

# Why is sports photography hard?

(and what we can do about it)

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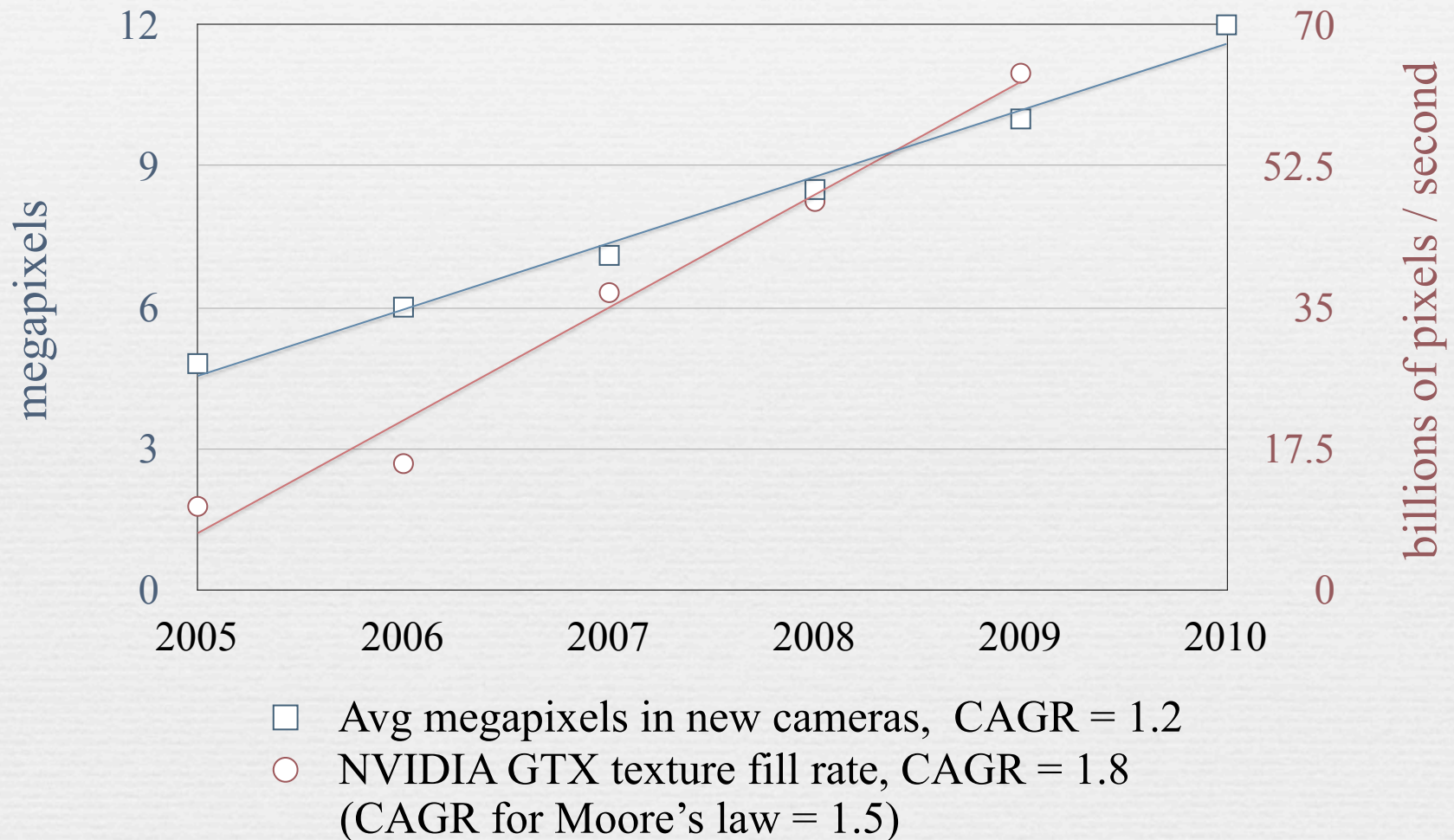


Marc Levoy  
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Sports photography operates  
at the edge of current camera  
performance and portability.

We might be able to help,  
but it ain't gonna be easy.

