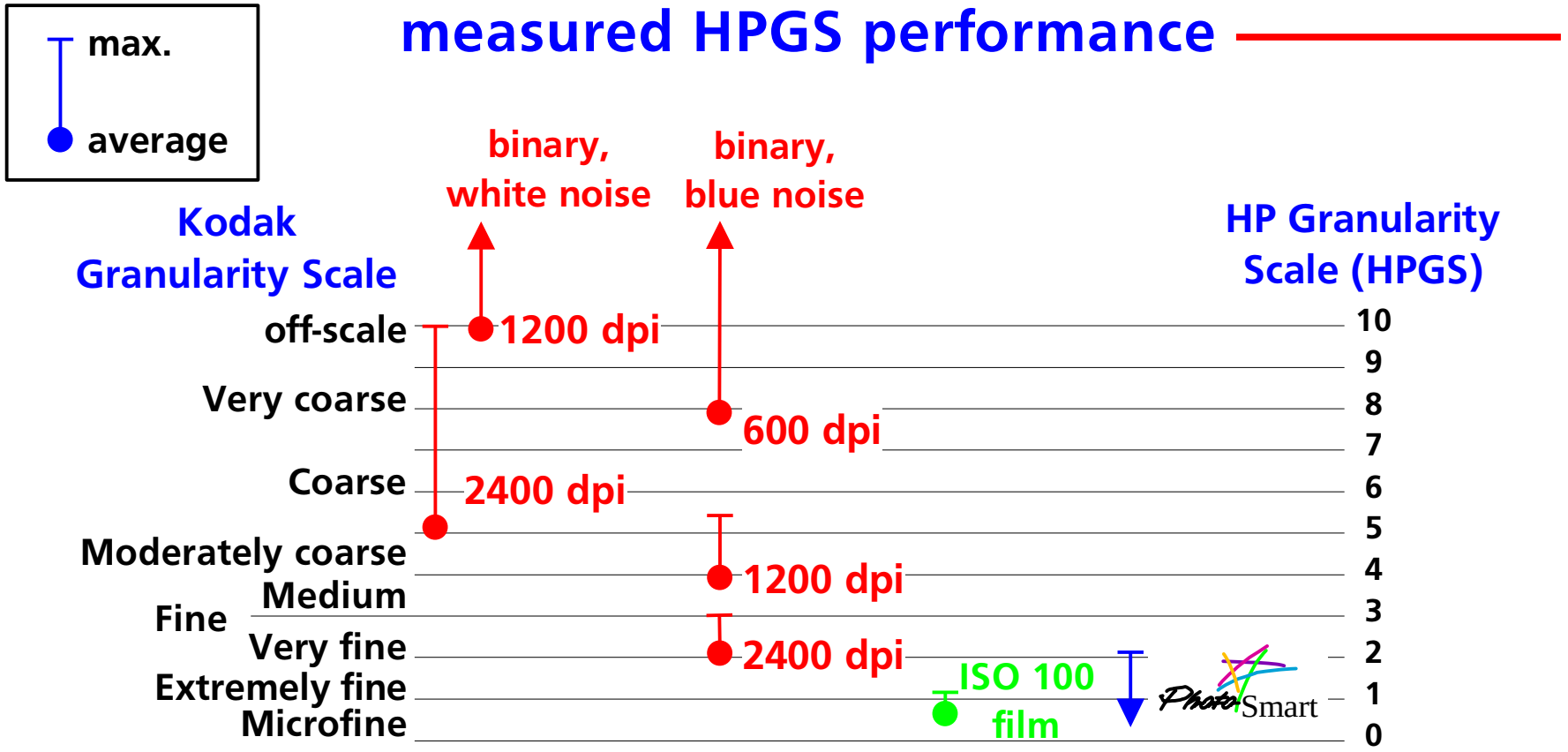
gran2a

Granularity

measured HPGS performance



- ✔ doubling "dpi" reduces granularity by half in a binary printer
- ✔ how dots are arranged can be more important to granularity than "dpi"
- ✔ HP's PhotoSmart printer creates halftones with very small dots in 300 dpi pixels
- ✔ halftone dots at 300 dpi achieve photo-quality granularity
- ✔ these examples *prove* that there is more to image quality than "dpi"

Photographic Quality

appearance & *performance*

A digital print has to look like a photograph...

- ✓ Accurate tone reproduction
- ✓ Sharpness & detail
- ✓ Pleasing color reproduction
- ✓ No visible printer artifacts
- ✓ No objectionable graininess

A digital print has to act like a photograph...

- ✓ Uniform surface gloss & physical texture
- ✓ Waterfast & smudge-proof
- ✓ Lightfast
- ✓ Pleasing texture, weight, & feel of the substrate ("hand")
- ✓ Sleevable & stackable

