

# What Google Glass means for the future of photography

TTI Vanguard [next]  
December 4, 2014

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Marc Levoy  
Computer Science Department  
Stanford University

mostly retired  
from Stanford  
to work at...





(Google)

<https://www.youtube.com/watch?v=5R1snVxGNVs>



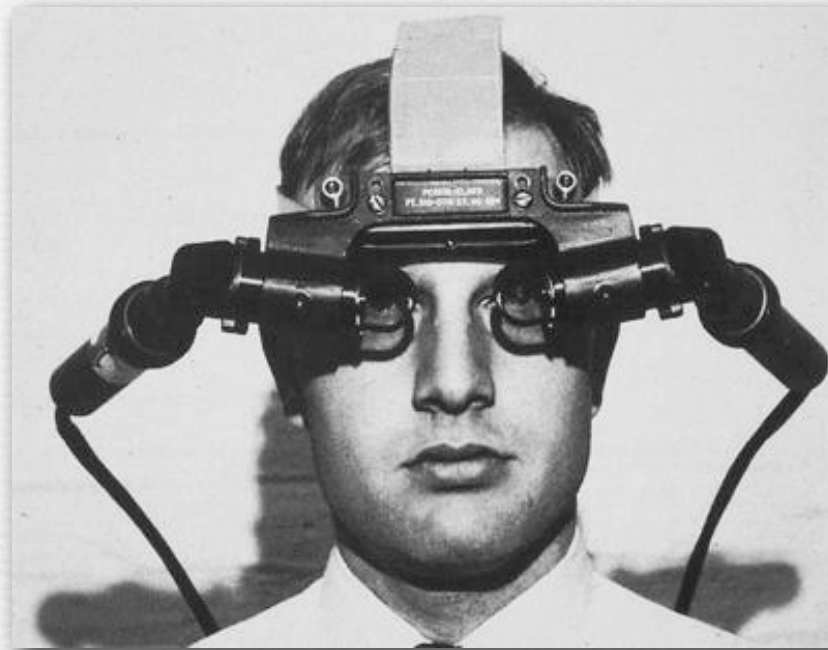
# Outline

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- ◆ a bit of history
- ◆ technical specs
- ◆ What's different about taking a picture using Glass?
- ◆ writing apps for cameras
- ◆ superhero vision

# Head-mounted displays are not new

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Ivan Sutherland's  
“ultimate display” (1965)

◆ conferences:

- International Symposium on Wearable Computers (ISWC)
- Pervasive and Ubiquitous Computing (UbiComp)

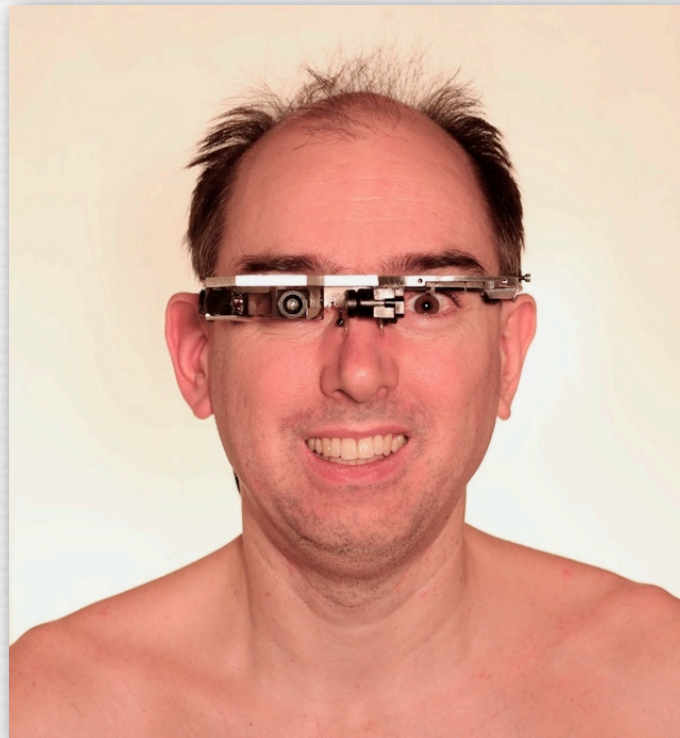
# Head-mounted displays are not new



(Google image search results for “head mounted display”)

