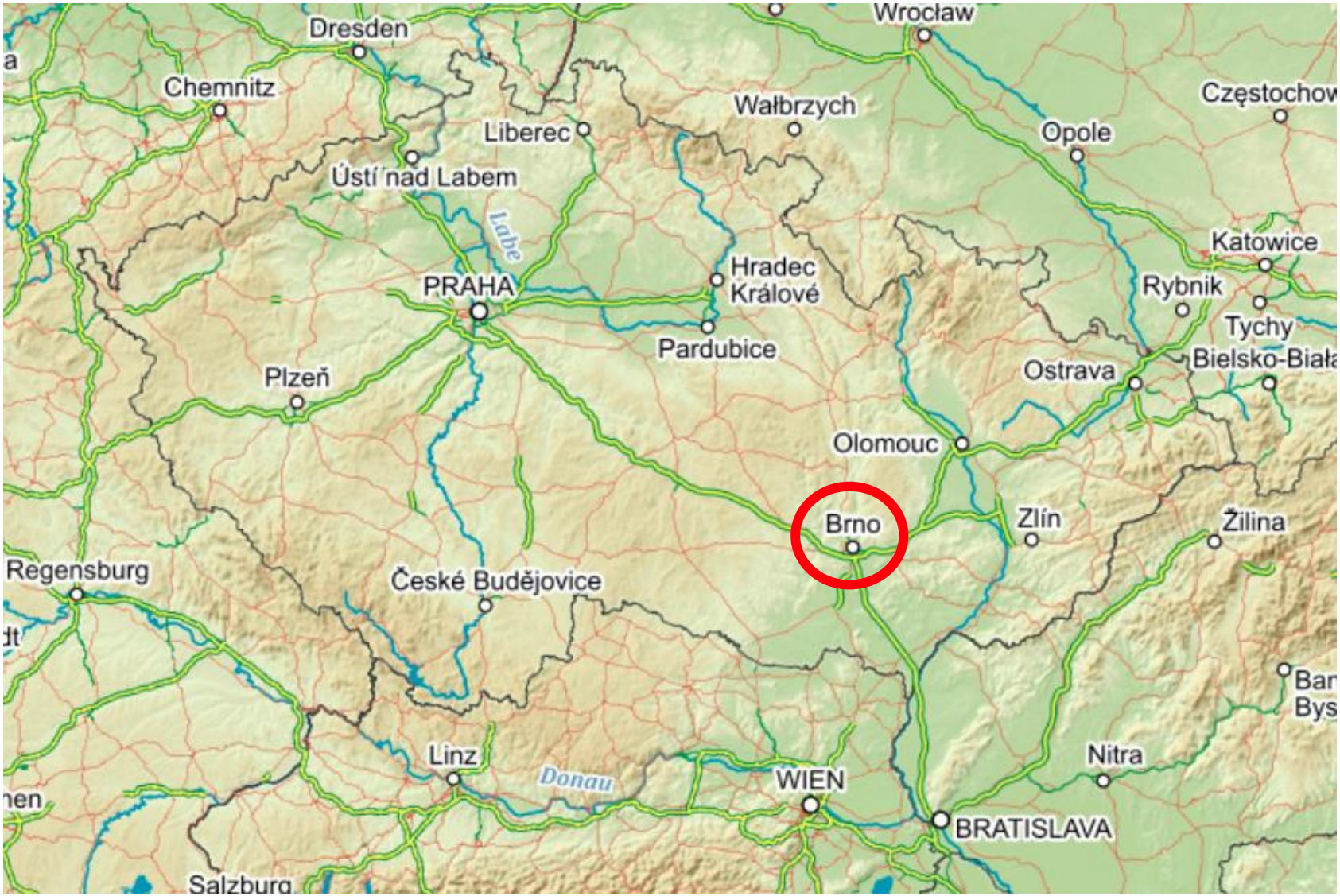
Computational Photography

Martin Čadík

Brno University of Technology, Faculty of Information Technology, CPhoto@FIT
Božetěchova 1/2, 612 66 Brno, Czech Republic
cadik@fit.vutbr.cz, http://cadik.posvete.cz

Brno University of Technology, Czech Republic




HEROIBUS

[Popková 18]

[Jaška 18]

[Jaška 18]

[Skála 18]


[Krasňanský 17]
pepsi

[Zvěřina 18]

[Klusoň 17]

[Mošner 17]


[Tomešek 17]

[Popková 18]

[Ostroukh 17]

