# High Dynamic Range Imaging and Visual Perception

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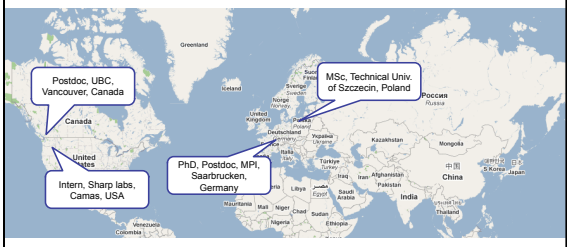
## Geo-Bio

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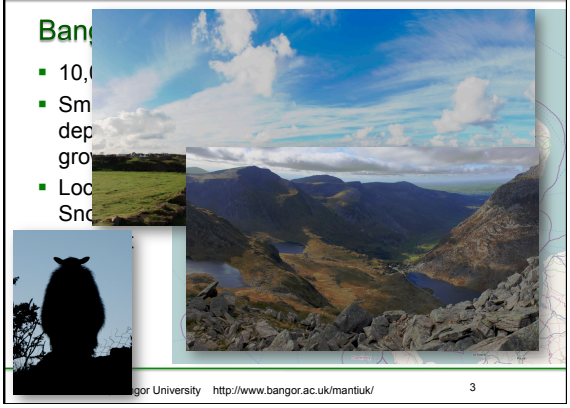
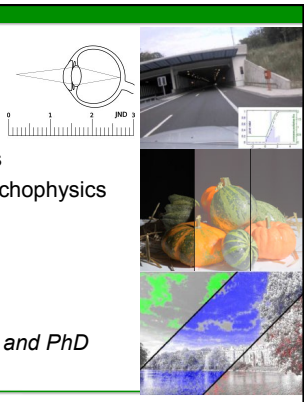




## Research Focus

- High dynamic range
- Visual perception
- Image quality metrics
- Psychometrics & psychophysics for graphics
- Image manipulation
- Tone mapping
- Video compression
- *Looking for postdocs and PhD students!*






## Outline

- What is high dynamic range imaging?
  - And why it matters?
- High dynamic range pipeline
  - Capture
  - Storage / compression
  - Display
  - Visual metrics

## Which image is computer generated?

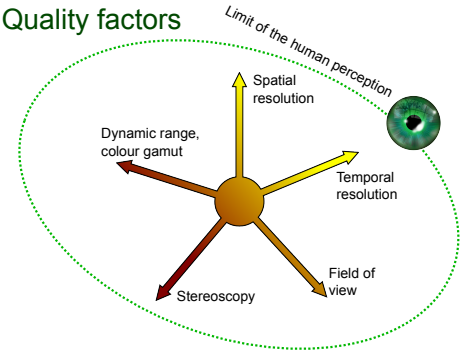
Source: http://www.mercedes-benz.co.uk/

## Computer graphics

- ☑ ~~Photorealism~~
- ☐ Perceptual realism
  - "holodeck" experience
  - window into a virtual world



## Quality factors






## Dynamic Range




## HDR display

Standard dynamic range

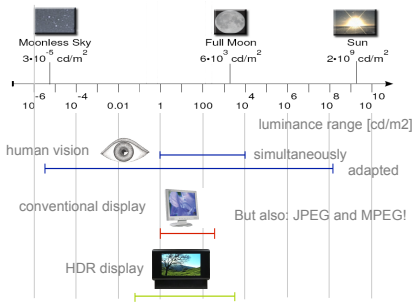


## HDR display

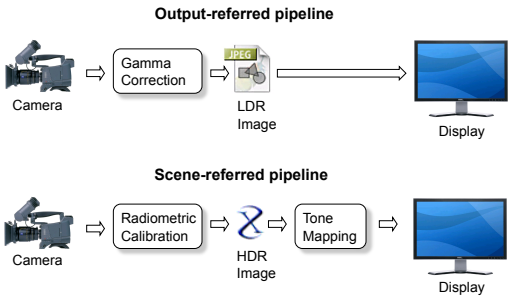
High dynamic range



## High dynamic range



## Output-referred and scene-referred

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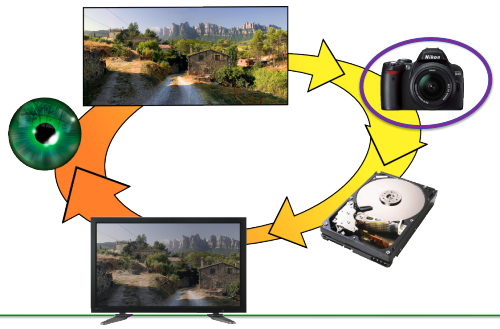
## Impact of HDR