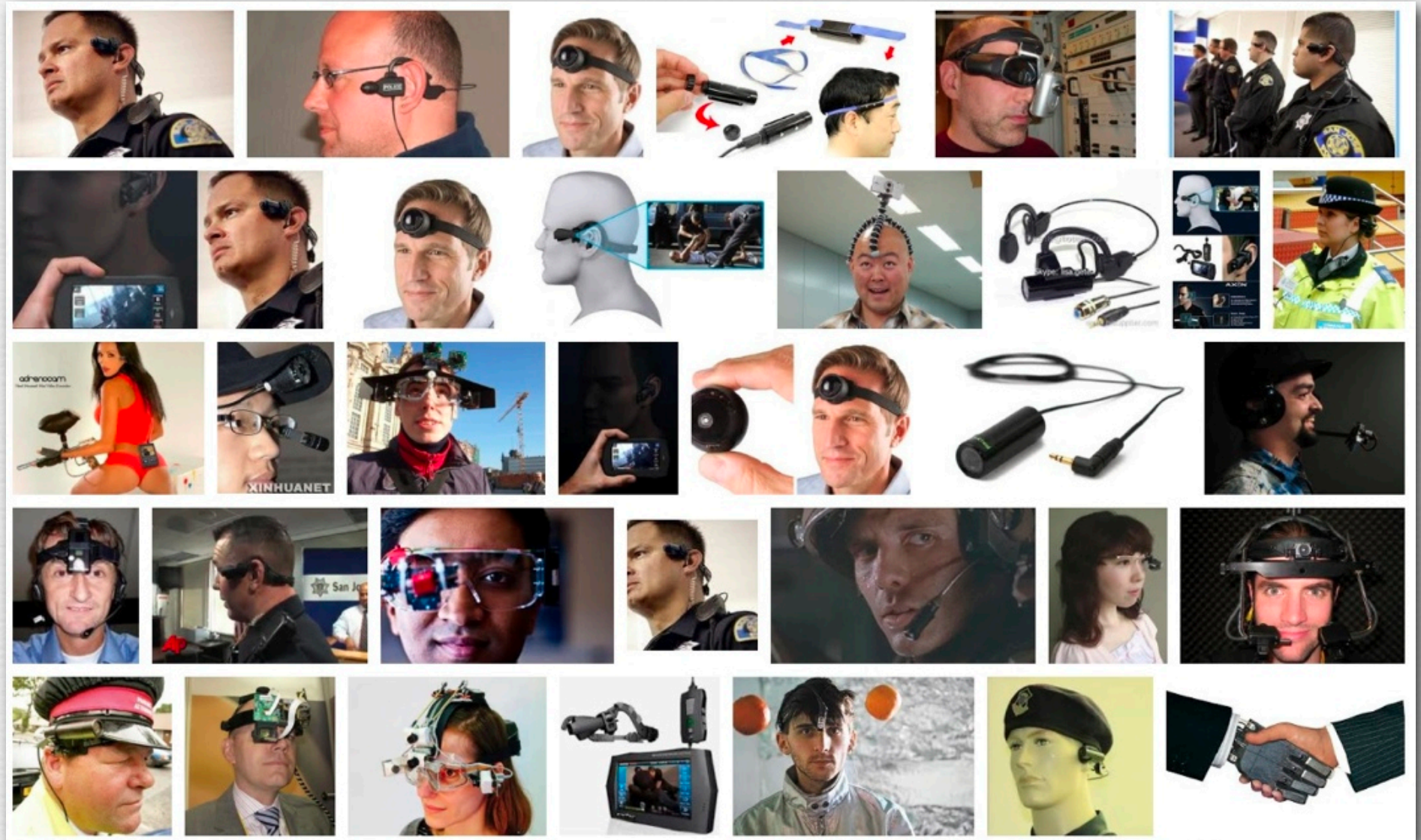
# Neither are head-mounted cameras

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Steve Mann's  
Eyetap (1981)

# Neither are head-mounted cameras



(Google image search results for “head mounted camera”)



(GoPro trailer)



(gopro.com)

<https://www.youtube.com/watch?v=A3PDXmYoF5U>

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# Technical specs

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- ◆ camera

- cell phone equivalent, 5Mpix still or 720p video, no flash



Nokia N95



Nokia N95



iPhone 5



Glass

# Technical specs

---

- ◆ camera
  - cell phone equivalent, 5Mpix still or 720p video, no flash
- ◆ display
  - heads-up, color, 640×360 pixels, focused at a distance
- ◆ sensors
  - accelerometer, gyro, compass, GPS
- ◆ radios
  - bluetooth tethering through your phone or direct Wifi
  - no cellular modem (3G/4G)
- ◆ computing
  - cell phone equivalent processor (OMAP4), memory, and OS
  - SDKs are becoming available in stages



# What's different about taking a picture using Glass?

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- ◆ the capture experience
  - hands-free



(picture by Sebastian Thrun)

# What's different about taking a picture using Glass?

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- ◆ the capture experience
  - hands-free
  - point-of-view

"All the News  
That's Fit to Print"

# The New York Times

National Edition  
Northern Edition: Navy expects  
for areas of burning, low clouds and  
fog along the coast. High 30s and  
60s coast to near 90 in the Central  
Valley. Weather map on Page 35.

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Chen Guangcheng, the blind Chinese dissident, arriving in New York on Saturday shortly after arriving at Newark Airport.

## Ordeal Ended, China Activist Lands in U.S.

This article is by Thomas Kaplan, Andrew Ross and Steven Lee Myers.

Chen Guangcheng, the blind legal advocate who recently sought refuge in the American Embassy in Beijing, arrived in the heart of Greenwich Village on Saturday holding the kind of open-air tent residence that he could have never imagined while under virtual house arrest in China. After a darling and heavily arranged flight from Beijing, Mr. Chen stood on a cotchete — with a lawyer at his side and facing reporters, cordoned off by the police — and addressed a throng

## Romney's Faith, Silent but Deep

Applying Mormonism's Lessons in Life and Campaign

By JOSE KANTOR

BEALMONT, Mass. — When Mitt Romney embarked on his first political race in 1994, he also slipped into a humble new role in the Mormon congregation he once led. On Sunday morning, he stood in the small chapel here teaching Bible classes for adults. Leading students through stories about Jesus and the prophet and LDS founder, who Mormons believe once populated the Americas, and tossing out peanut butter cups as rewards, Mr. Romney always returned to the same questions: How could students apply the lessons of Mormon scripture to their sta-

THE LONG RUN  
Scribed by the Book

whose faith in his design for living. The church is by no means his only influence, and its impact cannot be fully untangled from that of his family, which is also steeped in Mormonism. But being a Latter-day Saint is "at the center of who he really is," if you scrape everything else off, said Sandy Sorenson, who worked with Mr. Romney in church. As a young consultant who arrived at the office before anyone else, Mr. Romney was being "honest," a term from the Book

where he made uncommunicated addresses and sometimes discouraged mothers from working outside the home. He may have many reasons for adhering to, wanting to limit federal power, promoting self-reliance and stressing the unique destiny of the United States, but those are all traditionally Mormon traits as well. Outside the spotlight, Mr. Romney can be demonstrative about his faith, telling his former boss, "What a Friend We Have in Jesus," while horseback riding, fasting on designated days and leading a Mormon congregation.