# Premise underlying computational photography: *computing power in cameras is rising faster than resolution*



◆ this “headroom” permits more computation per image

# What this talk is about

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- ◆ sports, especially team sports on fields or in arenas
  - ◆ what is challenging about photographing these sports
  - ◆ the affordances and limitations of today's cameras
  - ◆ opportunities for computational photography
- 
- ◆ apprenticed myself to professional sports photographers for a year at Stanford



# What this talk is not about

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- ◆ technical photography
  - e.g. finish-line slit photographs
- ◆ sports photography using point-and-shoot cameras
  - shutter lag makes it almost impossible
- ◆ non-sports action photography, family & recreation
  - harder to generalize about
- ◆ sports videography
  - except to the extent video could help still photography
- ◆ making every shot count
  - that's impossible; goal is to improve from 1 in 100 to 10 in 100
- ◆ once-in-a-lifetime shots
  - you can't plan for them

# Once-in-a-lifetime shots

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(Jerry Lodriguss)



(Dave Black)



◆ and extreme sports

# Why is sports photography hard?

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- ◆ sports move fast
- ◆ fields are big, arenas are dark
  - you don't control the subject distance or the lighting
- ◆ you barely control the composition
  - long lenses compress the perspective
  - put yourself in the right place at the right time
  - know the game, know the players
- ◆ spray and pray
  - take 2000 pictures in a typical game
- ◆ post-process
  - big disk, fast computer, good workflow
  - mine is Lightroom + Photoshop



# Lightroom



- ◆ browsing, ratings, color labels, syncing across computers, etc.
- ◆ common tools are well done: white balance, exposure, touchups



# Ways of handling fast motion

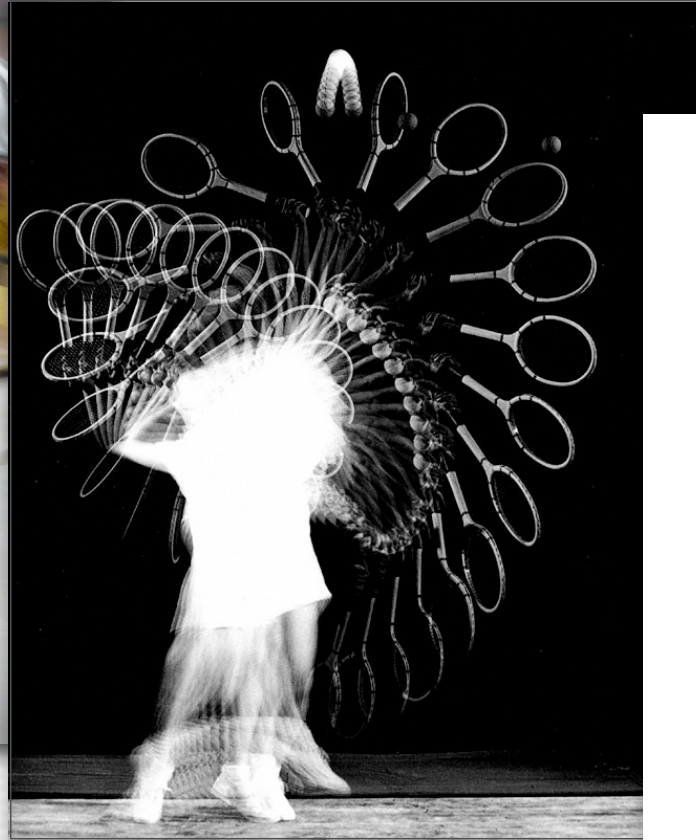
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(David Laird)



panning

(Harold Edgerton)



strobing

(Lois Greenfield)



freezing

- ◆ for most sports, “freezing” is the most interesting view
  - it’s also the easiest to capture reliably

# Photographic variables

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- ◆ shutter speed
- ◆ ISO
- ◆ aperture
- ◆ focal length
- ◆ megapixels
- ◆ pixel size
- ◆ camera body
- ◆ metering/focusing modes
- ◆ noise
- ◆ SNR
- ◆ frame rate
- ◆ burst size
- ◆ focus
- ◆ depth of field
- ◆ autofocusing

# Shutter speed

motion blur

Women's  
volleyball

(Canon 1DIII,  
1/800 second)



◆ work out shutter speed from motion in %FOV / second

# How fast is a volleyball spike?



frame 136



frame 137

5,000 pixels / sec  
requires 1/5000 sec  
to freeze motion!