- Redefine imaging as we know it today
- Beyond limitations of cameras
- Beyond limitations of displays
- Preserve at least all information visible to the human eye

## Example of HDR workflow

## Imaging Pipeline



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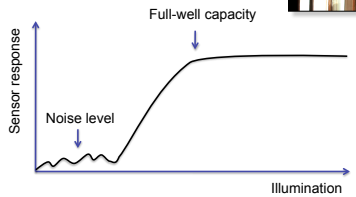
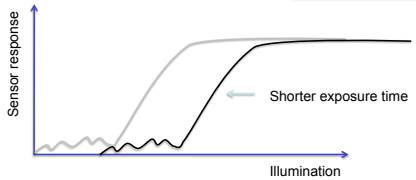
## HDR Capture

- Capture under- and over-exposed image regions

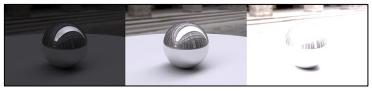



## HDR Capture

- Capture under- and over-exposed image regions



## Multi-exposure HDR capture



- Combine information from multiple-exposures
  - Weighted average
- Pros.
  - Can capture any dynamic range
  - Reduces noise level
- Cons.
  - Problematic for moving scenes

## Impact of multi-exposure HDR

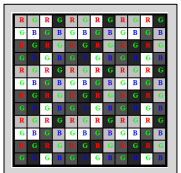
- Debevec, P.E. and Malik, J., *Recovering high dynamic range radiance maps from photographs, SIGGRAPH'97*
  - *1100 citations on Google Scholar*
  - *Not the first and not the best technique*
- *HDR Photography*
  - *Books on Amazon*


## Multi-exposure in photography

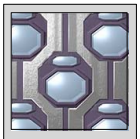
- The first photographic films could capture very low dynamic range
- In 1858 H.P. Robinson used 5 exposures to capture a high dynamic range scene
- The dynamic range of film negatives improved significantly over the years

1858 Robson *Fading away*
(combined 5 negatives)

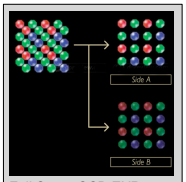
## HDR camera sensors



Assorted pixels
[Nayar Narasimhan 02]



Fuji Super CCD SR sensor



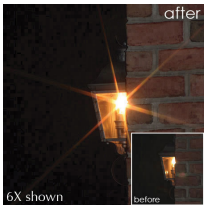

Fuji Super CCD EXR sensor



## Computational photography HDR capture

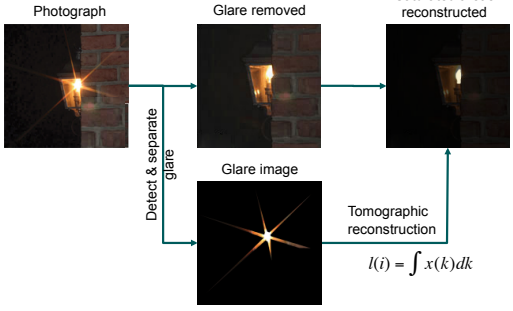
[Rouf, Mantiuk et al., CVPR'11 submission]


Star (cross-screen) filter





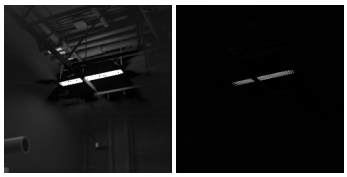

## HDR reconstruction



## Results

Photograph

Reconstruction



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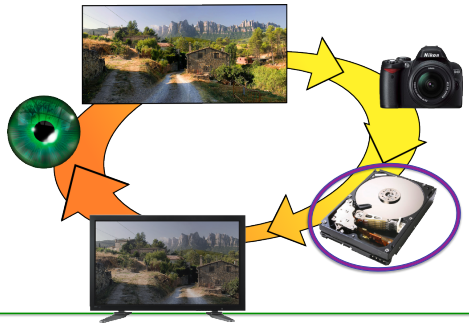
## Imaging Pipeline