Digital Image Quality

HP's RealLife Imaging System

- ✔ Sharp blacks
- ✔ Vivid colors
- ✔ Media versatility
- ✔ Ease of use

HP print cartridges

HP TIJ Technology

REt, C-REt, Photo-REt,

PhotoSmart

PhotoREt II

HP media

ColorSmart

user interface

printing architecture

print modes

Digital Color & Image Science

HP color rendering technologies

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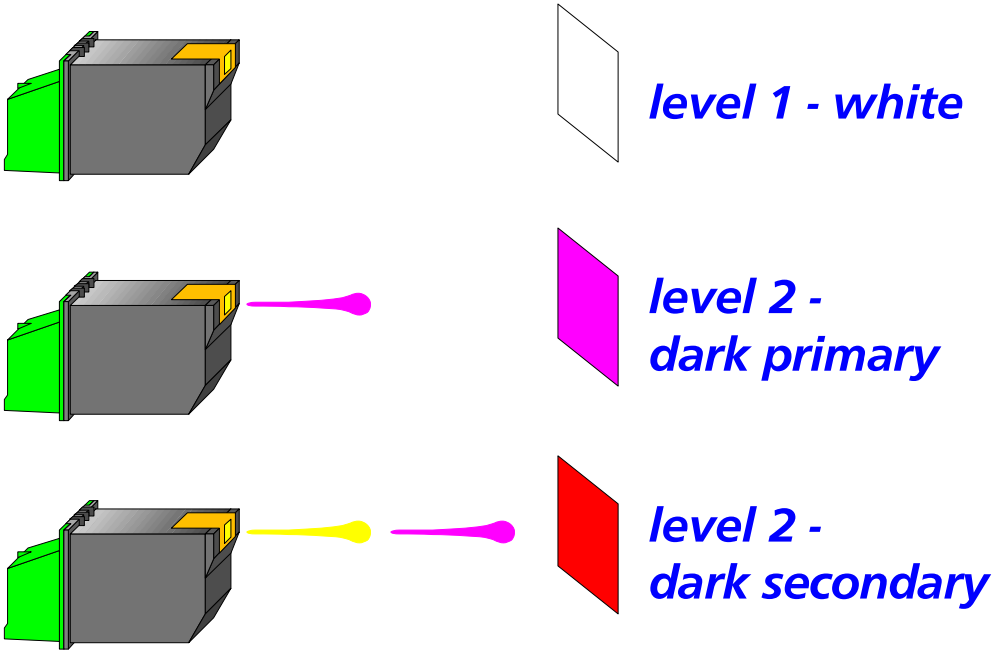
Digital Image Quality

binary printing



- saturated C M Y K dots
- 0 - 1 drop C M Y K per pixel
- 2 drops for R G B pixels
- 8 colors per pixel
- limited ability to print neutrals

  even at high resolution,
  dark K printer produces
  visible grain in highlights

Digital Image Quality

superpixels

pixel

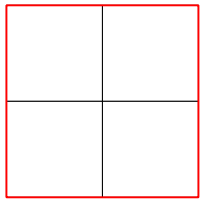
N dpi

- binary printer: only 8 colors at "N" dpi

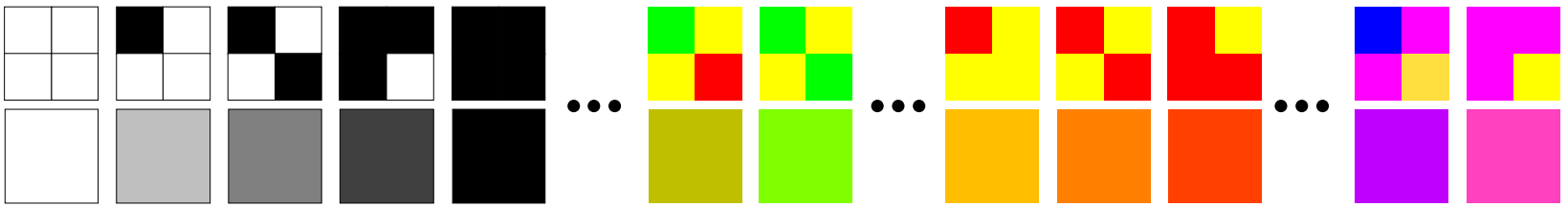
Pixels are combined into groups called *superpixels* to render more than 8 colors

2X2 superpixel

N/2 dpi



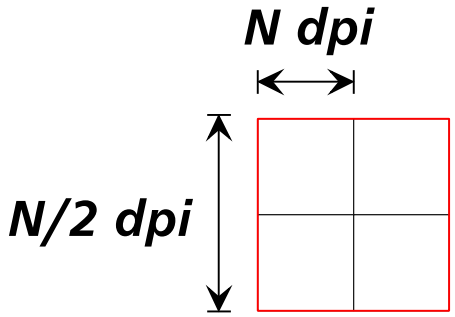
- a 2X2 superpixel
  more apparent colors at half the "dpi"



Digital Image Quality

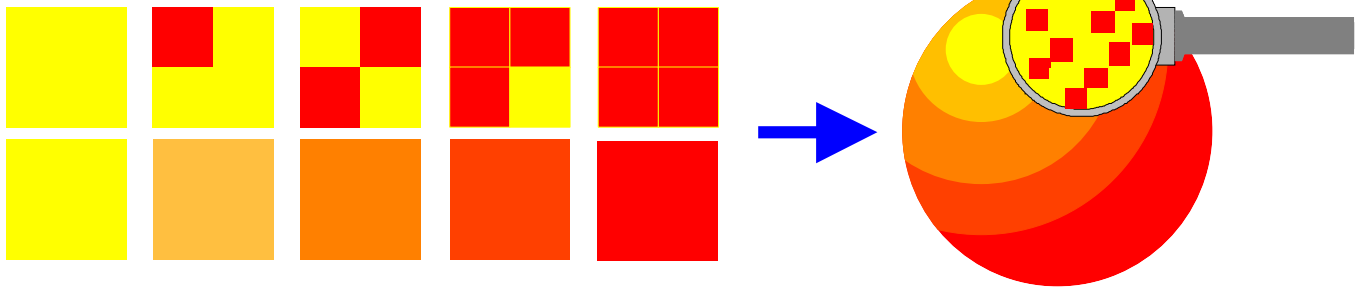
superpixels

- 2X2 superpixel colors



a 2X2 superpixel *of binary dots* gives
5-levels per CMYK & RGB
(0% 25% 50% 75% 100% coverage)