Canon 1DIII  
does 10fps

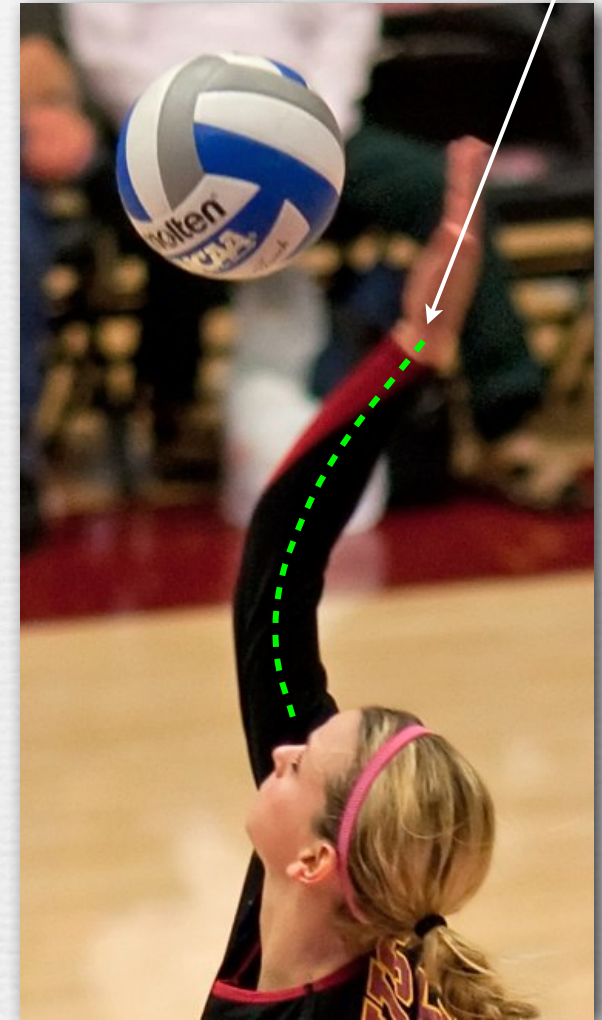
◆ 1cm in 1/800sec suggests 80cm in 1/10sec ✓

# Shutter speed

focal plane  
shutter distortion

Women's  
volleyball

(Canon 1D III,  
1/800 second)



- ◆ 1/1000 is min for typical framing and fast human motion
  - kicks, strokes, spikes, punches require 1/2000 or higher

# ISO

## Women's volleyball

(Canon 1D III,  
1/800 second,  
ISO 3200)



- ◆ should have been 1/1600s at ISO 6400
- ◆ can sometimes control stadium strobes to add light

# Aperture

out of focus

Women's  
volleyball

(Canon 1D III,  
1/800 second,  
ISO 3200, f/2.8)



- ◆ fighting for every photon, so wide open (“big glass”)
- ◆ sacrifices depth of field even when you don't want to

# Focal length



Canon 600mm/4.0  
\$8,000, 12 lbs



monopod

- ◆ the right view often means shooting from far away
- ◆ long lenses are heavy, and they compress perspective



# Megapixels and pixel size

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Canon 1D Mark III  
\$3,800, 10 Mpix, 10 fps  
7.2 $\mu$  × 7.2 $\mu$  pixels

compare to 6.4 $\mu$   
on 21Mpix 5DII



- ◆ modest # of megapixels
  - but the pixels are big, which means less noise in low light
  - also permits fast readout, hence frame rate, and small files
- ◆ crop factor is 1.3 $\times$  (APS-H)
  - not full-frame, which is too slow to read out
  - not 1.6 $\times$  like APS-C format, which gathers less light

# Physical affordances



- ◆ optical viewfinder
  - infinite resolution, dynamic range
- ◆ small LCD, because you seldom have time to look
- ◆ 2<sup>nd</sup> set of shutter controls when rolled for vertical shots
- ◆ large and heavy, especially the battery, circa 1500 shots

# Other useability considerations



- ◆ analog “fighter pilot” controls, so requires lots of practice
- ◆ shoot RAW, M or Av, autofocus (AF) on, stabilization (IS) off
- ◆ hard to change lenses, so professionals carry multiple bodies
- ◆ few professionals use zooms - no time to fiddle, smaller aperture
- ◆ why no radio to upload the “decisive moment” to your publisher?