## Charting Obama's Journey To a Shift on Afghanistan

NATO Meeting Reflects His Early Reversal  
on Strategy and Achievable Goals

By DAVID E. SANGER

It was just one brief exchange about Afghanistan with an aide late in 2010, but it suggests how President Obama's thinking about what he once called "a war of necessity" began to radically change less than a year after he took up residency at the White House. Not long before, after a highly contentious debate within a war cabinet that was riddled with leaks, Mr. Obama had reluctantly decided to order a surge of more than 30,000 troops. The aide told Mr. Obama that he believed military leaders had agreed to the tight schedule to begin withdrawing those troops just 18 months later only because they thought they could persuade an inexperienced president to grant more time if they demonstrated it.

Mr. Obama responded that day, "I'm not going to give them more time." A year later, when the president and a half-dozen White House aides began to plan for the withdrawal, the generals were out of control. There was no debate, and there were no leaks. And when Mr. Obama joins the leaders of other NATO nations in Washington on Sunday and Monday in Chicago on Sunday and Monday, the full extent of how his thinking on Afghanistan has changed will be apparent. He will announce what he has already told the leaders in private: All combat operations led by American forces will cease in summer 2012, when the United States and other NATO forces move to a "support role" whether the Afghan military can secure the country or not.

Mr. Obama concluded in his first year that the Bush-era dream of reuniting Afghanistan's people through a conventional approach emphasizing security. Privately recognizing "that the right measures are not the same for each of us," the leaders of the group of 28 nations, at a meeting

## World Leaders Urge Growth, Not Austerity

By HELENE COOPER

CAMP DAVID, Md. — Leaders of the world's richest countries banded together on Saturday to demand Germany to back more aggressive policies to halt the deep-growth problem in Europe, as rising debt crisis in Europe, as President Obama for the first time gained widespread support for his approach that Europe and the United States to extend, cannot afford Chancellor Angela Merkel's one-size-fits-all approach emphasizing security. Privately recognizing "that the right measures are not the same for each of us," the leaders of the group of 28 nations, at a meeting

Continued on Page 15

Continued on Page 9

# What's different about taking a picture using Glass?

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# What's different about taking a picture using Glass?

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- ◆ the capture experience
  - hands-free
  - point-of-view
  - always available
  - instantly triggerable
  - your eyes are unobstructed





Madame & Bébé Gayno

(Google)

<https://www.youtube.com/watch?v=cCmfpHYAAz0>

# What's different about taking a picture using Glass?

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- ◆ the capture experience
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- ◆ new reasons to take pictures
  - people I've met





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  - something cool I saw
  - information I'd like to remember

# Compressive Light Field Photography: Single Shot Resolution Preserving Light Field Camera

Kshitij Marwah, Gordon Wetzstein, Ashok Veeraraghavan and Ramesh Raskar

Light field cameras have ushered a new revolution in consumer photography with extended post capture control such as refocusing and view point changes. Unfortunately, they suffer a severe loss in resolution turning a sixteen megapixel sensor to a one megapixel light field image. We present a computational and theoretical framework in conjunction with a practical mask based optical design for a first single shot resolution preserving light field camera.



Real reconstructed scene showcasing refocusing between two occluding books.

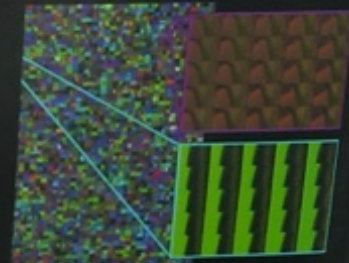
Captured scene from our new light field camera demonstrating view point changes and refocusing on slanted books.



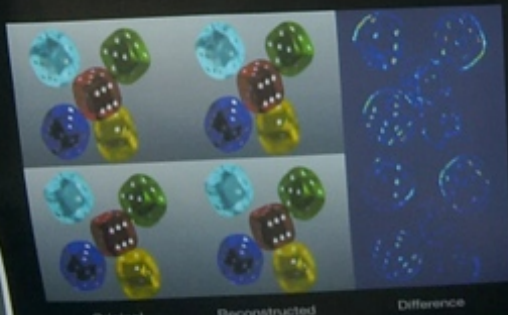
We extract a  $320 \times 240$  image from the sensor and compute a  $320 \times 240$  in space and  $3 \times 3$  in angle light field back. Our light field camera design captures depth discontinuities, occlusions (as shown near the blue bear's hand), specularities (girl's forehead) and other global illumination effects.



Our light field camera design places an incoherent mask between the aperture and the sensor.