5 steps of Y to R



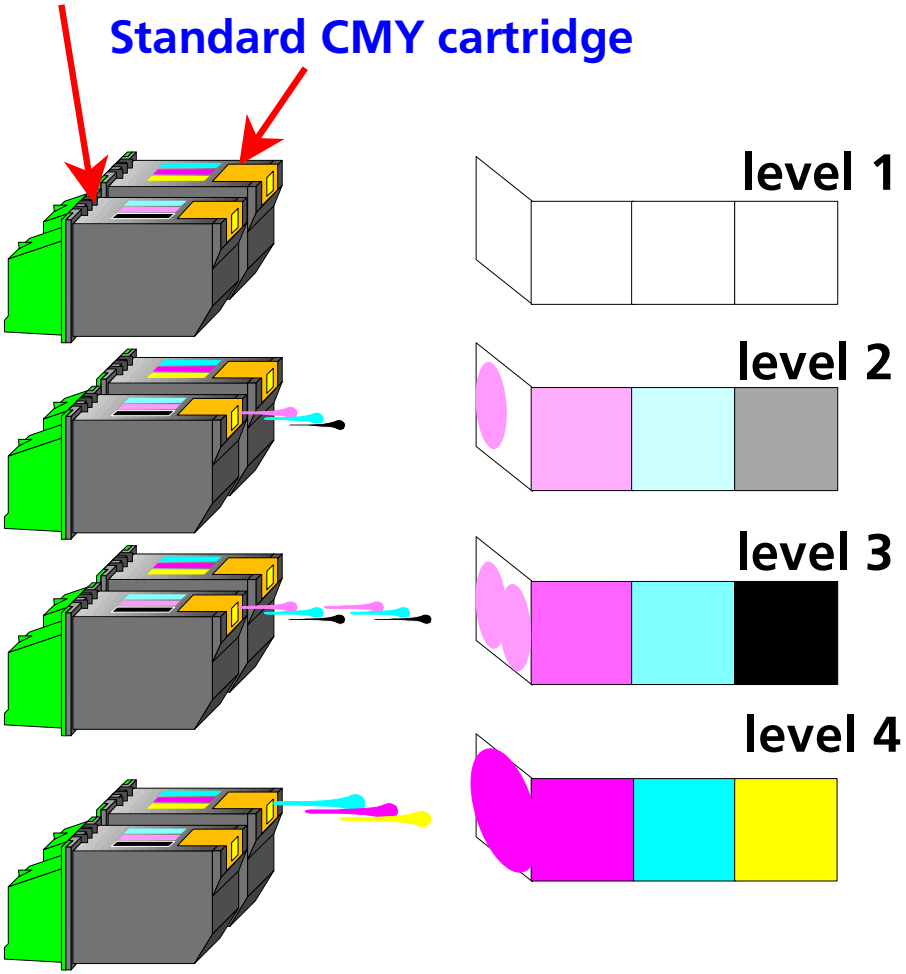
- over a field of pixels, a halftone dither (with error diffusion) renders colors that cannot be printed directly

Photographic Image Quality

HP PhotoREt

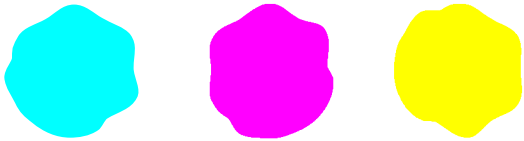
c m K Photo cartridge

Standard CMY cartridge



- 2 cartridge printing system
- multiple dye load with 6 primaries
- small, desaturated c & m drops
- small saturated K drop