# Noise

Women's  
gymnastics

(Canon 7D,  
1/1000 sec,  
ISO 3200,  
f/1.8, 85mm)



original



denoised in  
Lightroom 2



◆ with mild denoising,  
ISO 3200 is fine on  
high-end cameras

# Noise

Women's  
gymnastics

(Canon 7D,  
1/1000 sec,  
ISO 3200,  
f/1.8, 85mm)



original



denoised in  
Noise Ninja

- ◆ with mild denoising, ISO 3200 is fine on high-end cameras

# Signal-to-noise ratio

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$$SNR = \frac{\text{mean pixel value}}{\text{standard deviation of pixel value}} = \frac{\mu}{\sigma}$$

$$= \frac{P Q_e t}{\sqrt{P Q_e t + D t + N_r^2}}$$

in sports photography,  
photon shot noise is a given,  
dark current is unimportant,  
and read noise has been  
improving

♦ where

$P$  = incident photon flux (photons/pixel/sec)

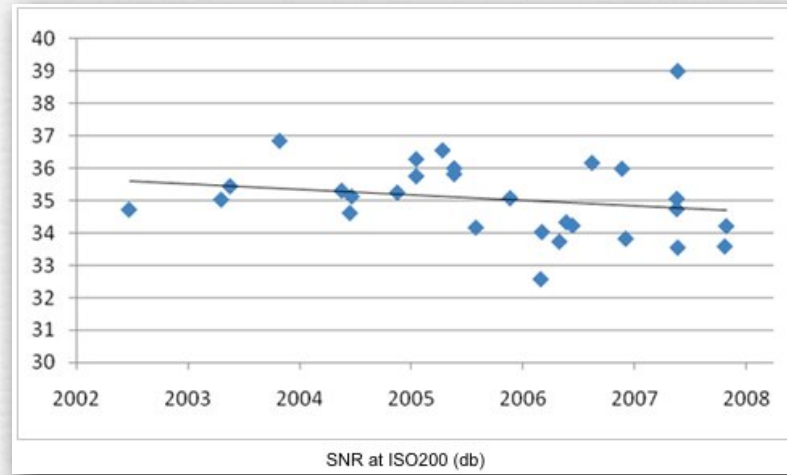
$Q_e$  = quantum efficiency

$t$  = exposure time (sec)

$D$  = dark current (electrons/pixel/sec), including hot pixels

$N_r$  = read noise (rms electrons/pixel), including fixed pattern noise

# SNR and ISO over the years



(<http://www.dxomark.com/index.php/eng/Insights/SNR-evolution-over-time>)

- ◆ SNR has been improving with better sensor designs
  - ◆ but total # of megapixels has risen to offset these improvements, making pixels smaller, so SNR in a pixel has remained static
- 
- ◆ display resolutions have not risen as fast as megapixels, so we're increasingly downsizing our images for display
  - ◆ if you average 4 camera pixels to produce 1 for display, SNR doubles, so for the same display area, SNR has been improving
  - ◆ this allows higher ISOs to be used in everyday photography



Nikon D3S, ISO 3200, photograph by Michael Kass





Nikon D3S, ISO 6400, photograph by Michael Kass



Nikon D3S, ISO 25,600, denoised in Lightroom 3, photograph by Fredo Durand



Fredo says it was nearly too dark to read the menu, so it really looked like this (darkened)



or maybe it looked like this? (tone mapped to approximate human dark adaptation)

# Frame rate and burst size

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Canon 1D Mark IV  
\$5,000, 16 Mpix, 10 fps  
5.7 $\mu$  × 5.7 $\mu$  pixels  
“standard” ISO to 12,800



- ◆ frame rate is (probably) limited by readout rate
  - 16 Mpix × 10fps × 16-bit pixels = 320 MB/s
  - mirror flip and shutter reset may also be limiters
  - shutter life is > 300,000 (only 150 games!)
- ◆ burst size is limited by writing to card
  - 121 JPEG or 28 RAW shots before buffer is full

# Frame rate

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Men's water polo

(Canon 1D III,  
1/2000 sec,  
ISO 200,  
f/4.5, 300mm)