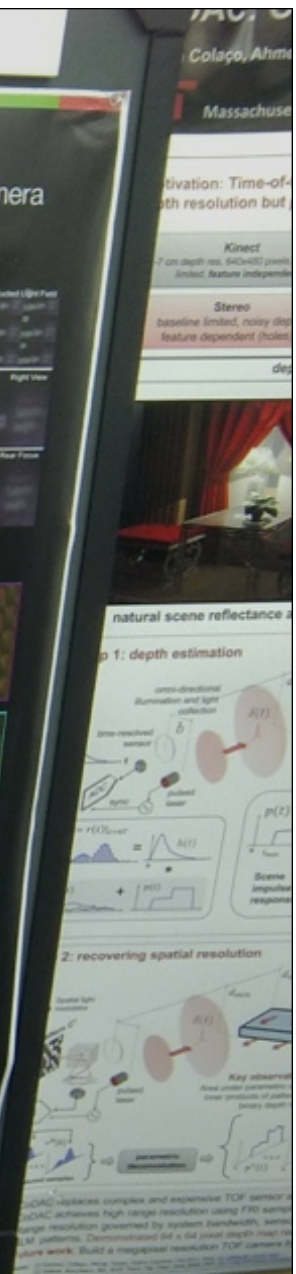
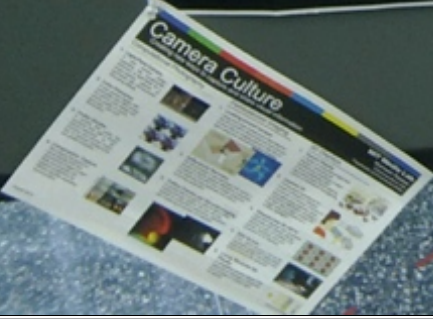


An overcomplete dictionary of resolution  $16 \times 16$  in space and  $5 \times 5$  in angles learned from natural light field patches.

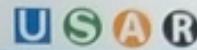


Simulations showing high resolution reconstruction of light field from a single dippled sensor extract. Parallax can easily be observed between views accompanied by recovery of challenging effects such as transparencies. Difference image is shown for comparison.

Light fields can be interpreted as different view points of the same scene. By definition, they have a lot of redundancy and many four dimensional basis have been proposed ranging from cosine transforms to principal components. Though useful they fail to capture specific structure in light field images such as shears representing depth ranges and t-junctions depicting occlusion boundaries. We use this insight to learn a first four dimensional basis from natural light fields themselves. Our basis, namely, an overcomplete dictionary specifically captures depth discontinuities, transparencies, specularities and other global illumination effects.



Schnellbahn-/Regionalverkehr  
Rapid Transit / Regional Rail



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**Schnellbahn**  
 Schnellbahn-Linien sind durchgezogene Linien. Regionalbahnen sind gestrichelte Linien.

Die Verbindung zwischen den S-Bahn-Linien und den Regionalbahnen erfolgt über die Regionalbahnhöfe. Die Verbindung zwischen den S-Bahn-Linien und den Buslinien erfolgt über die Busstationen.

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- ◆ new reasons to take pictures
  - people I've met
  - something cool I saw
  - information I need to remember
  - things I gotta do

**PRESIDENT**



**BARBER SHOP**

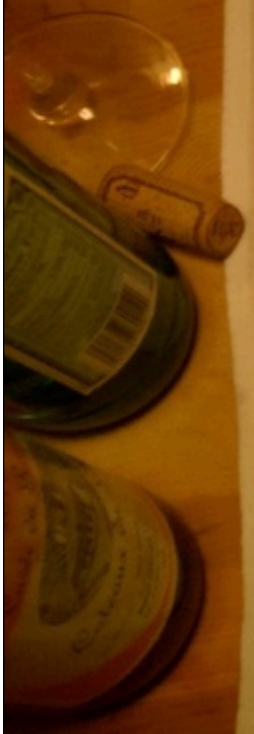
*Family Owned Since 1949*



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  - life logging





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Glass also takes nice photographs







# Video and other formats

---

- ◆ straight video



(video not available)

# Video and other formats

---

- ◆ straight video
- ◆ slo-mo and timelapse



(video not available)



# Video and other formats

---

- ◆ straight video
- ◆ slo-mo and timelapse
- ◆ video hangouts and eye swapping

Hangout with Daddy

(Google)

<https://www.youtube.com/watch?v=cCmfpHYAAz0>

# Video and other formats

---

- ◆ straight video
- ◆ slo-mo and timelapse
- ◆ video hangouts and eye swapping
- ◆ every photograph is a cliplet

# Cliplets

---



Nikon V1 Motion Snapshot  
(60fps for 1 second, slowed 2.5x, cross-dissolve to still, played with music)

⇐ THE BEAUTY OF A **SECOND** ⇒  
ROUND 3

<http://vimeo.com/36897783>

# Photomontage from bursts

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# Photomontage from bursts

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# Multiplicity



## TRICK PHOTOGRAPHY AND SPECIAL EFFECTS

The Ultimate Guide of Tricks, Techniques, and  
Ideas that Create Mind-Twisting Images



By Evan Sharboneau



# Video and other formats

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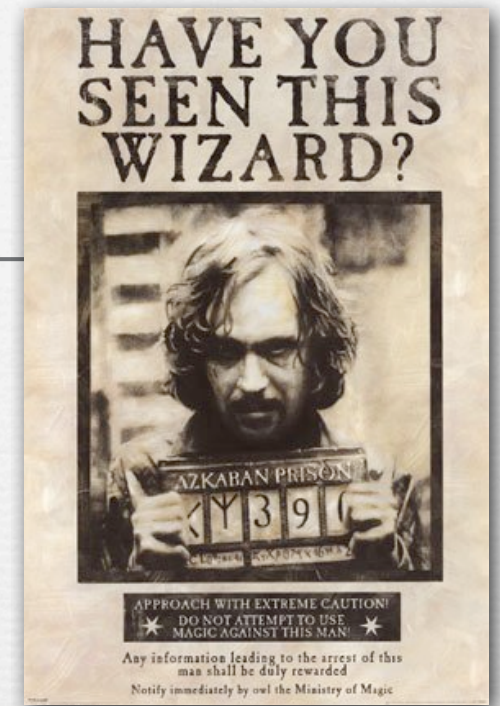
- ◆ straight video
- ◆ slo-mo and timelapse
- ◆ video hangouts and eye swapping
- ◆ every photograph is a cliplet
- ◆ cinemagraphs

# Cinemagraphs: between photography and video

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(cinemagraphs.com)



# Video and other formats

---

- ◆ straight video
- ◆ slo-mo and timelapse
- ◆ video hangouts and eye swapping
- ◆ every photograph is a cliplet
- ◆ cinemagraphs
- ◆ other games with video...