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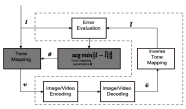
## High dynamic range video encoding

Perception-motivated
HDR Video Compression
[Mantiuk et al., SIGGRAPH'04]

SIGGRAPH2006 DOLBY


Backward compatible
HDR MPEG Encoding
[Mantiuk et al., SIGGRAPH'06]



Optimizing Tone-mapping
for HDR Video Compression
IEEE Image Processing submission

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## High dynamic range video compression


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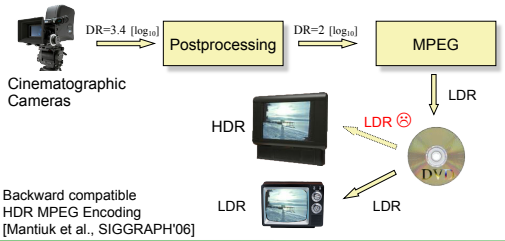
## Backward-compatible HDR Video Compression

SIGGRAPH2006
30 July - 3 August Boston




Backward compatible
HDR MPEG Encoding
[Mantiuk et al., SIGGRAPH'06]

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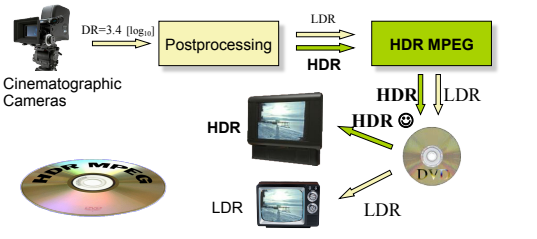
## Backward-compatible HDR Video Compression

SIGGRAPH2006
30 July - 3 August Boston

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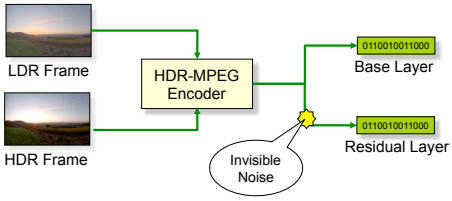
## HDR MPEG Data Flow

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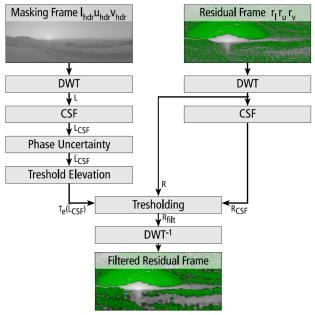
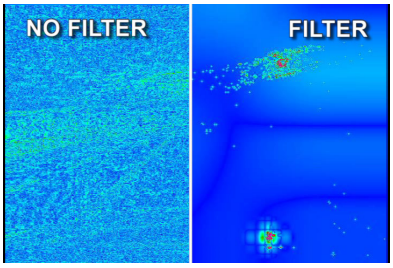
## Filtering of Invisible Noise




## Filter Invisible Noise - Demo

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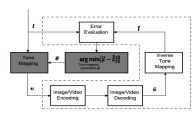
## High dynamic range video encoding

Perception-motivated HDR Video Compression [Mantiuk et al., SIGGRAPH'04]

SIGGRAPH2006 DOLBY


Backward compatible HDR MPEG Encoding [Mantiuk et al., SIGGRAPH'06]

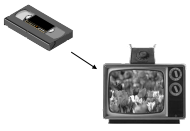


Optimizing Tone-mapping for HDR Video Compression
IEEE Image Processing

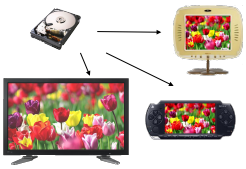
## Video encoding: Future directions

- Multi-target video encoding
  - Multiple color-grading profiles
  - Multiple resolutions
  - Varied audience

Some time ago:



Currently:



