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
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

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

substrate detail (DeskJet 720C)

- polyimide or nickel orifice plate
- photoimageable polymer
- silicon substrate
- thin-film conductor
- heater (thin-film resistor)
- refill channel
- ink
- barrier
- heater
- refill channel
Piezo Inkjet Technology

- 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

Example Piezo Architecture

Piezo Ejection Process

- Deform diaphragm
- Eject drop
- Breakoff & refill
**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

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Type</th>
<th>Devices</th>
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<tbody>
<tr>
<td>1985</td>
<td>4ml</td>
<td>Bladder</td>
<td>ThinkJet</td>
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<tr>
<td>1987</td>
<td>17ml</td>
<td>Foam</td>
<td>DeskJet</td>
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<tr>
<td>1992</td>
<td>40ml</td>
<td>Hi-Capacity</td>
<td>DeskJet 500 &amp; DesignJet 600</td>
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<td>42ml</td>
<td>Spring-Bag</td>
<td>DeskJet 1200C &amp; DesignJet 650C</td>
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<tr>
<td>1997</td>
<td>410ml</td>
<td>Ink Kit</td>
<td>DesignJet 2000CP</td>
</tr>
<tr>
<td>1998</td>
<td></td>
<td>Modular Ink</td>
<td>HP 2000C</td>
</tr>
</tbody>
</table>

#### Storage & Delivery Features

- **Disposable Printheads**
- **High-Capacity Disposable Printheads**
- **Modular Ink Delivery System**
- **DesignJet Replaceable Printheads & Cartridges**
Ink Storage & Delivery
inside a print cartridge

- bag film (2)
- frame
- plates
- ink-level indicator
- side cover (2)
- label
- filter (2)
- seal ball
- spring
- printhead & interconnect assembly
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
- **ThinkJet (1985)**
  - 12 orifices
  - 13 pads
  - 1.2 kHz
  - 92 dpi

- **PaintJet (1987)**
  - 30 orifices
  - 32 pads
  - 3.5 kHz
  - 180 dpi

- **DeskJet (1987)**
  - 50 orifices
  - 56 pads
  - 5 KHz
  - 300 dpi

### Multiplexed Addressing
- **DeskJet 1200C (1993)**
  - 104 orifices
  - 64 X 3 orifices
  - 32 pads
  - 8 kHz
  - 300 dpi

- **DeskJet 850C (1995)**
  - 64 orifices
  - 52 pads
  - 6 kHz
  - 300 dpi

- **DeskJet 850C (1995)**
  - 300 orifices
  - 32 pads
  - 8 kHz
  - 600 dpi

- **HP 2000C (1998)**
  - 304 orifices
  - 17 pads
  - 12 kHz
  - 600 dpi

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**ThinkJet** (1985)  
**PaintJet** (1987)  
**DeskJet** (1987)  
**DeskJet 1200C** (1993)  
**DeskJet 850C** (1995)  
**DeskJet 850C** (1995)  
Addressing

integrated electronics & orifice density

- 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

- Transfer
- Photographic Image Quality
- Best Text Quality
- Maintain & Enhance Throughput
- nucleation processes
- consistent drop volume & placement
- advances in TIJ materials & processes
- higher drop rates
- more orifices
- smaller features
- lower drop volume
- smaller dots
- halftone pixels

Best Text Quality
Photographic Image Quality

smaller dots
halftone pixels
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!

...no moving parts except the ink itself
Elements of Bubble Nucleation

understanding nucleation is necessary to deliver consistency in drop ejection

Liquid Composition
Liquid Density
Liquid Viscosity
Surface Tension

Temperature Distribution
Vapor Density
Vapor Enthalpy
Superheat Limit
Surface Roughness

Thermal Diffusivity
Heating Rate

Static Bubbles

• HP supports fundamental research on the physics of bubble nucleation

Near the Institute of Thermophysics
Novosibirsk, Siberia, Russia
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, and 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
• 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

• 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
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
  - Number of orifices
  - Drop frequency
  - Resolution
  - Number of 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.

<table>
<thead>
<tr>
<th>orifices</th>
<th>dpi</th>
<th>KHz</th>
<th>passes</th>
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<tbody>
<tr>
<td>3</td>
<td>8</td>
<td>300</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
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<tr>
<td>3</td>
<td>4</td>
<td>300</td>
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<tr>
<td>3</td>
<td>4</td>
<td>600</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>600</td>
<td>2</td>
</tr>
</tbody>
</table>
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

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

- **spread**
- **penetration**
- **evaporation**
- **chemical reaction**
- **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
- spot-size, optical density, strike-through
- feathering color bleed
Fixing

Paper is a complex chemical system

Microscopic view of paper surface

- **Filler** (acidic) clay, TiO₂, silica; (basic) CaCO₃
  - Increases stiffness
  - Affects porosity
  - Absorbs water
  - Increases brightness & opacity

- **Sizing** Starches, PVA
  - Improves strength
  - Affects wettability
  - Holds colorant at surface
  - Improves smoothness

- 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

Cellulose fiber

Strength

~100 μm
Fixing

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

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

- dull surface color
- uncontrolled dot spread & penetration*
- whiter surface
- controlled dot spread & penetration

*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-insoluble 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

- 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

- integrated control logic & drivers
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

Ink
- Spot size & saturation
- Optical density
- Color bleed
- Feathering
- Edge sharpness

Media
- Surface gloss
- Uniformity
- Bright & white
- Opacity
- Flexibility/stiffness

- Color gamut
- Optical density
- Drytime
- Fastness
- Curl

Media handling & reliability
Media recognition
Environmental performance
Photographic Image Quality

