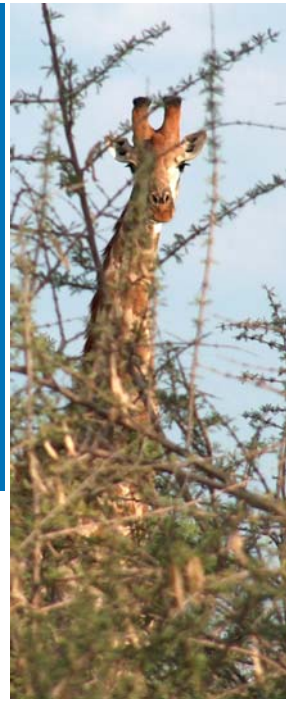
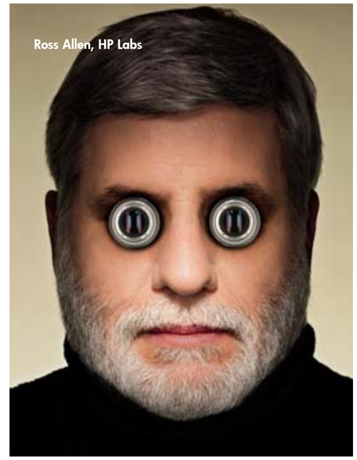
The Future of Digital Photography

Macworld '06

Dr. Ross R. Allen,
HP Imaging and Printing Group



How I got started as a futurist…



HP WW "Inventors" Campaign
2000 - 2001

Your eyes never take a bad picture.

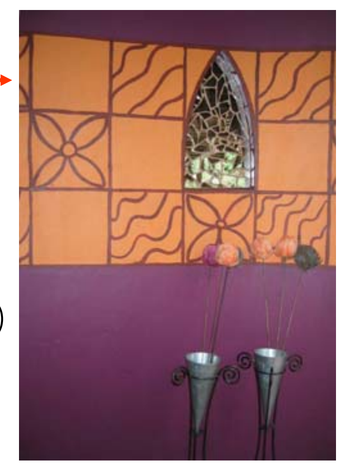
This simple fact is the inspiration behind the next generation digital cameras Ross is inventing.

Powered by image processing chips designed to work like the human eye, they automatically balance colors and compensate for poor lighting conditions.

So when it comes to your pictures at least, what you see is what you get.

to predict the future
start with understanding
how things are

Digital photography



- Image quality is determined by
  - ✓ optical design
  - ✓ focus & exposure accuracy
  - ✓ image sensor
    - dynamic range, noise, sharpness
  - ✓ electronics (analog noise & digital bit-depth)
  - ✓ image processing
    - tone reproduction algorithms
    - white balance algorithms
    - compression algorithms
  - ✓ output device dynamic range & resolution
  - ✓ printer technology, color maps, ink & paper

Digital photography:
elements of success (I)

- Economics
  - Highly-competitive pricing of cameras and inkjet photo printers
  - Capture is virtually free
  - Inkjet prints within ~2X the cost of a traditional 4” X 6”
  - Only “good” photos are printed
  - Reprints and enlargements made at cost of materials
- Image quality
  - More good photos, especially under difficult lighting conditions
  - Wide exposure latitude (at least potentially)
  - Automatic and accurate white balance
  - Adaptive tone reproduction: “seeing like the eye”

Digital photography:
elements of success (II)

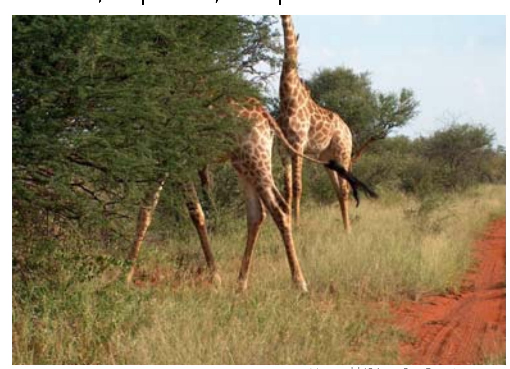
- Usability
  - Novel and compact camera designs
    - no constraints from film transport
  - Large number of exposures on-board
    - Ex.: 512Mb / 5Mp = 300 images

  - Images are easy to archive, organize, and retrieve
  - Photos can be immediately viewed/edited/shared
  - Image life unlimited by photo chemistry
  - Multimedia (sound and video)
  - Print any size, anytime, any number
  - Special effects

seeing

Seeing like a camera

- The world - in millisecond glimpses
  - I traveled 22,400 miles and spent 3 days on safari
    - I was awake 64,800 seconds
    - My camera recorded 342 milliseconds
  - Focus, exposure, composition fix a moment in time



This image is odd because people do n’t sees things this way.