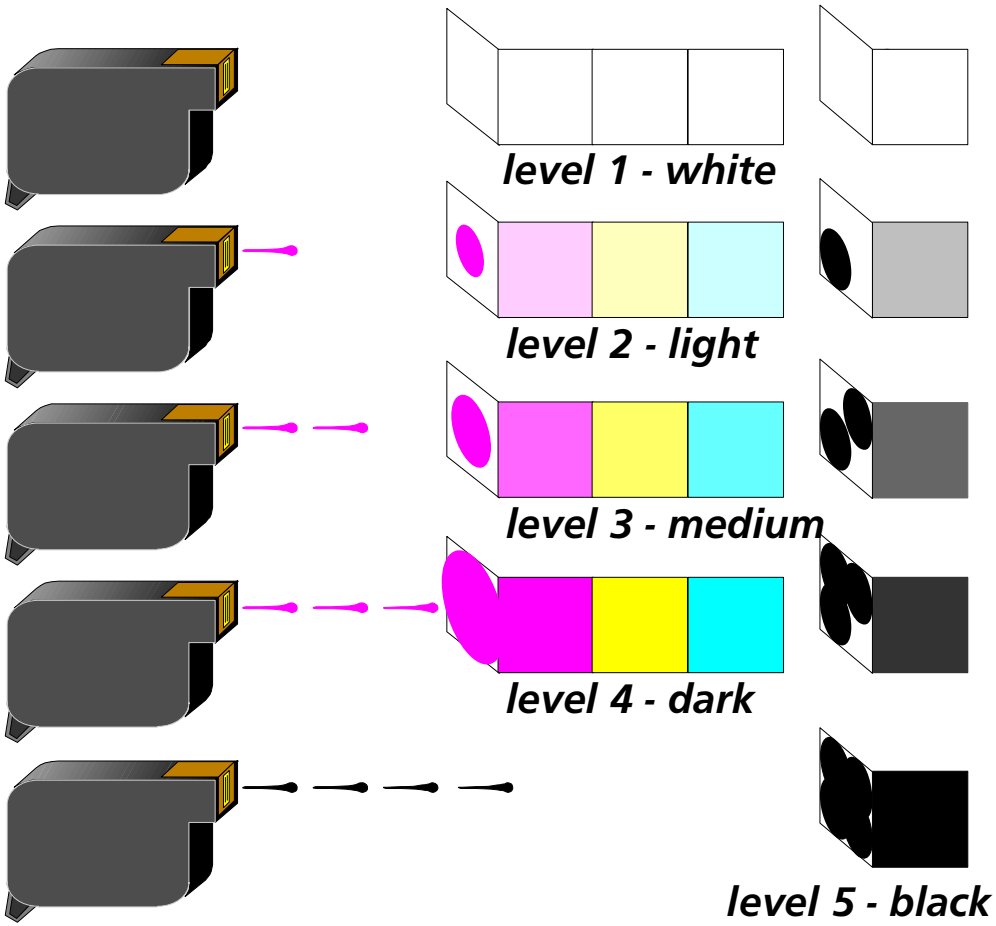
- 0 - 2 c m K drops per pixel
- full saturation CMY printing



- 0 - 1 C M Y drops per pixel
- 10's of colors per pixel

Achieving Higher Image Quality

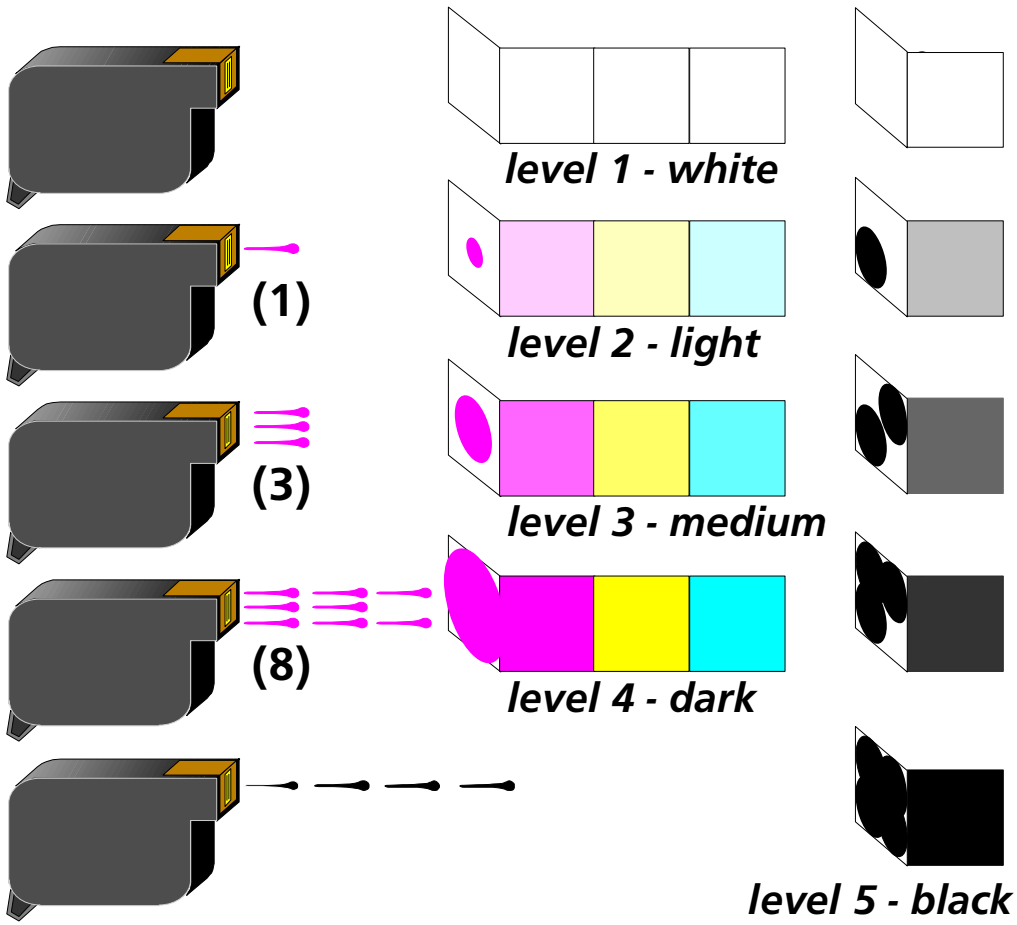
HP Color Resolution Enhancement technology



- implemented in the HP DeskJet 85X, 820, & 870
- 4 color / 2 cartridge printing system
- small, saturated CMY drops
- 0 - 3 CMY drops per pixel
- small, saturated K drop
- 0 - 4 K drops per pixel
- 10's of colors per pixel