+0.0s

# Frame rate

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Men's water polo

(Canon 1D III,  
1/2000 sec,  
ISO 200,  
f/4.5, 300mm)



+0.1s

# Frame rate

bursts are not identified on any current camera, so it's hard to find them

Men's water polo

(Canon 1D III,  
1/2000 sec,  
ISO 200,  
f/4.5, 300mm)



+0.2s

◆ even 10fps is not fast enough for many sports



# Another example

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Women's  
soccer

(Canon 1D III,  
1/1600 sec,  
ISO 200,  
f/4, 300mm)



+0.0s

# Another example

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Women's  
soccer

(Canon 1D III,  
1/1600 sec,  
ISO 200,  
f/4, 300mm)



+0.1s

# Another example

---

Women's  
soccer

(Canon 1D III,  
1/1600 sec,  
ISO 200,  
f/4, 300mm)



+0.2s

# Another example

---

Women's  
soccer

(Canon 1D III,  
1/1600 sec,  
ISO 200,  
f/4, 300mm)



+0.3s

◆ argh, missed again!

# Another example

might be able to adjust shutter speed in next frame based on motion blur in current frame

Women's  
soccer

(Canon 1D III,  
1/1600 sec,  
ISO 200,  
f/4, 300mm)



+0.3s

- ◆ motion estimation / optical flow is unlikely to work
  - to adjust shutter speed, perform denoising, view interpolation,...

# Nailing the shot: could the camera help?

- ◆ detect the ball, detect faces, trigger when they are close
- ◆ but can't capture 60fps burst at full res on today's cameras, so must be detectable from low-res viewfinder stream

- 
- ◆ if cameras were faster, could capture a 60fps burst and save the decisive shot

Moore's Law will help

- ◆ or let the photographer choose which frames to save (like Casio EX-F1), but when do they have time for this?

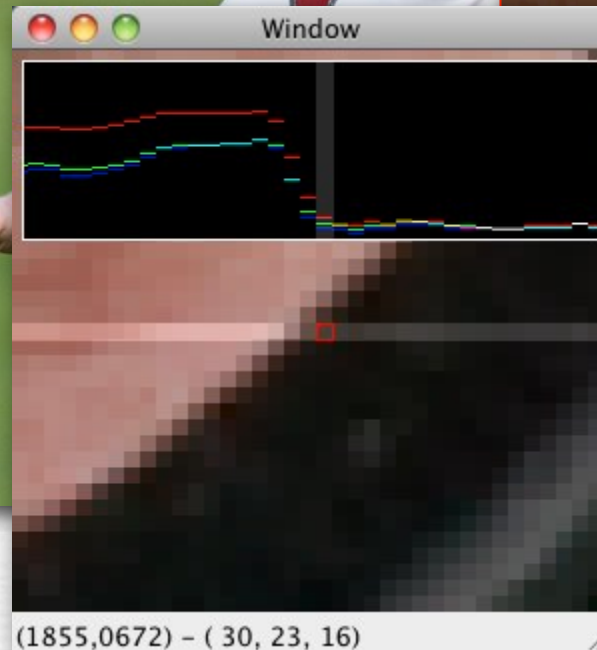
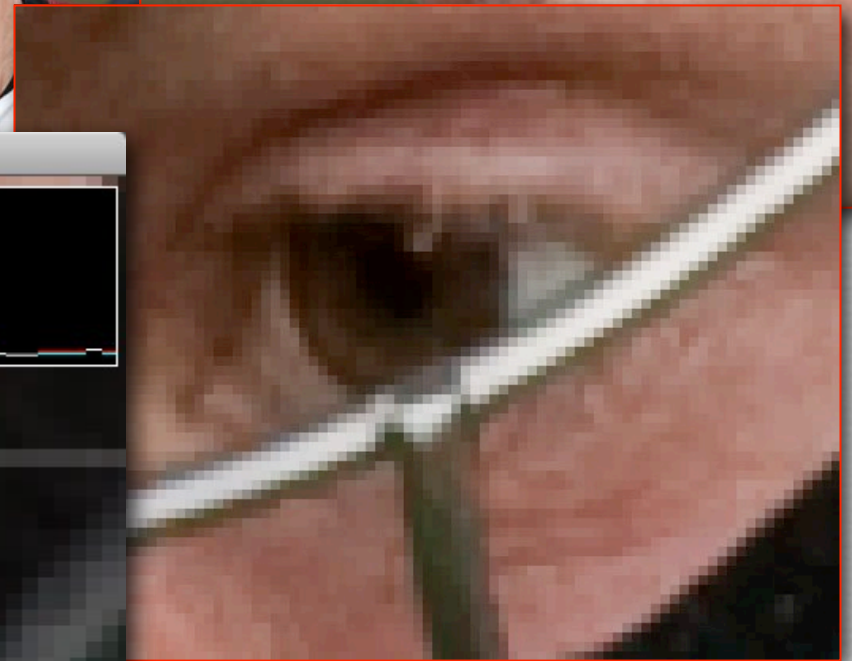