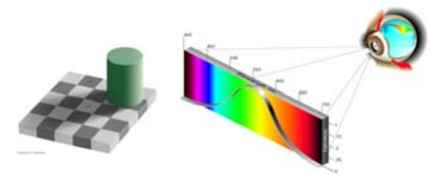
But,… the image has excellent sharpness, exposure, color, and tone reproduction!

Seeing like the eye

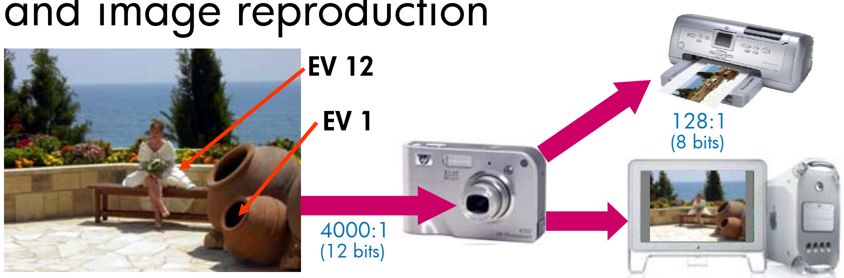
- What does the eye/brain really see?
  - "Your eyes never take a bad picture"
  - A continuous image in space and time
    - tone and contrast maintained throughout the scene from highlights to shadows
    - no image grain or "jaggies"
  - Adaptive white balance and contrast
  - Adaptive sharpness (foveal vision and selective focus)
  - Edges and lines: especially vertical and horizontal
  - Things that move
  - What it expects to see…

Seeing like the eye

- "Seeing" is done by the human visual system: the eye and brain together
- Goal of an imaging system:
  - produce a pleasing rendering of a scene
  - mimic the perception of a human observer
- Imaging systems must consider:
  - the physical limits in scene capture and image reproduction
  - the complexity of human vision
    - wide dynamic range
    - selective focus
    - edge detection
    - color and luminance sensitivity
    - contrast perception
    - white point adaptation



Physical limits in scene capture and image reproduction

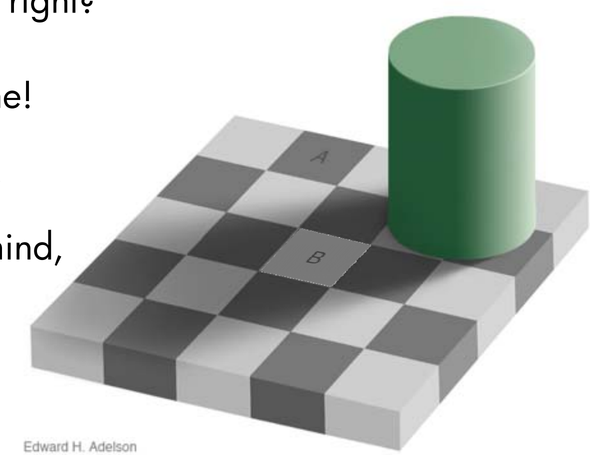


- brightness ranges in natural scenes between 10:1 to 4000:1
- complex and varying illuminants
  - daylight (highly variable)
  - tungsten (various)
  - fluorescent (various)
  - reflected light from colored surfaces
- moving and unpredictable subjects
  - animals, children, sports, national political figures
- sensor has limited dynamic range
- sensor/optics have fixed spatial resolution
- entire image must be sharp
- dynamic range of monitors and reflective prints: ~ 128:1 (8-bits)
- many different viewing conditions
- metamerism in capture and display
- camera, monitor, and print: different color systems & gamuts

Complexity of Human Vision
Example: contrast adaptation

- Squares A and B are different grays, right?
- No, they are exactly the same!
- Can you really trust your eyes?
- "It's all in the mind, you know."