Achieving Higher Image Quality

PhotoREt II on the HP DeskJet 720C

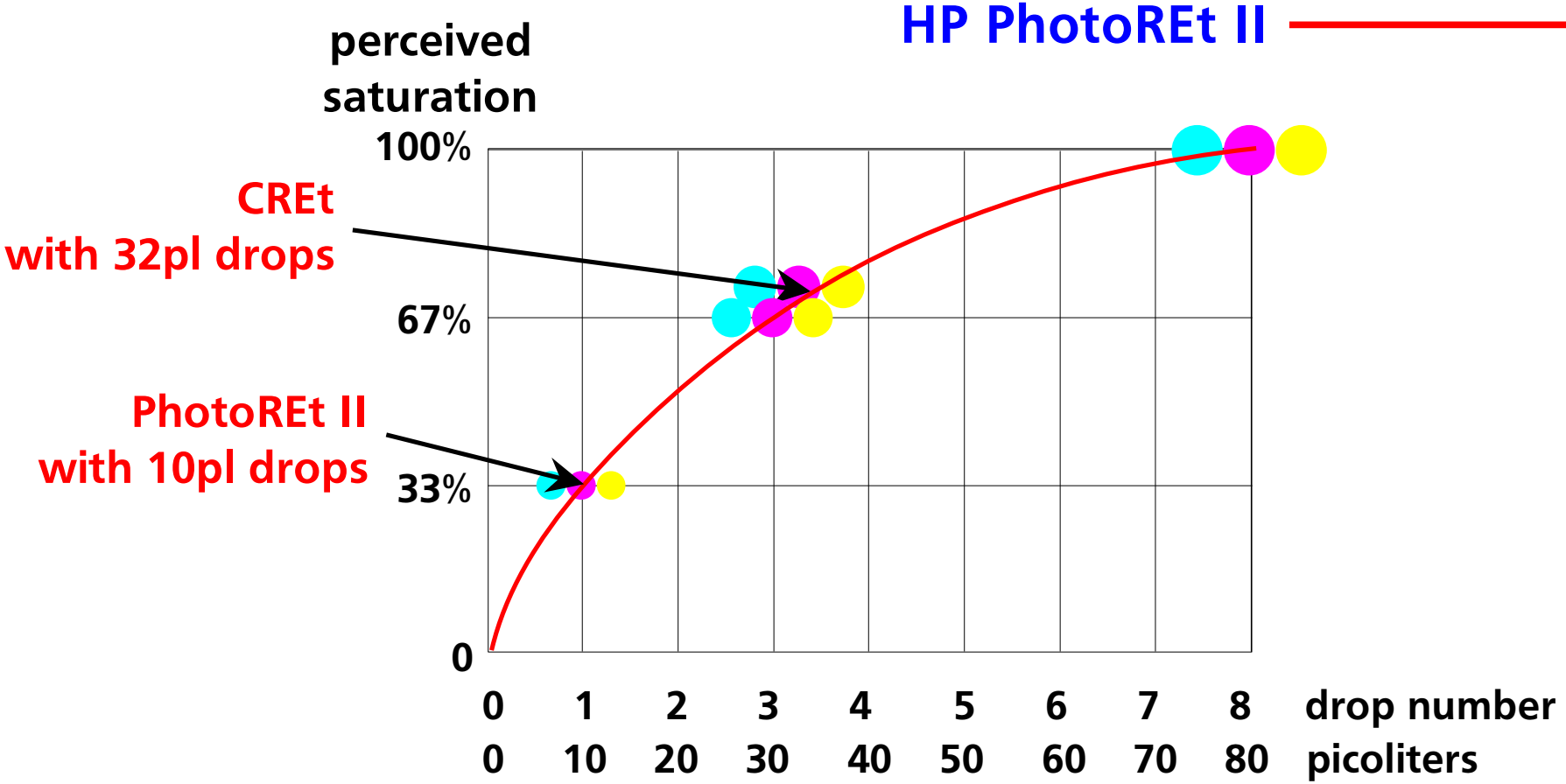


- ✔ improved neutral tones
- ✔ reduced highlight grain
- ✔ > 250 directly printable colors/pixel

- 4-color printing system
- 10pl CMY & 35pl K
- 0, 1, 3, or 8 CMY drops/pixel for up to 16 total drops
- 0 - 4 black drops/pixel