(Hector Garcia-Molina)

# Focus

Women's  
lacrosse

(1D III,  
300mm,  
1/4000 sec,  
ISO 800,  
f/3.2)



✓ critical focus

# Depth of field



- ◆ DoF is demanding at low F-numbers and high magnifications!

$$D_{TOT} \approx \frac{2NCU^2}{f^2}$$

- ◆  $N = f/4$   
 $C = 7.2\mu$   
 $U = 15\text{m (50')}$   
 $f = 300\text{mm (equiv to 384mm)}$   
 $D_{TOT} = 144\text{mm (6")}$

- ◆ 1 pixel on this video projector  
 $C = 7.2\mu \times 3984 / 1024$  pixels  
 $D_{EFF} = 560\text{mm (22")}$



# Depth of field is useful

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Women's  
lacrosse

(1D III,  
400mm,  
1/4000 sec,  
ISO 400,  
f/4)





(Hector Garcia-Molina)



(Hector Garcia-Molina)



(Hector Garcia-Molina)

# Depth of field can be too shallow

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Big Game 2009

(7D, 300mm,  
1/1250 sec,  
ISO 1600, f/2.8)

- ◆ ability to extend depth of field would be useful
  - different problem from fixing misfocus
  - fighting for photons, so can't stop down the aperture

# Autofocusing

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Women's lacrosse

(1D III, 400mm,  
1/5000 sec, ISO 400, f/4)