  - John Lennon



Complexity of Human Vision
Example: contrast perception

- This example demonstrates that visual perception of an object depends on the luminosity of its surroundings

The camera saw this

You saw this

- Models of human vision describe these phenomena
  - these models form the basis for image processing algorithms that mimic the response of the human eye and brain
- HP Adaptive Lighting
  - an algorithm designed to render an image on a display or print that evokes the scene you saw

Seeing like the eye
scene relighting

- HP Adaptive Lighting Technology has its basis in "Retinex" (Retina + cortex = eye + brain)
  - Retinex was developed by Edwin Land
    - Polariod's 1983 patent on Retinex has expired
- Scene relighting processes, like Retinex and HP Adaptive Lighting Technology, create a contrast modulation mask
  - large contrast differences in the scene are identified
  - contrast ratios between scene areas are modified *by considering the entire image* (impossible with film!)

original scene

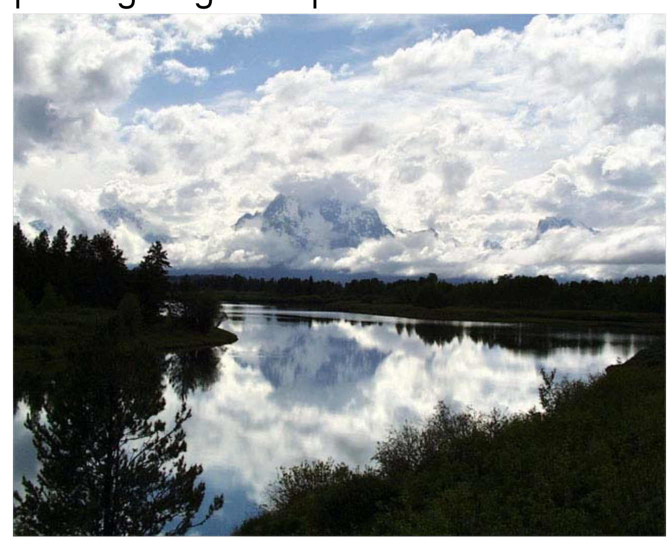
scene after HP Adaptive Lighting

Seeing like the eye
scene relighting

- HP image scientists improved on Retinex by developing a ratio modification operator*
  - small contrast ratios are preserved
    - ex.: within the clouds
  - large contrast ratios are compressed
    - ex.: between the foreground and the sky

* R. Sobol, "Improving the Retinex algorithm for rendering wide dynamic range photographs", Journal of Electronic Imaging 13(1),65–74 (January2004)

Seeing like the eye
HP Adaptive lighting example

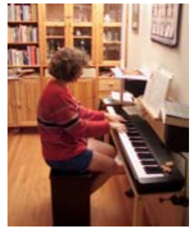


Complexity of Human Vision
Example: white point adaptation

- The human visual system automatically adapts to keep "white" objects "white" under different illuminants
  - this requires "white balance" of the image to give a pleasing result

This is accurate scene color under tungsten light

This is what a human observer saw and expects to see in a reproduction



- In film cameras, filters and films ("daylight" or "tungsten") can provide limited white balance compensation
- Digital cameras determine the illuminant and provide automatic white balance under complex conditions

Seeing like the eye
Automatic White Balance

- Many different kinds of natural and artificial light:
  - sunrise / sunset
  - overcast sky
  - full sun
  - shade
  - incandescent
  - halogen incandescent
  - fluorescent (many kinds)
  - reflected light from colored surfaces
  - …

- Digital cameras use a variety of methods to identify the illuminant and correct the white balance of each image
  - For example, HP uses up to six different methods to assure reliable identification of the light source

Seeing not like a camera
things that cameras do

- An image sensor/lens system has aberrations that vary with lens aperture ("f/") and focal length
  - Vignetting: light falls off from the optical axis
    - common to both film and digital cameras
    - particularly visible in wide-angle photos taken at wide aperture
  - Color Shading: color shifts occur at edges of the frame
    - dependent on incidence angle of light on color filter array
- These effects can be eliminated in digital photography by camera calibration and image processing
  - compensation can be optimized *for every combination of f/ and zoom*
  - compensation can be applied *to every image* and *in the camera*

pixels

Dynamic Range and Noise

- A sensor with high Dynamic Range ("DR")
  - captures detail in scene highlights and shadows
    - important to support advanced tone reproduction algorithms
- DR is the ratio of maximum to minimum recordable light intensity
- DR in natural scenes can be more than 4000:1 (12 bits)
- Consumer negative film offers DR ~ 10 bits
- Many consumer digital cameras have 10- and 12-bit ADCs and algorithms, but sensors have DR ~ 8 bits