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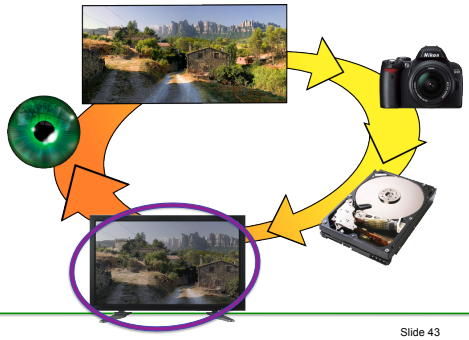
## Imaging Pipeline



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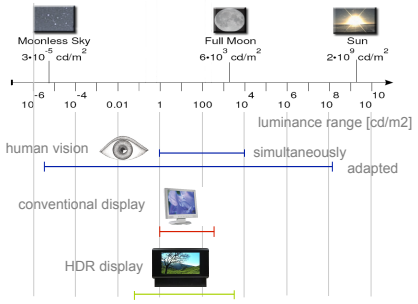
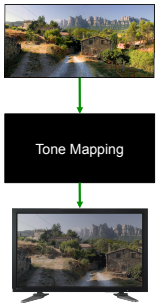
## Tone mapping




## Tone mapping

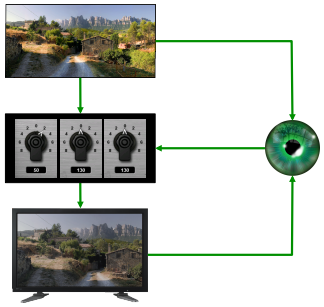
Reduce image contrast so that it can be shown on a display device.

## Tone Mapping – least distortion





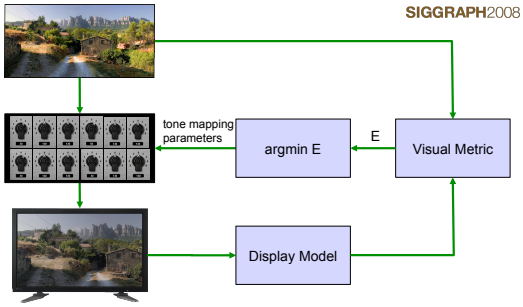

## Tone Mapping – typical approach





## Display Adaptive Tone Mapping

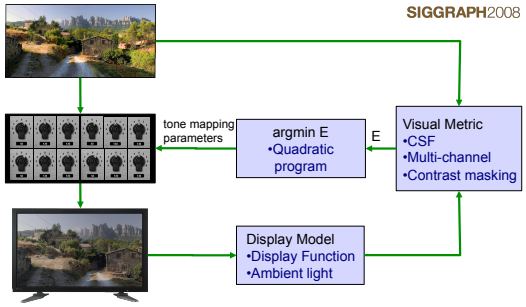
SIGGRAPH2008





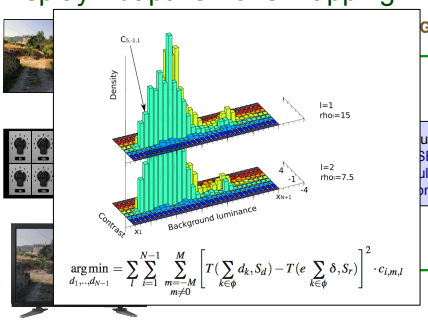

## Display Adaptive Tone Mapping

SIGGRAPH2008



## Display Adaptive Tone Mapping

GGRAPH2008




ual Metric
SF
lti-channel
ntrast masking

$$\arg\min_{d_1,\ldots,d_{N-1}} = \sum_{l}\sum_{i=1}^{N-1}\sum_{m=-M,m\neq 0}^{M}\left[T\left(\sum_{k\in\phi} d_k, S_d\right) - T\left(e\sum_{k\in\phi}\delta_k, S_r\right)\right]^2 \cdot c_{i,m,l}$$

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## DLP projector image: dark room