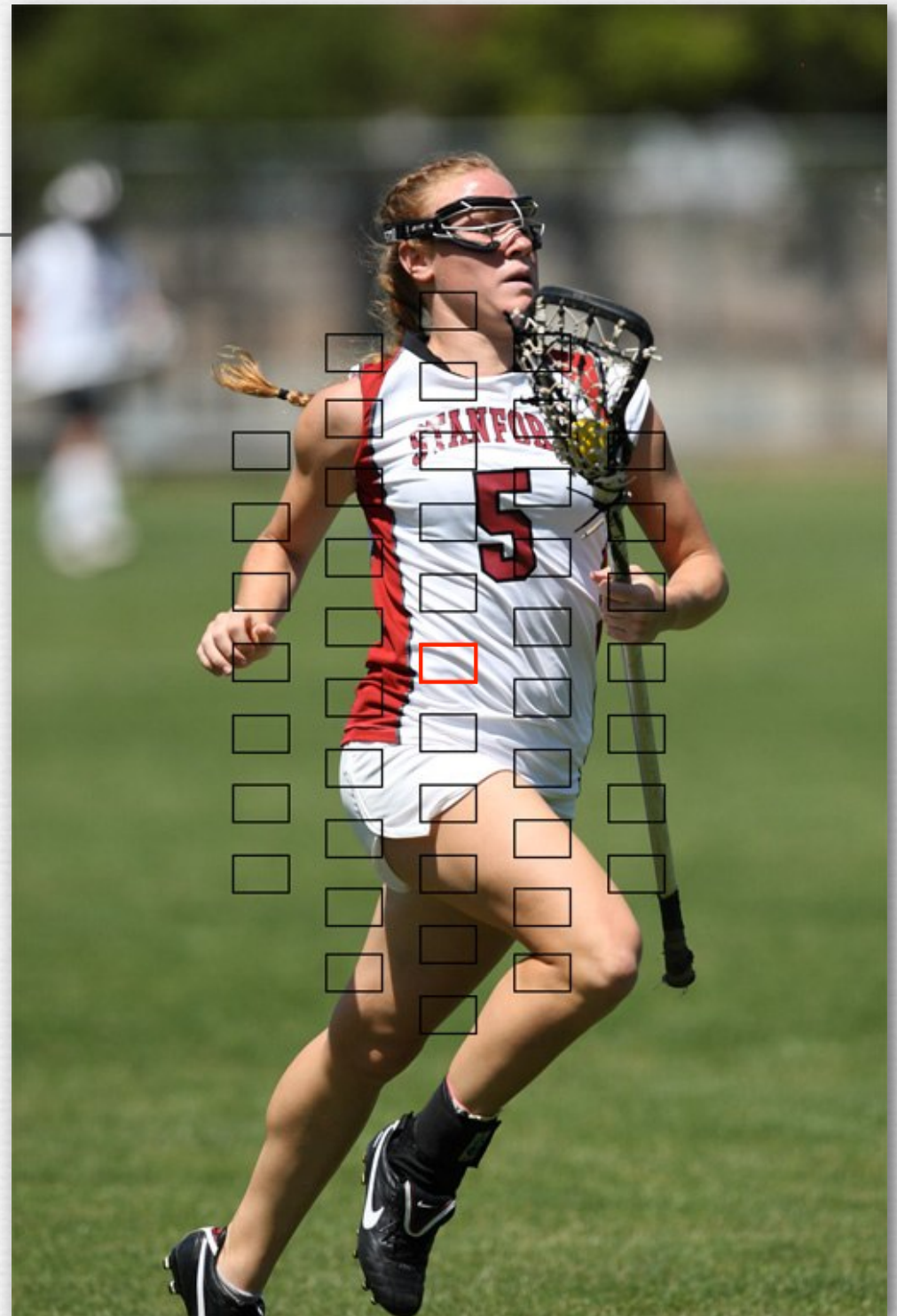
# Autofocusing

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Women's lacrosse

(1D III, 400mm,  
1/5000 sec, ISO 400, f/4)

- ◆ single centered AF point is most reliable
  - otherwise it often focuses on peripheral players or objects



# Subjects aren't always centered

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(Hector Garcia-Molina)

- ◆ use manual AF button, before or during action
  - requires a lot of practice



# Auto-misfocusing

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Women's lacrosse

(1D III, 400mm,  
1/4000 sec, ISO 400, f/4)



# Auto-misfocusing

Women's lacrosse

(1D III, 400mm,  
1/4000 sec, ISO 400, f/4)

- ◆ solve by prohibiting focusing on the grass?
  - trainable before the game, to allow unusual fields
  - use color & texture?
- ◆ or focus on moving objects?
  - as detected by motion blur
  - must overlook/compensate for panning the camera



# Auto-misfocusing

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Women's soccer

(1D III, 400mm,  
1/2000 sec, ISO 200, f/4)



# Auto-misfocusing

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Women's soccer

(1D III, 400mm,  
1/3200 sec, ISO 200, f/4)

- ◆ fix focus in blurry shot using information from sharp shot later in the same burst?
- ◆ also applicable to casual photography - use imagery captured while aiming and focusing to fix noise, blur,...
- ◆ needs a programmable camera



# Auto-misfocusing

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Women's soccer

(1D III, 400mm,  
1/2000 sec, ISO 200, f/4)



# Auto-misfocusing

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Women's soccer

(1D III, 400mm,  
1/3200 sec, ISO 200, f/4)

- ◆ need “soccer ball focus”
  - plug-in for sports
  - trainable before the game, to allow unusual balls
  - specialized algorithm to recognize any rotation
  - could also use to set white balance and exposure



# “Pre-game warmup” for cameras

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Courtney Verloo

- ◆ train on ball
- ◆ train on each player
- ◆ adjust focus and exposure for best shot
- ◆ adjust depth of field to span player and ball



# This is harder than it sounds

player carries  
wireless chip?



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Courtney Verloo



?