Dynamic Range and Noise

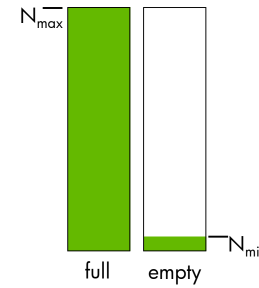
- The DR of an electronic image sensor is the ratio N_{max}/N_{min}:

  N_{max} = photoelectrons at saturation
  typically 10's of 1000's of photoelectrons

  N_{min} = noise floor
  typically measured in 10's of photoelectrons

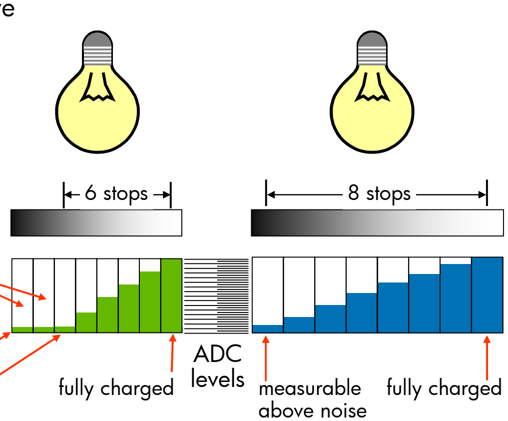
- N_{max} and N_{min} depend upon pixel design, sensor technology (CCD or CMOS), and pixel area

pixel analogy:
a tank that holds photoelectrons



Dynamic Range

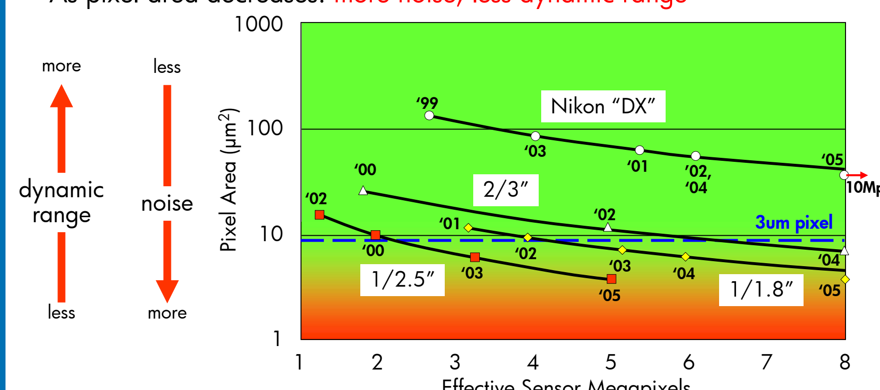
- In general, smaller pixels give lower dynamic range and have higher noise
- Expose "small" and "large" pixels to saturate at the brightest part of a scene (using a density ramp)



- Adding more ADC levels doesn't give more dynamic range, just better precision

Consumer digital cameras
pixel area vs. sensor megapixels

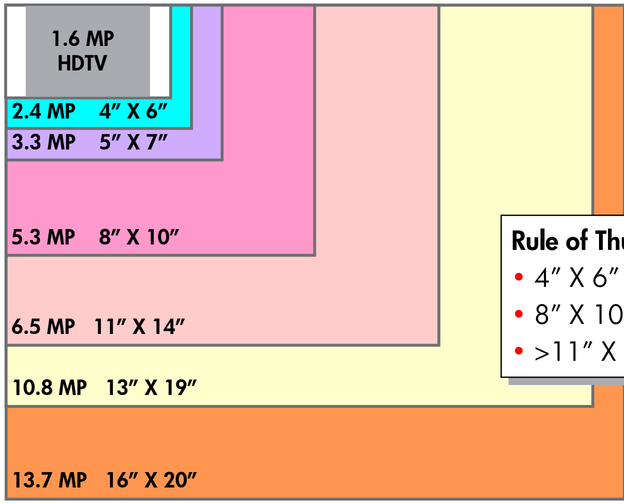
- More megapixels: more sharpness (within optical limits), but at the expense of other image attributes: noise and dynamic range
- The current trend is to offer more pixels in the same sensor area
- As pixel area decreases: more noise, less dynamic range



source: www.dpreview.com

Can you ever have enough pixels?