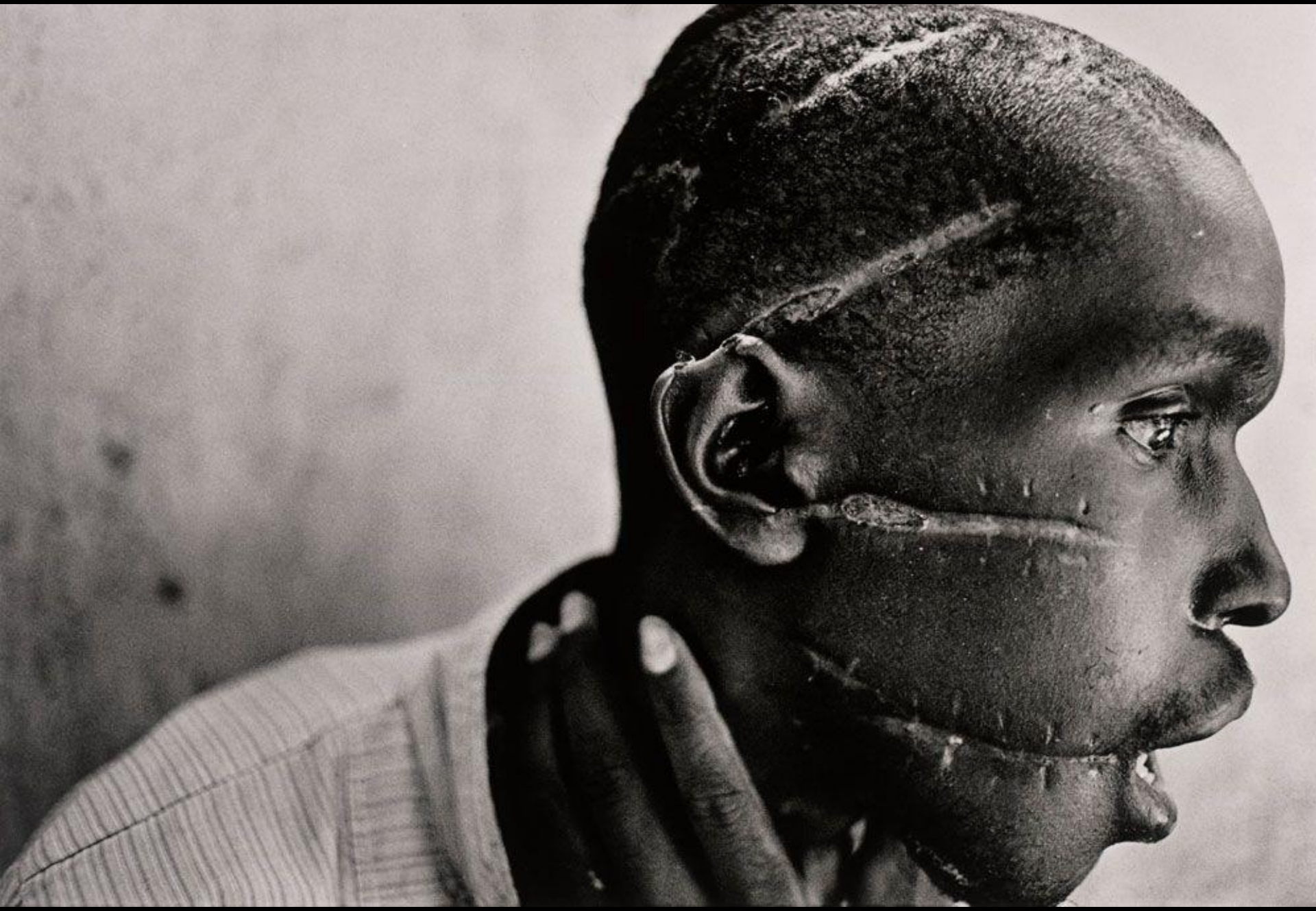
[Melcer 18]