Achieving Higher Image Quality

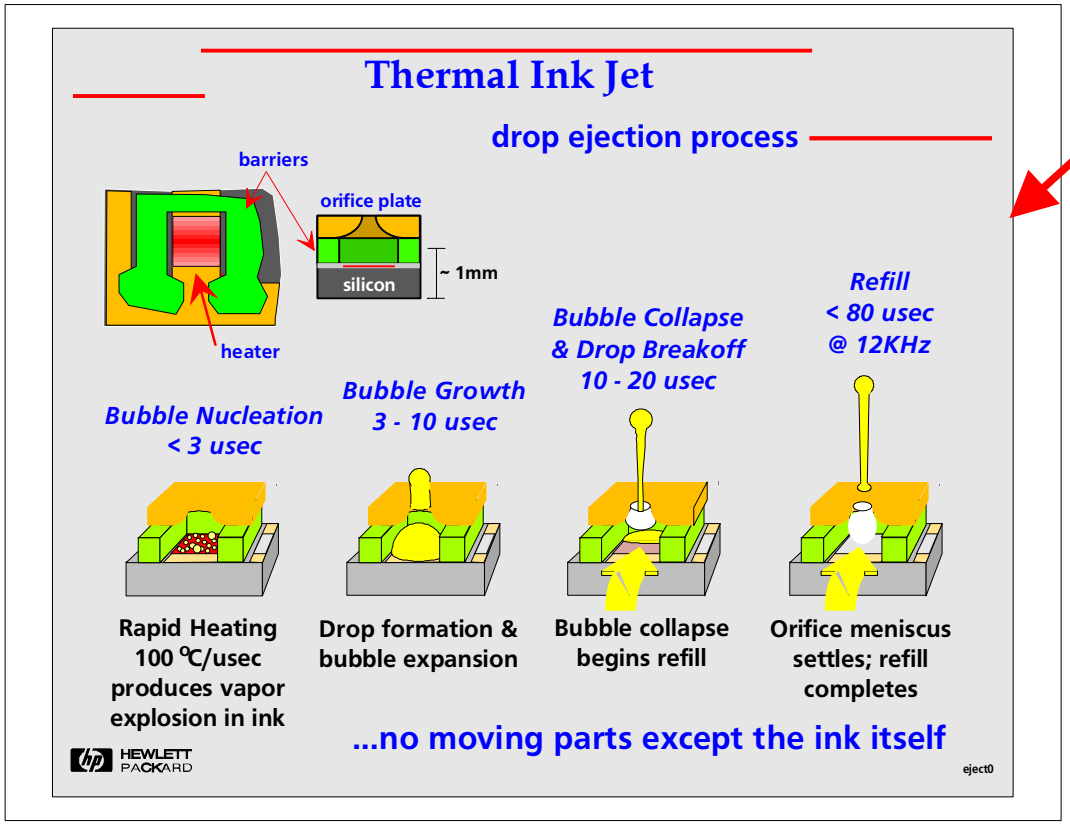
HP PhotoREt II



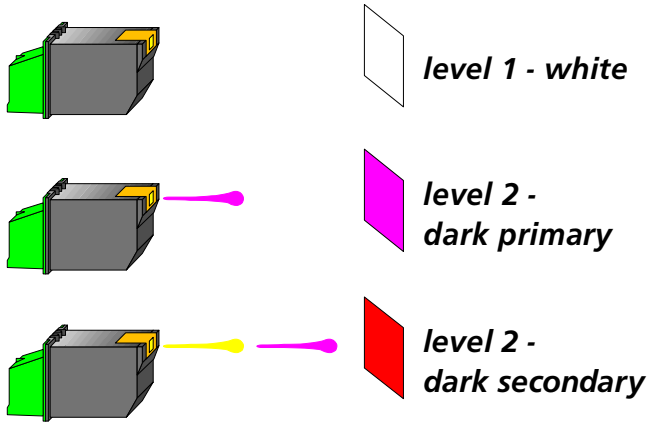
- 10pl drops improve highlights: lighter tones & less-visible smallest dot
- 1-3-8 drops: equal steps in L* for C, M, & Y for more colors per pixel
- 2-bits/color gives high image quality & high throughput
- offers flexibility to choose other image quality/throughput tradeoffs with more bits/color/pixel

Digital Image Quality

dpi & addressibility



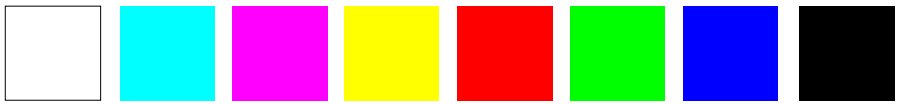
- 8" X 10" print area



page data for binary CMYK at 3 bits/pixel:

- 300dpi = 2.7Mbytes
- 600dpi = 10.8Mbytes
- 1200dpi = 43.2Mbytes
- 1440dpi = 62.2Mbytes

a 3-bit binary coding scheme for 8 colors



000 001 010 100 110 101 011 111

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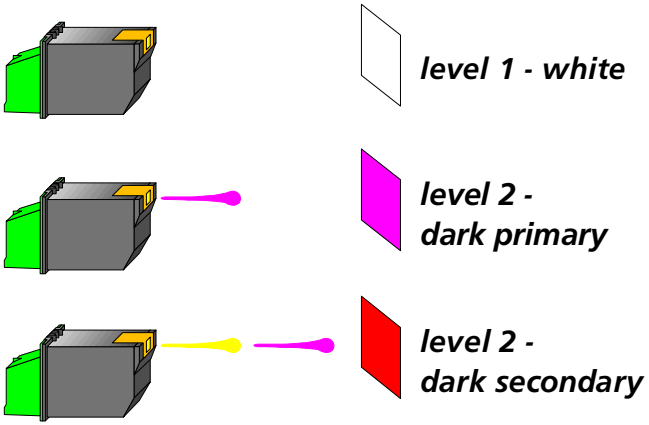
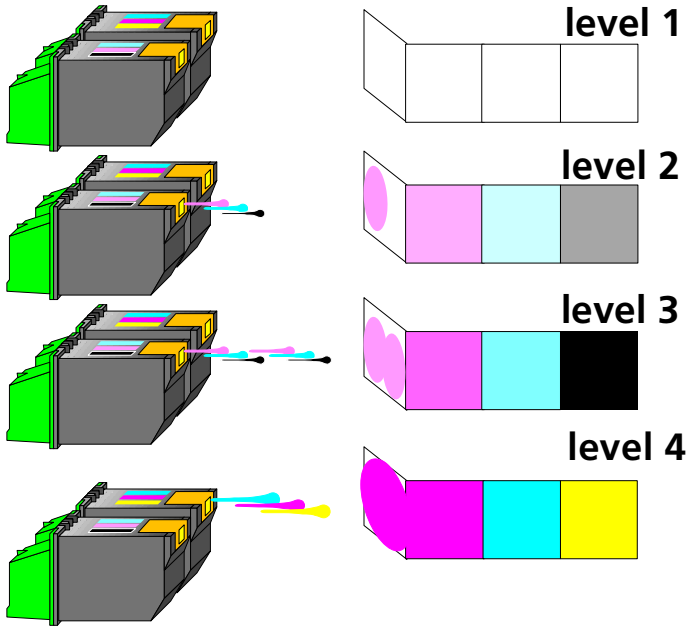
Digital Image Quality