Yes. How many do you need?



relative print sizes

image sensor aspect ratio = 4:3

Rule of Thumb for Prints:
- 4" X 6" : ppi = ~ 300
- 8" X 10": ppi = ~ 250
- >11" X 14": ppi = ~ 200

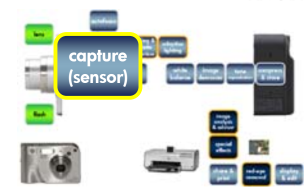
pipe dreams

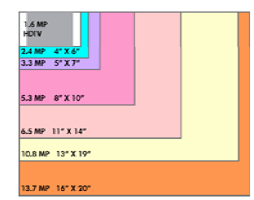
Digital Imaging Pipeline

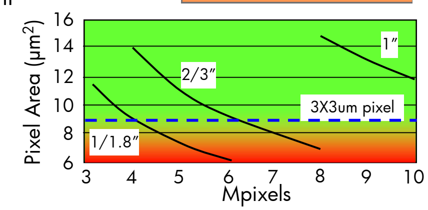
each element offers an opportunity to improve image quality and provide more photographic functionality

Some predictions*

- Continuing the Megapixel race will further compromise "consumer" image quality
  - Where *could* it end?
    Rationally,… a case can be made for:
    - 6Mp for point and shoot compacts
      - makes a sharp 11" X 14" print
    - 10Mp for prosumer SLRs
      - makes a sharp 13" X 19" print
  - Low noise, high dynamic range sensors for 6 and 10Mp will need larger ICs
    - 6Mp on 2/3" (or bigger)
    - 10Mp on 1" (or bigger)

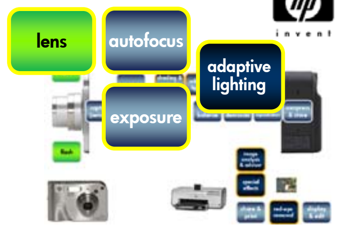






* May 2004

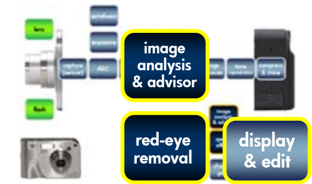
Some predictions*



- Improved image capture
  - lenses
    - very compact zoom lenses 2005
    - silent: zoom during video capture
  - better available light photography
    - faster lenses
    - lower image noise
    - higher sensor dynamic range
    - advanced tone reproduction algorithms
    - active image stabilization 2005
  - higher quality audio recording
    - directional microphone(s) with ambient noise suppression
  - image packets and brackets
    - manual and auto selection among several shots

* May 2004

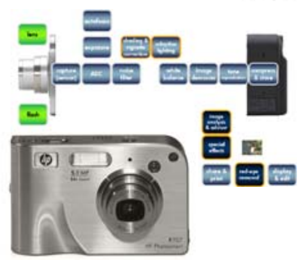
Some predictions*



- Improved on-camera displays
  - bigger and brighter
  - full-frame, bright optical viewfinders
- More in-camera editing features
  - camera's computing resources optimize photos
    - robust automatic Red-Eye Removal 2005
    - panorama stitching
- Intelligent photography
  - real-time capture analysis warns and fixes problems:
    - inappropriate or "left-over" manual settings
      - camera takes a backup photo in full auto mode
    - sound quality analysis
    - face recognition and analysis

* May 2004

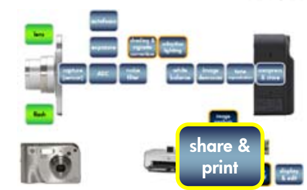
Some predictions*



- Design improvements
  - more stylish
  - more ergonomic
    - especially important for compacts
  - improved mechanical robustness for the camera you take everywhere
    - fewer electrical connectors
    - stronger moving parts (hatches, doors)
    - better moisture & dust sealing
  - improved thermal management
    - reduced power consumption
      - reduces sensor noise
      - eliminates warm surfaces