Non-adaptive TMO | Display adaptive TMO

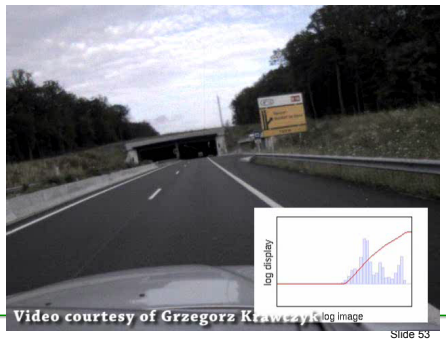
<1 lux

## DLP projector image: bright room

Non-adaptive TMO | Display adaptive TMO

400 lux

## Results: Video




Video courtesy of Grzegorz Krawczyk

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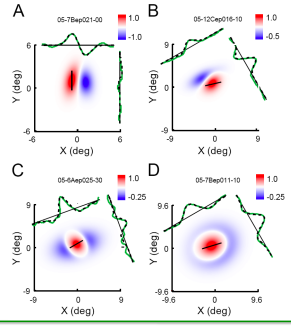
## Perception-inspired contrast enhancement

Enhance image details without producing disturbing artifacts.

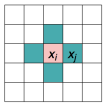
Rafał Mantiuk

## Retinal receptive fields




Source: http://www7.bpe.es.osaka-u.ac.jp/publications/CSRF2008-9/

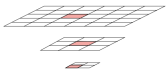
## Multi-scale, over-complete contrast representation




- Difference between the pixel and its four neighbors

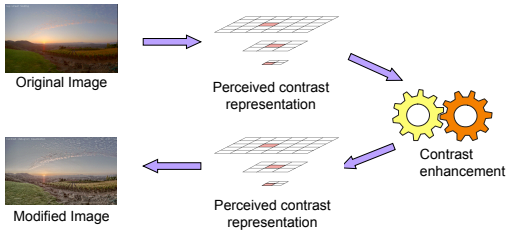
$$G^k_{i,j} = x_i - x_j = log_{10}(L^k_i / L^k_j)$$

- In the logarithmic domain



- For each level of the Gaussian pyramid

## Operate on perceived contrast rather than pixel values




Rationale: Human eye is more sensitive to contrast than luminance



## Reconstructing image from contrast

- Reconstruction can be formulated as the minimization problem:

$$f(x_1, x_2, \ldots, x_N) = \sum_{k=1}^{K} \sum_{i=1}^{N} \sum_{j=1}^{M} (G^k_{i,j} - \hat{G}^k_{i,j})^2$$

- where:
  - $x_1, x_2, \ldots, x_N$ pixel values
  - $\hat{G}^k_{i,j}$ desired contrast
  - $G^k_{i,j}$ realized contrast
- Solved with conjugate gradient

## Contrast Equalization: Examples

Log-Linea mapping

Contrast equalization



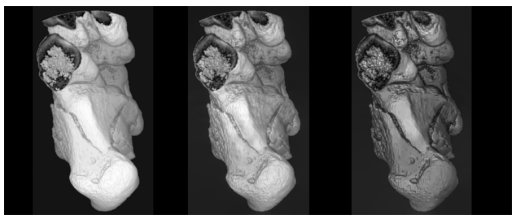
## Contrast Equalization: Examples

Log-Linear Sc ast mapping

Contrast equalization



## Contrast TMO can enchance medical images without introducing artifacts



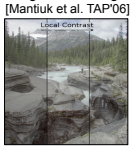
## Tone mapping


Color-correction for tone-mapping
[Mantiuk et al., Eurographics 2009 ]

SIGGRAPH2008
SHARP

Display Adaptive Tone Mapping
[Mantiuk et al., SIGGRAPH'08]

Contrast Domain Image Processing
[Mantiuk et al. TAP'06]




Modeling Generic TMO
[Mantiuk & Seidel, EUROGRAPHICS'08]

Enhancement of Bright Video Features
[Didyk, Mantiuk, Hein, Seidel, EGSR'08]

## Blur-aware image downsampling

- Create a small-resolution image that would preserve the blur of the full resolution image

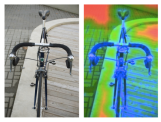
Standard downsampling

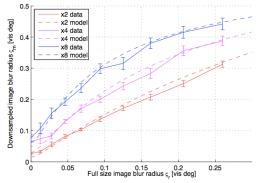
Blur-aware downsampling

Trentacoste, Mantiuk and Heidrich, Eurographics 2011

## Blur-aware image downsampling

- How much blur is in the image?
  - Ratio of the original and additionally blurred image is a robust blur estimator
- How much blur needs to be added?
  - Blur-matching experiment