# The many faces of Kelley O'Hara

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◆ soccer, #19, top U.S. collegiate player 3 years in a row

# Auto-misfocusing

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Women's  
lacrosse

(1D III, 400mm,  
1/4000 sec,  
ISO 400, f/4)



# Auto-misfocusing

Women's  
lacrosse

(1D III, 400mm,  
1/4000 sec,  
ISO 400, f/4)



- ◆ solve by prohibiting focusing beyond a certain distance?
  - tricky since camera often pans and field is rectangular

# Plenoptic camera + post-focusing

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Big Game 2009

(Canon 50D with  
microlens array,  
300mm, 1/500 sec,  
ISO 1600, f/4)

**(FLASH DEMO)**



- ◆ plausible optical recipe:  $18 \text{ Mpix} \div 4 \times 4 \text{ pixels}$  behind each microlens
  - $1200 \times 900$  pixel output image - enough for the web
  - 24' of Z-refocusing - enough for the line of scrimmage

# Plenoptic camera + post-focusing

Big Game 2009

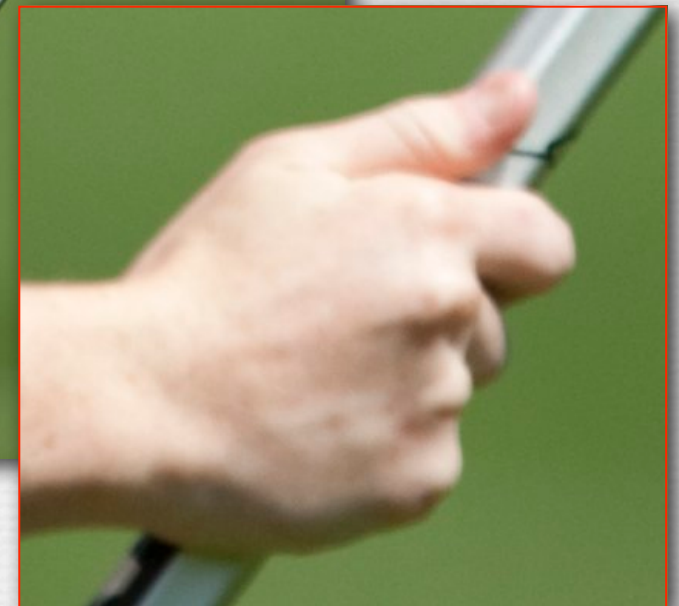
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**(FLASH DEMO)**



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  - 24' of Z-refocusing - enough for the line of scrimmage

# Shots that could have been saved



◆ almost well focused

# Shots needing a bit more DoF

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(Marc Levoy)

(Hector Garcia-Molina)



- ◆ refocus to create focal stack, apply all-focus algorithm
  - or another EDoF technique: coded aperture, lattice focal, etc.

# Shots that could use a tilted focal plane

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(Hector Garcia-Molina)



- ◆ easily done with plenoptic camera
- ◆ curved focal surfaces also possible



# Cluttered backgrounds

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## Women's gymnastics

(Canon 7D, 1/1000 sec,  
ISO 3200, f/1.8, 85mm)



- ◆ common problem in most indoor and stadium sports

# Meaningless backgrounds

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(Hector Garcia-Molina)

- ◆ no solution except to look for a different vantage point



# Fixing cluttered backgrounds

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Women's soccer

(1D III, 400mm,  
1/2500 sec, ISO 200, f/4)



# Fixing cluttered backgrounds

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Women's soccer

(1D III, 400mm,  
1/2500 sec, ISO 200, f/4)

cropped  
original



- ◆ this took a long time to do
  - darkened and desaturated using Lightroom 2's "auto-masked" brush
  - need focus-based region selector for editing

# Conclusions

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- ◆ some aspects of sports photography are intrinsically hard
  - ◆ some might yield to comp photo / vision algorithms
  - ◆ faster bursts (or video) would help
- 
- ◆ implementing any of this might need specialized hardware
  - ◆ it is not clear how to affect commercial high-end cameras
- 
- ◆ camera as light field probe - frameless photography?
    - the sensor on our soon-to-be-released Frankencamera F3 will allow arbitrary regions of interest and non-destructive readout
  - ◆ autonomous sports photography (except for cropping)?
  - ◆ new ways of depicting sports action?

# Parting thoughts: good sports photographers make it look easy

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(Hector Garcia-Molina)



# Another parting thought: sports can be rough

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(Hector Garcia-Molina)



© Marc Levoy

# Parting thoughts: swing the camera around once in a while

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(Marc Levoy)



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