* May 2004

Some predictions*

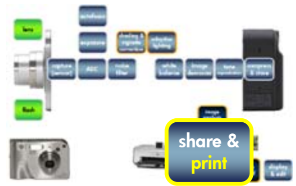


- Sharing
  - cameras and printers work better together
  - wireless image transfer
    - camera – camera
    - camera – printer
    - camera – on-line photo finishing services
  - more options for portable image storage and backup
  - advances in "intelligent" photo albums
    - automated story-telling based on
      - image recognition
      - face recognition 2005
      - time & location data

* May 2004

Some predictions*

- Printing
  - photo printers will be inkjet
  - intense price/feature competition
  - 2005 image quality "specs" satisfy "all reasonable expectations"
    - 4X6" prints in 15 seconds
    - image grain: "invisible"
    - fade resistance > 200 years
    - 8- and 10-ink photo printing
      - easier consumables management
    - prints are smear- and waterfast
  - 2005 competition migrates from image quality to usability and throughput
  - better direct-to-print use models



* May 2004

Some predictions*

- Images
  - super panorama
    - consistent exposure and focus
    - more accurate image-to-image alignment
    - 360° X 90° with camera-assisted pointing and stitching
  - document capture
    - camera-assisted alignment
    - automatic distortion and illumination compensation
    - sharpening and contrast optimized for documents
  - 2005 convergence of still and digital video cameras
    - quality ~ miniDV with > 1 hour video capacity
    - high-capacity (100Gb) WORM memory card

* May 2004

Some predictions

- Images
  - Still/video convergence motivates more use of mini "moving pictures," capturing an essence missing from stills

- how will these moving pictures be displayed?
- how will new kinds of images affect printing and display technologies?

A new direction

- What if image quality is good enough?
- How are cameras used?
  - Photography is a deliberate process
  - A photographer
    - <u>decides</u> to take a photograph or a video
    - <u>readies</u> the camera for the photo
    - <u>chooses what</u> to photograph
    - <u>decides how</u> to compose the image
    - <u>decides when</u> to capture the image
      - oh yeah, and there's that shutter lag…
  - This process works for formal photography
  - Photographic deliberation gets in the way of capturing memories

"Never work with children or animals"

- W. C. Fields

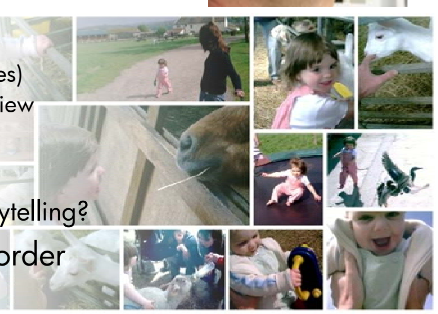
Some more predictions
along a different vector

- Cameras disappear
  - just like "computers", most cameras will lose their separate identity
    - ubiquitous, inexpensive, embedded
    - offers opportunities for radical changes in the way cameras are used

- Wearable cameras offer a new direction for casual photography

Some predictions
back to "seeing like the eye"

- Unconscious image capture
  - be a participant, not an observer
  - always-on: a richer record of events
    - good bits buried in lot of really boring stuff
  - automatic and manual selection of
    - capture mode: video, still, panorama
  - capture driven by
    - head/body motion and gestures
    - events (past 30 sec + next 5 minutes)
    - learning from post-capture user review
- Challenges
  - how to optimize real-time capture?
  - how to analyze and automate storytelling?
- A path to a personal visual recorder that sees the way you do

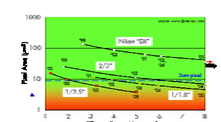


Summary

- Human vision involves a complex interaction between the eyes and the brain
  - it's actually the brain that "sees"

- Cameras don't see like the eye, but image processing advances deliver images that look more like what you saw

- The megapixel race is offering sharpness at the expense of image noise - curb your enthusiasm for more & more pixels!



- There are many exciting opportunities ahead to improve and develop (digital) photography in traditional and novel directions