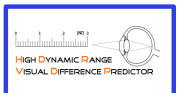





## Imaging Pipeline

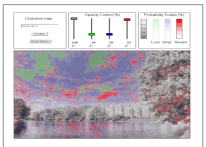


## Visual Perception



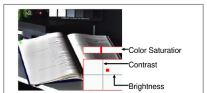

High Dynamic Range Visual Difference Predictor
[Mantiuk et al., SPIE HVEI'05]

Brightness of Glare Illusion
[Yoshida, Mantiuk, et al., APGV 08]

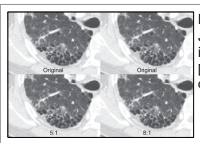


Dynamic Range Invariant Quality Assessment,
[Aydin, Mantiuk, et al. SIGGRAPH'08]

SIGGRAPH2008




Preferred image reproduction on HDR displays
[Yoshida, Mantiuk, et al., EUROGRAPHICS'06]



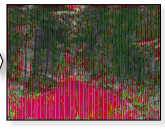

Prediction of JPEG2K artifacts in CT images
[American Journal of Roentgenology '08]

American Journal of Roentgenology

## HDR-VDP: Visible Difference Predictor for High Dynamic Range Images

o Display size
o Display resolution
o Viewing distance

HDR-VDP

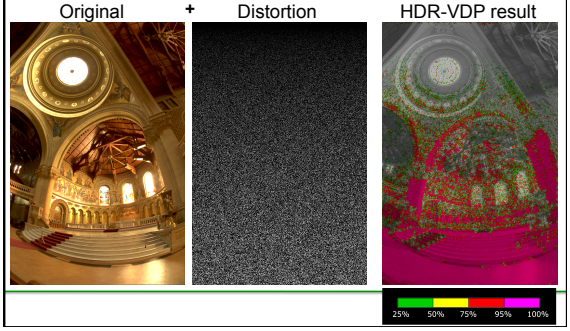


- Can the human eye see the differences between two images?

Source code available at: http://hdrvdp.sf.net/

## How to interpret HDR-VDP results?

Original + Distortion HDR-VDP result

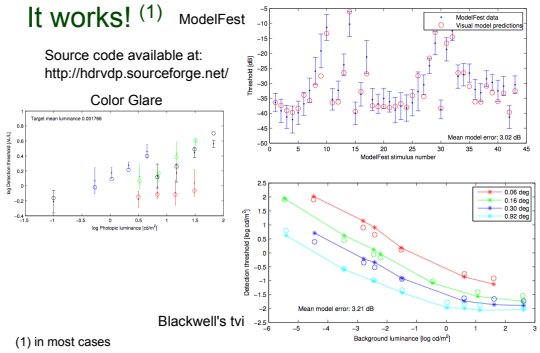



## It works! (1)

ModelFest

Source code available at:
http://hdrvdp.sourceforge.net/

Color Glare




Blackwell's tvi

(1) in most cases

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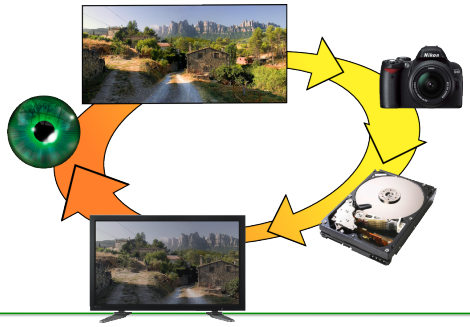
## Summary



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## Why to go for PhD?

- You work for yourself (not a company)
- You have freedom to develop your passion
- Exit scenarios
  - You get your PhD
  - Make great invention, get your own start-up company (and become millionaire)
  - Your employability improves as you do your PhD (more experience)

## Why to go for PhD to Bangor?

- Internationally-recognized research
- Contacts
  - Intel, Nvidia, Dolby, Philips, Adobe
- Language
- International-experience
- Nice place to live
  - 10 min to coastline
  - 15 min to Snowdonia
- Interested in PhD or postdoc?
  - Send me an e-mail or call.