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 cyan
- Too blue
- Too green
- Too yellow
- Too red
- 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

- **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

- **Resolving Power: lines/mm**
- **RMS Granularity**

unsharp

grainer

image of candy apples
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**
  - addressable 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

Dye spot is a color filter
White substrate
Incident light
Reflected light

C + M = Blue
C + Y = Green
M + Y = Red

400 500 600 700

100%
50%
0%

Yellow
Magenta
Cyan

Transmission

Transmission

Transmission

Transmission

400 500 600 700

Wavelength (nm)
Basic Color Science

chromaticity diagram: a coordinate space for describing colors

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

gamut of the NTSC television standard

highly saturated colors outside the tri-color gamut cannot be printed

gamut of real colors

gamut of the block dyes
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)

addressable 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

- poor dot placement

- missing or weak dots

- paper feed errors

- ragged edges

- uneven edges & lines

- banding

- banding
Insuring Image Quality

Multipass printing hides artifacts

Neighbor dots are printed by different orifices on different passes.

Scrambling the dots...

Pass 1

Pass 2

Pass 3

Pass 4

Advance media

Advance media

Advance media

Advance media
• **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
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

<table>
<thead>
<tr>
<th>Graininess Level</th>
<th>Code</th>
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<tr>
<td>45 - 55</td>
<td>Very coarse</td>
</tr>
<tr>
<td>33 - 42</td>
<td>Coarse</td>
</tr>
<tr>
<td>26 - 30</td>
<td>Moderately coarse</td>
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<tr>
<td>21 - 24</td>
<td>Medium</td>
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<tr>
<td>16 - 20</td>
<td>Fine</td>
</tr>
<tr>
<td>11 - 15</td>
<td>Very fine</td>
</tr>
<tr>
<td>6 - 10</td>
<td>Extremely fine</td>
</tr>
<tr>
<td>&lt;5</td>
<td>Microfine</td>
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</tbody>
</table>

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

Human Visual Response

The human eye is less sensitive to high spatial frequencies.

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

The difference between patches is how the dots are grouped.
Granularity

measured HPGS performance

Kodak Granularity Scale

- off-scale
- Very coarse
- Coarse
- Moderately coarse
- Medium
- Fine
- Very fine
- Extremely fine
- Microfine

HP Granularity Scale (HPGS)

- ISO 100 film
- 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"

✔ doubling "dpi" reduces granularity by half in a binary printer
✔ how dots are arranged can be more important to granularity than "dpi"

max.
average

binary, white noise
binary, blue noise

- 1200 dpi
- 600 dpi
- 2400 dpi

✔ 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 media
print modes
Digital Color & Image Science
HP TIJ Technology
HP color rendering technologies
REt, C-REt, Photo-REt,
PhotoREt II
ColorSmart
user interface
printing architecture
Digital Image Quality

binary printing

- **level 1 - white**
- **level 2 - dark primary**
- **level 2 - dark secondary**

- 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**

\[ N \text{ dpi} \]

- **pixel**

\[ \frac{N}{2} \text{ dpi} \]

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

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

- *a 2X2 superpixel*
  - more apparent colors
  - at half the "dpi"
Digital Image Quality

superpixels

• 2X2 superpixel colors

\[ N \text{ dpi} \]

\[ \frac{N}{2} \text{ dpi} \]

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

- Level 1 - white
- Level 2 - light
- Level 3 - medium
- Level 4 - dark
- Level 5 - black

- 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

✔ improved neutral tones
✔ reduced highlight grain
✔ > 250 directly printable colors/pixel
Achieving Higher Image Quality

- 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

Thermal Ink Jet

- 8" X 10" print area
- Thermal Ink Jet
- ...no moving parts except the ink itself

a 3-bit binary coding scheme for 8 colors

- 000
- 001
- 010
- 100
- 110
- 101
- 011
- 111

page data for binary CMYK at 3 bits/pixel:
- 300dpi = 2.7Mbytes
- 600dpi = 10.8Mbytes
- 1200dpi = 43.2Mbytes
- 1440dpi = 62.2Mbytes
Digital Image Quality

dpi & addressibility

8" X 10" page with binary CMYK at 3 bits/pixel:
• 300dpi = 2.7Mbytes
• 600dpi = 10.8Mbytes
• 1200dpi = 43.2Mbytes
• 1440dpi = 62.2Mbytes

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
Q: A printer places 1200 dpi dots at 1/1200" locations on a page. What's the printer's "dpi"?
(a) 300 dpi  (d) it depends...
(b) 600 dpi  (e) wrong question!
(c) 1200 dpi

"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 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**

**Color Made Easy**

Provided with every HP color printer, ColorSmart analyzes documents to identify images, text, and graphics and then adjusts color settings to produce optimal results. ColorSmart uses a variety of image processing tools to create exceptional color output, including proprietary halftone algorithms and color transformations to map screen colors into vivid printed colors.

- **best settings for text**
- **best settings for images**
- **best settings for business graphics**

*for each image type, rasterize with optimal halftone method color matching color mapping*
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
- Media
- Colors/pixel
- Image processing
- Transfer
- Drop volume

Print & Image Quality
Throughput
Reliability
Media Independence
Product Cost
Cost per Page

Ink colors, color density, dyes & pigments
Resolution
Ink Jet Printing

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.
Fun Facts about TIJ

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

- ~200MW/m² for 5,000,000,003 years
- ~500MW/m² for 0.000003 seconds
- ~300,000 TIJ Heaters fit here