# Video synopsis

[Pritch et al.]

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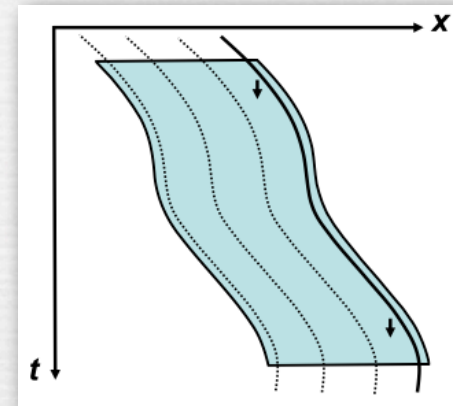


<http://www.cs.huji.ac.il/~yaelpri/demos.php>

# Dynamosaicing

[Rav-Acha, Pritch, et al. 2007]

---



<http://www.cs.huji.ac.il/~yaelpri/demos.php>

# What's hard about computational video?

---

- ◆ finding effects that are fun, useful, and not creepy
- ◆ making these effects easy for consumers to author
- ◆ making them robust enough to work most of the time
- ◆ making them efficient enough to compute on the device

# The future of digital cameras

---

- ◆ the megapixel wars are over (long overdue)
- ◆ computational photography is the next battleground in the camera industry (it's already starting)

*nope, still raging in the  
cell phone marketplace*

*actually, it's the main  
battleground right now*

# The future of digital cameras

---

- ◆ the megapixel wars are over (long overdue)
- ◆ computational photography is the next battleground in the camera industry (it's already starting)



Casio EX ZR1000

- burst mode low-light
- auto-HDR
- all-focus
- background defocus

- captures a burst of 40 shots at 30fps and auto-selects the best 5

Nikon 1 V2





# The future of digital cameras

---

- ◆ the megapixel wars are over (long overdue)
- ◆ computational photography is the next battleground in the camera industry (it's already starting)
  
- ◆ how will these features appear to consumers?
  - standard and invisible
  - standard and visible (and disable-able)
  - aftermarket plugins and apps for your camera

# Example computational photography app: SynthCam for the iPhone

---

The advertisement features a dark background with a large, stylized camera lens on the left and several smaller lens icons on the right. The word "SynthCam" is written in a large, white, sans-serif font across the center. Below the title, the text "SynthCam is an app for the iPhone 4, 3GS, iPod Touch 4G, and iPad2" is displayed in a smaller white font, with "(requires iOS 4.2 or higher)" in a smaller orange font underneath. The price is listed as "Free" in a white box, and the current version is "2.0". At the bottom, there is a red button with a white iPhone icon and the text "Available on the iPhone App Store".

**SynthCam**

SynthCam is an app for the iPhone 4, 3GS, iPod Touch 4G, and iPad2  
(requires iOS 4.2 or higher)