dpi & addressibility



8" X 10" page with binary CMYK at 3bits/pixel:

- 300dpi = 2.7Mbytes
- 600dpi = 10.8Mbytes
- 1200dpi = 43.2Mbytes
- 1440dpi = 62.2Mbytes



states: 3 3 3 2 2 2

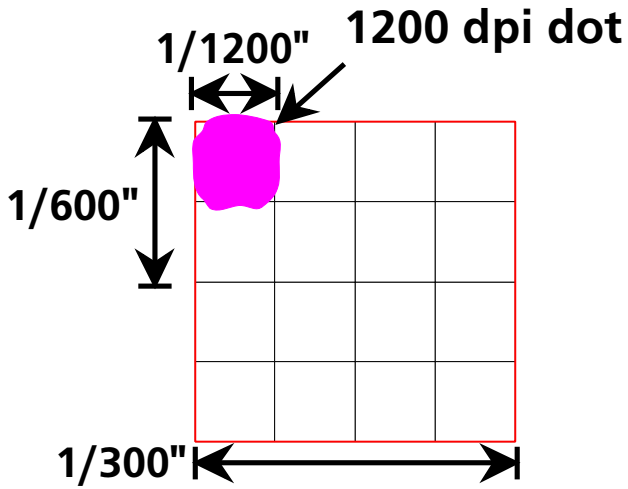
total states: 15 = 4 bits

8" X 10" page with HP PhotoRet cCmMYk at 4 bits/pixel:

- 300dpi = 3.6Mbytes

HP's PhotoREt offers significantly higher image quality with a minor impact on data processing & throughput

Digital Image Quality



dpi & addressibility

Q: A printer places 1200 dpi dots at 1/1200" locations on a page.

What's the printer's "dpi"?

(a) 300 dpi
(b) 600 dpi
(c) 1200 dpi
(d) it depends...
(e) wrong question!

Answer is (e)

- **"dpi" is often used to specify:**
  - pixels/inch in a binary printer
  - the size of an isolated dot made from a single drop of ink
  - the resolution of the printer's scan & paper axis encoders
- **"dpi" specifications can be misleading because**
  - dot size & encoder resolution may not be matched for binary printing
  - multiple drops overlap and combine nonlinearly in halftone pixels
  - positioning resolution IS NOT the number of pixels/inch actually delivered
  - positioning resolution DOES NOT specify the number of printable colors
- **pixels/inch & printable colors/pixel *are* related to image quality**
  - the relationship to image quality is still very complex
  - but, there is no direct relationship between dpi & image quality in halftone printing

(see next slide for proof!)

Digital Image Quality

the effect of HP's halftone pixels

Both images were printed at the same resolution.
Halftone pixels break the link between print quality and "dpi."

4-color binary printing

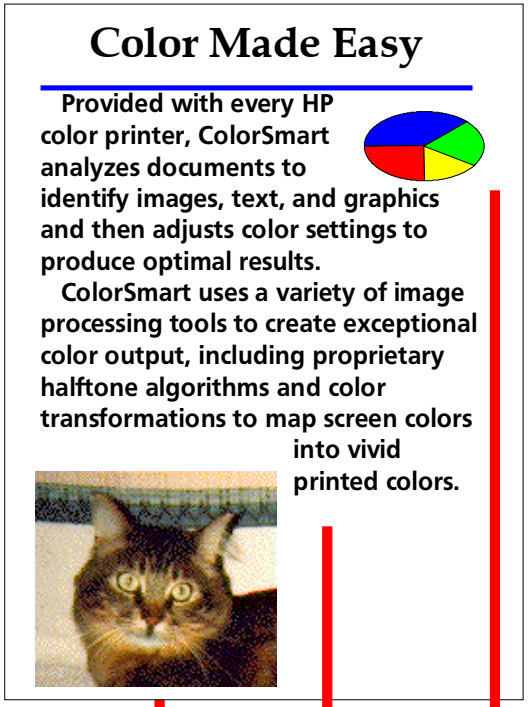
- 1-drop CMYK 2-drop RGB
- 8 colors per pixel
- visible image grain

6-color halftone printing

- multiple drops per pixel
- 10's to 1000's of colors per pixel
- smooth color transitions
- low image grain