Price: **Free**      Current version: 2.0

Available on the iPhone  
**App Store**

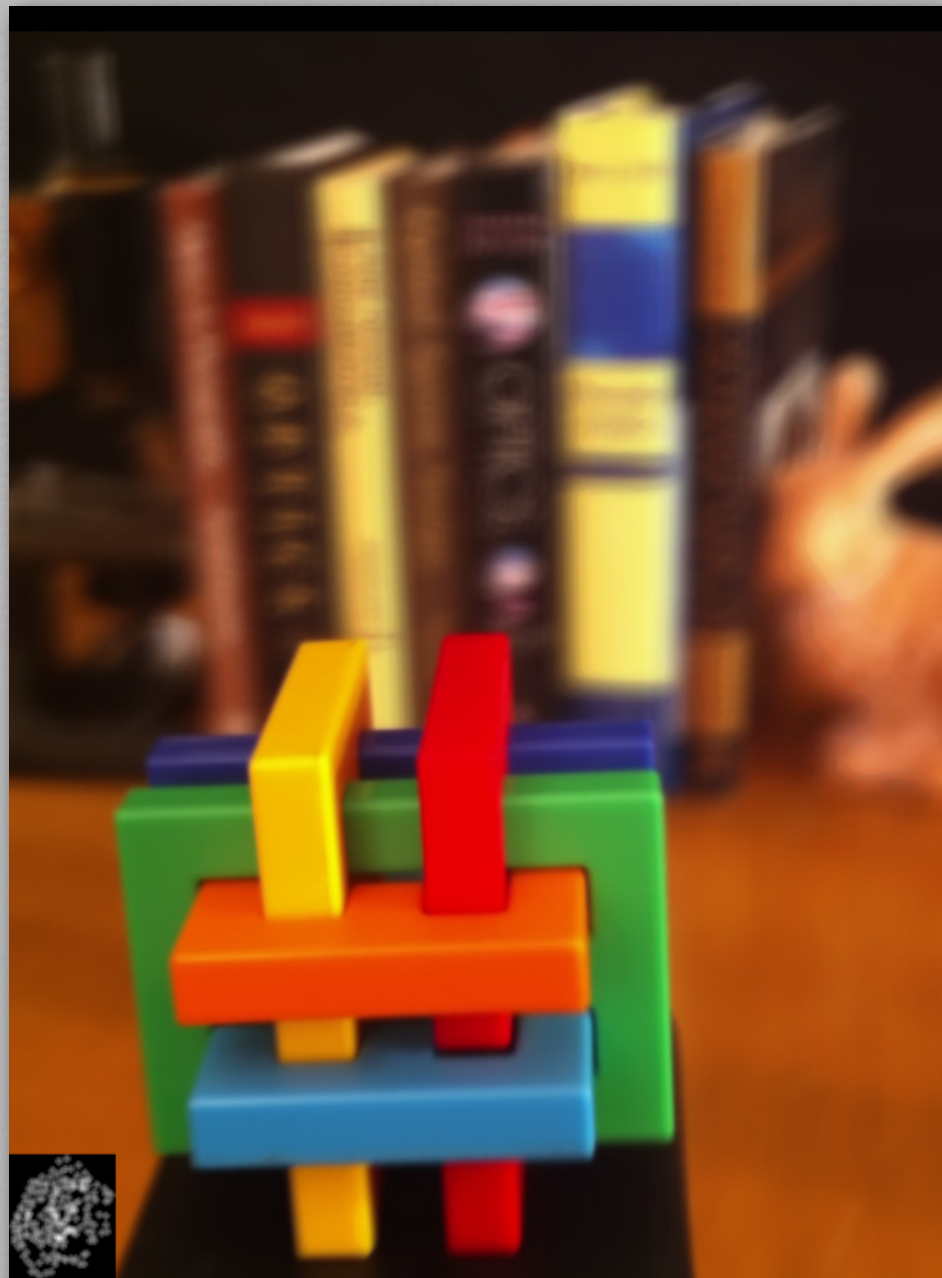




1



while recording



1



synthetic aperture photograph



single frame



synthetic aperture photograph



single frame



synthetic aperture photograph



strong defocus



subtle defocus



tilt-shift “miniature-model” effect



# Superhero vision

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(Hector Garcia-Molina)

# Superhero vision

---

- ◆ seeing in the dark

# Digital photography can easily exceed human vision

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(Jesse Levinson Canon 10D, 28mm f/4, 3 min, ISO 100, 4 image pano)

- ◆ required a tripod
- ◆ can't currently do this using a cell phone, but it's not impossible
  - dark current (if one shot) or read noise (if a burst) must be very low

Low-light imaging using  
burst-mode computational  
photography

single frame  
(iPhone 4)



# Low-light imaging using burst-mode computational photography

SNR increases as  
 $\sqrt{\text{\# of frames}}$

average of  
~30 frames  
(SynthCam)




IF WE SHALL SUPPOSE THAT AMERICAN SLAVERY IS ONE OF THOSE OFFENSES WHICH IN THE PROVIDENCE OF GOD MUST NEEDS COME BUT WHICH HAVING CONTINUED THROUGH HIS APPOINTED TIME HE NOW WILLS TO REMOVE AND THAT HE GIVES TO BOTH NORTH AND SOUTH THIS TERRIBLE WAR AS THE WOE DUE TO THOSE BY WHOM THE OFFENSE CAME SHALL WE DISCERN THEREIN ANY DEPARTURE FROM THOSE DIVINE ATTRIBUTES WHICH THE BELIEVERS IN A LIVING GOD ALWAYS ASCRIBE TO HIM FONDLY DO WE HOPE - FERVENTLY DO WE PRAY - THAT THIS MIGHTY SCOURGE OF WAR MAY SPEEDILY PASS AWAY - YET IF GOD WILLS THAT IT CONTINUE UNTIL ALL THE WEALTH PILED BY THE BONDSMAN'S TWO HUNDRED AND FIFTY YEARS OF UNREQUITED TOIL SHALL BE SUNK AND UNTIL EVERY DROP OF BLOOD DRAWN WITH THE LASH SHALL BE PAID BY ANOTHER DRAWN WITH THE SWORD AS WAS SAID THREE THOUSAND YEARS AGO SO STILL IT MUST BE SAID "THE JUDGMENTS OF THE LORD ARE TRUE AND RIGHTEOUS ALTOGETHER." WITH MALICE TOWARD NONE WITH CHARITY FOR ALL WITH FIRMNESS IN THE RIGHT AS GOD GIVES US TO SEE THE RIGHT LET US STRIVE ON TO FINISH THE WORK WE ARE IN TO BIND UP THE NATION'S WOUNDS TO CARE FOR HIM WHO SHALL HAVE BORNE THE BATTLE AND FOR HIS WIDOW AND HIS ORPHAN - TO DO ALL WHICH MAY ACHIEVE AND CHERISH A JUST AND LASTING PEACE AMONG OURSELVES AND WITH ALL NATIONS -

single frame

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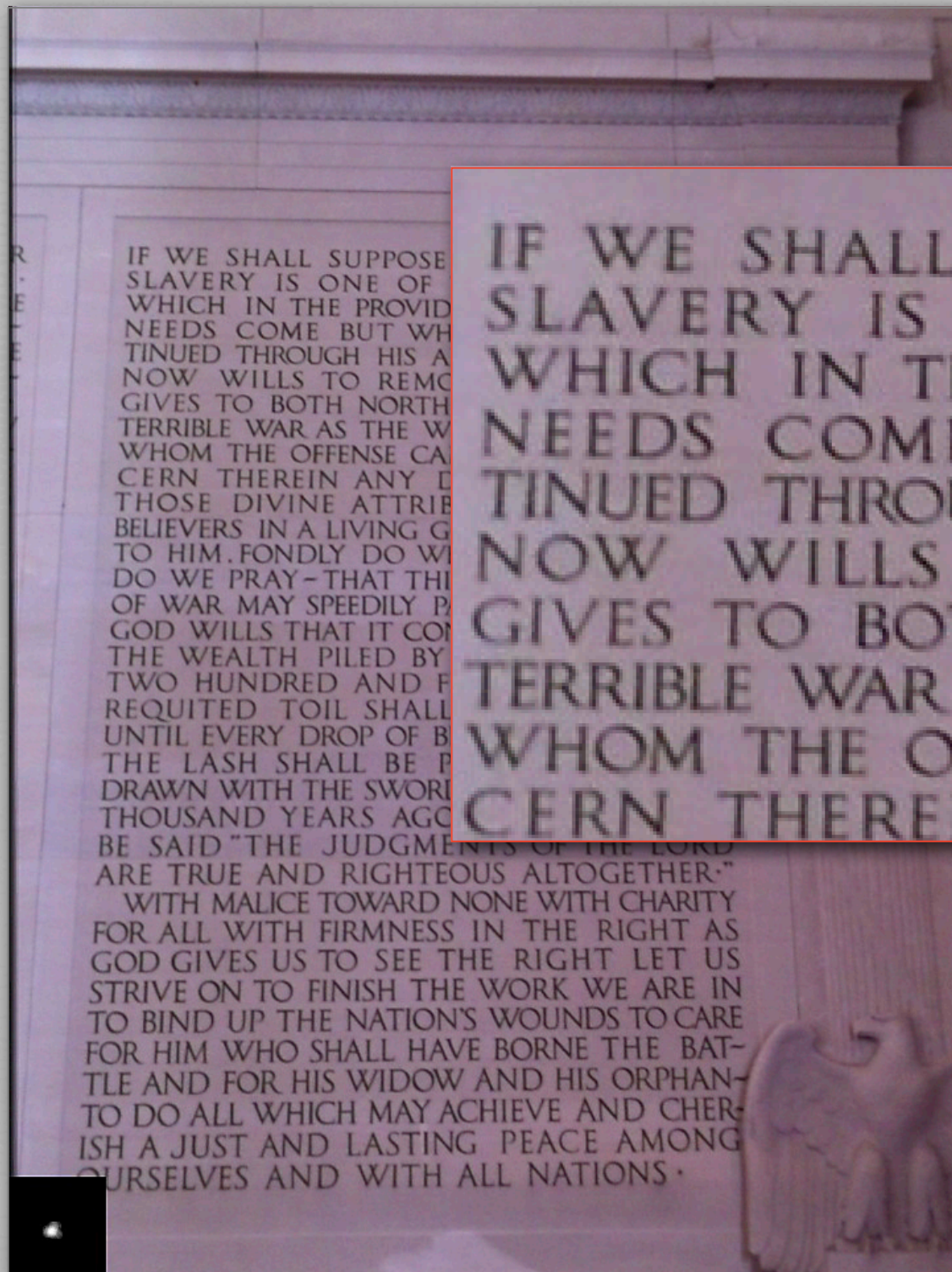
average of  
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single frame



average of  
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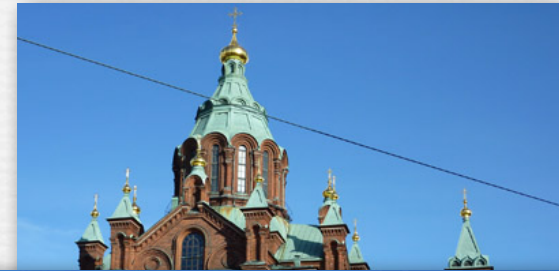
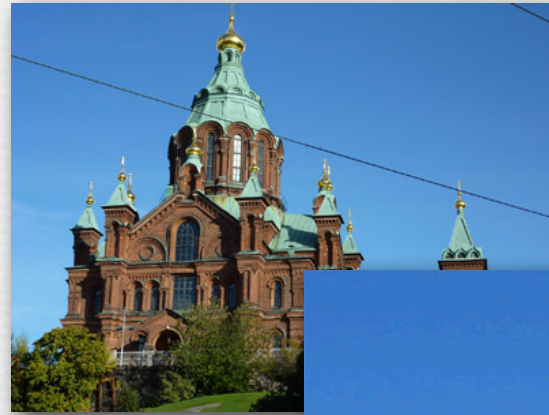
# Superhero vision

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- ◆ seeing in the dark
- ◆ seeing through objects