ColorSmart II

analyze document in the rasterization process



best settings for images

best settings for text

best settings for business graphics

improved automatic optimal color processing

ColorSmart II builds on ColorSmart's capabilities with

- optimization of images printed from the Internet & multimedia
- consistent color with industry-standard sRGB support
- utilization of Intel MMX technology for 2X improvement in rendering throughput

for each image type, rasterize with optimal

- halftone method
- color matching
- color mapping

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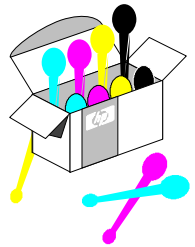
Digital Image Quality

elements of photographic quality

- precision media advance
- small dots
- large number of printable colors per pixel
- optimized halftoning & error diffusion
  - ✔ minimizes image granularity
  - ✔ matched to media
- optimized multipass print modes
  - ✔ high photo-quality throughput
- inks, media, and printer designed together as a complete imaging solution

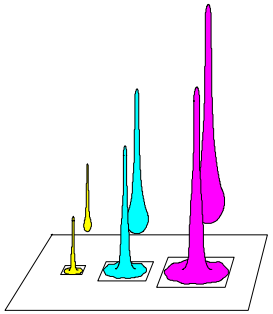
HP's Design Objective

choose the best combination to maximize customer value



ink chemistry

transfer

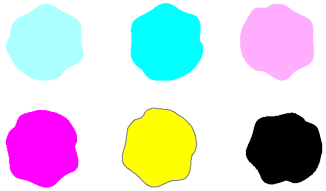


drop volume

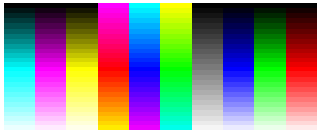
media

Print & Image Quality
Throughput
Reliability
Media Independence

Product Cost
Cost per Page



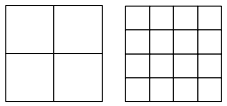
ink colors, color density, dyes & pigments



colors/pixel

HP REALLIFE IMAGING SYSTEM

image processing



resolution

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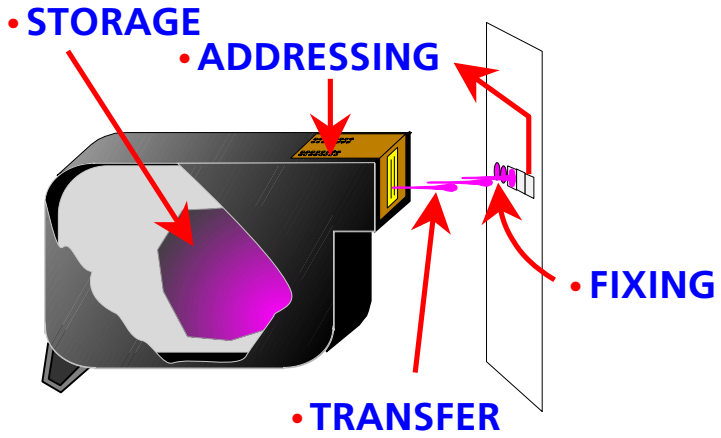
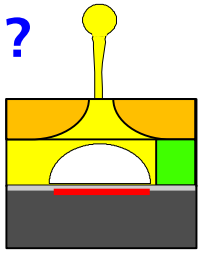
Ink Jet Printing

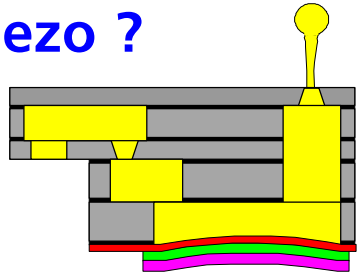


So,... which is *better*?

- TIJ ?



- piezo ?



Transfer* is only one element of the printing process.

What is important to the user is *balanced performance* and the value delivered by the complete printing system:

- image quality & text quality
- *real* throughput
- reliability
- flexibility (print text & images)
- media flexibility (plain & special paper)
- ease of use & connectivity
- initial cost of purchase
- cost of supplies

* HP believes that TIJ provides the superior transfer technology as part of a complete system solution

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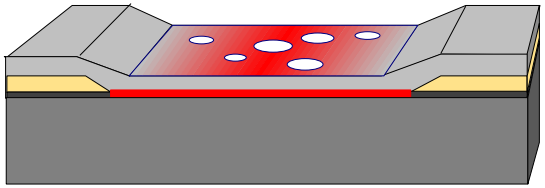
Fun Facts about TIJ

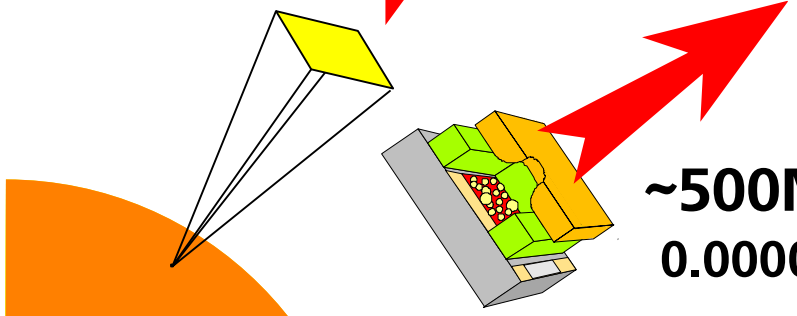
A useful vapor bubble requires heating at 100,000,000 °C/second



~200MW/m^2
5,000,000,003 years

~300,000 TIJ Heaters fit here

1cm



~500MW/m^2
0.000003 seconds

TIJ

Sun