# Removing foreground objects by translating the camera

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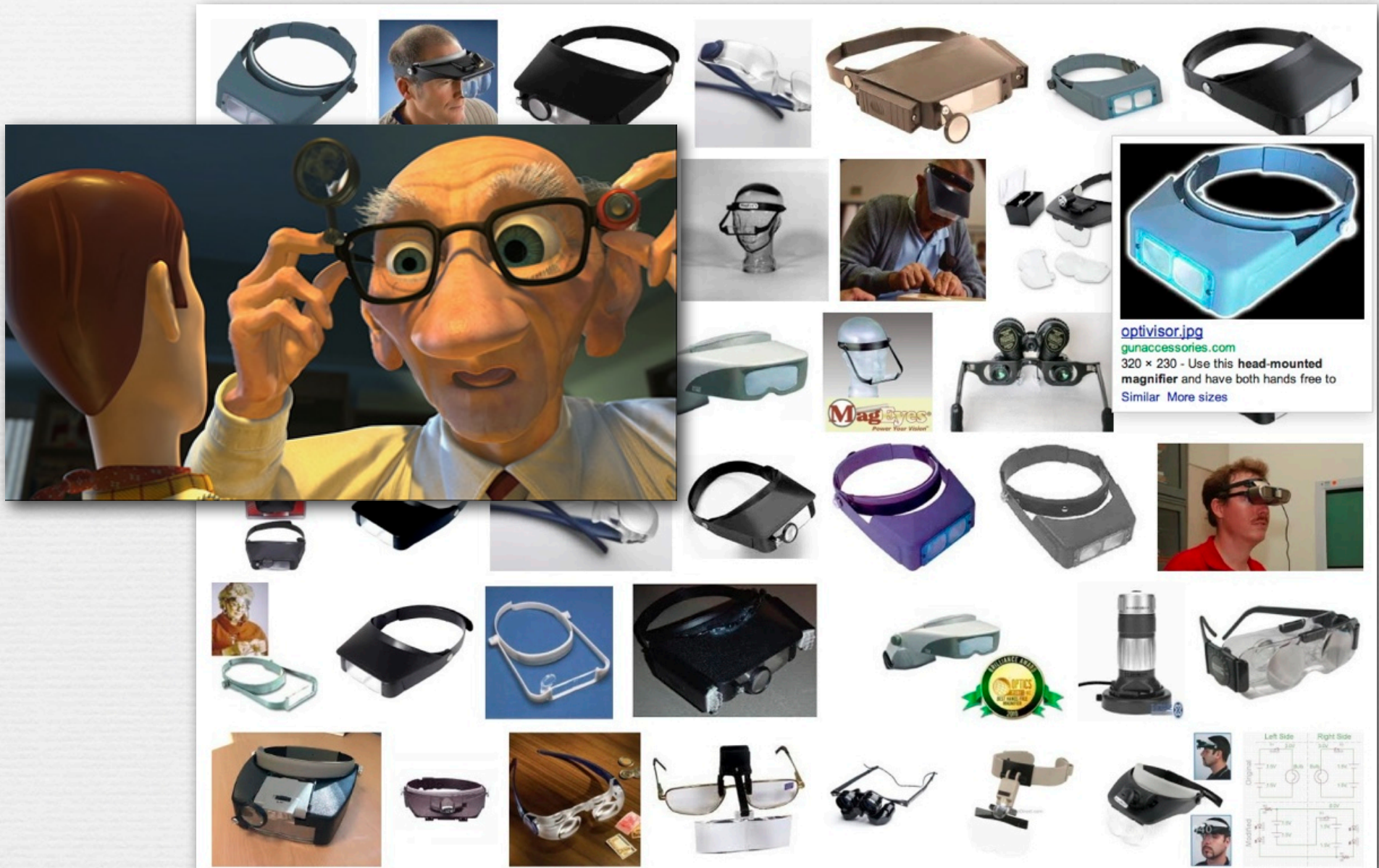
- ◆ align the shots
- ◆ match histograms
- ◆ apply median filter

# Superhero vision

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- ◆ seeing in the dark
- ◆ seeing through objects
- ◆ magnifying glass, telescopic vision

# Head-mounted magnifiers



# Camera-based magnifiers

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- ◆ optical zoom
  - requires a long optical path



- ◆ digital zoom (cropping)
  - requires a high pixel count, hence a thick camera



Nokia 808

- ◆ super-resolution
  - results typically look oversharpened

# Beyond SLRs: Superhero vision

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- ◆ seeing in the dark
- ◆ seeing through objects
- ◆ magnifying glass, telescopic vision
- ◆ slowing down motion





(Dogs in Slow Motion, Devin Graham)

<https://www.youtube.com/watch?v=7ZIjkvdz4Ko>

# Superhero vision

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- ◆ seeing in the dark
- ◆ seeing through objects
- ◆ magnifying glass, telescopic vision
- ◆ slowing down motion
- ◆ motion magnification, change magnification

# Motion magnification

[Liu, SIGGRAPH 2005]

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- ◆ can this be done using a (shaky) handheld camera?
- ◆ can it be computed on a (slow) mobile device?

# Change magnification

[Wu, SIGGRAPH 2012]

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- ◆ how much SNR is needed to detect this signal?
- ◆ is it socially acceptable to run this on Glass?

# Superhero vision

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- ◆ seeing in the dark
- ◆ seeing through objects
- ◆ magnifying glass, telescopic vision
- ◆ slowing down motion
- ◆ motion magnification, change magnification
- ◆ language translation

# Word Lens

(app for iOS and Android)

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- ◆ mediocre translation, but clever user interface
- ◆ recently bought by Google, runs on Glass

# Superhero vision

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- ◆ seeing in the dark
- ◆ seeing through objects
- ◆ magnifying glass, telescopic vision
- ◆ slowing down motion
- ◆ motion magnification, change magnification
- ◆ language translation
- ◆ face recognition

# If you met this man at a party...

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- *name:* Jack Sparrow
- *address:* Black Pearl
- *profession:* pirate
- *net worth:* zero
- *spouse:* many
- *criminal record:* long



# Face recognition

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- ◆ recognition from uncontrolled photos is still sci-fi
  - ◆ Google has pro-actively prohibited it on Glass
- 

- ◆ it could eventually work
  - ◆ if it does, someone will build a device to do it
- 

- ◆ giving up anonymity  $\neq$  giving up privacy

# Parting thought: new business models

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- ◆ remote medical diagnosis
  - or agricultural, or mechanical
- ◆ pay or be paid for every picture you take
  - posting pictures of empty parking spaces
- ◆ instantly available cameras improve safety and security
  - “ok glass, report that unsafe driver!”
  - personal safety in bad neighborhoods

# Parting thought: new aesthetics

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- ◆ new technologies begin by mimicking old technologies, but eventually develop their own idioms



Georges Méliès, *20,000 Leagues Under the Sea* (1907)



Canon 5DII, 1/400 sec



Canon 5DII, average of 15 shots of 1/6 sec





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# SynthCam

SynthCam is an app for the iPhone 4, 3GS, iPod Touch 4G, and iPad2  
(requires iOS 4.2 or higher)

Price: \$0.99      Current version: 2.0

Available on the iPhone  
**App Store**