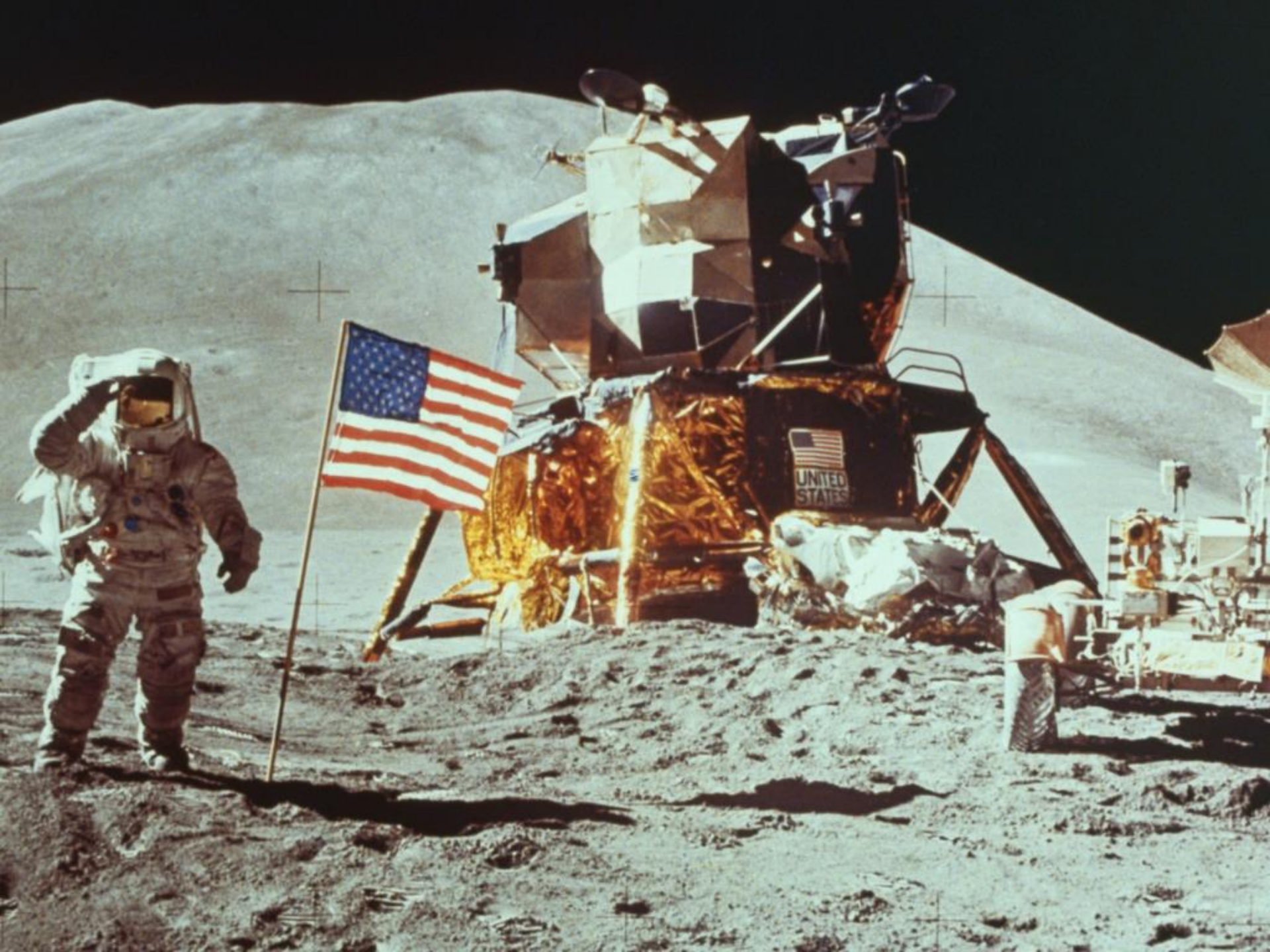
[Ostroukh 17]

[Ostroukh 17]

- CPhoto@FIT
  http://cphoto.fit.vutbr.cz/
  B.Sc., M.Sc., **Ph.D.** and other projects
- Computational Photography Course
  http://www.fit.vutbr.cz/study/course-l.php?id=12352
- VGS-IT - Invited Talks on Vision, Graphics, and Speech@FIT
  http://vgs-it.fit.vutbr.cz/
- HiVisualComputing Conference
  http://www.hiviscomp.cz/


WODKA
[VODKA]
GREYHOUND
Great Vodka. Priced Right.
JERSEY BOYS
BEST MUSICAL
2006 TONY AWARD WINNER
ALDO
Nocturnal.
CONAN
Why the city never sleeps?
all night.
So Much Happened Before Dorothy Dropped In.
WICKED
THE UNTOLD STORY OF THE WITCHES OF OZ
Tonight belong
PHAN
TADS Steaks
sbarro
sbarro
sbarro
sbarro
GIFTS
GIFTS
GIFTS
city outdoor
LA CAGE AUX FOLLES
JERRY HERMAN
LACAGE.COM
RNAL



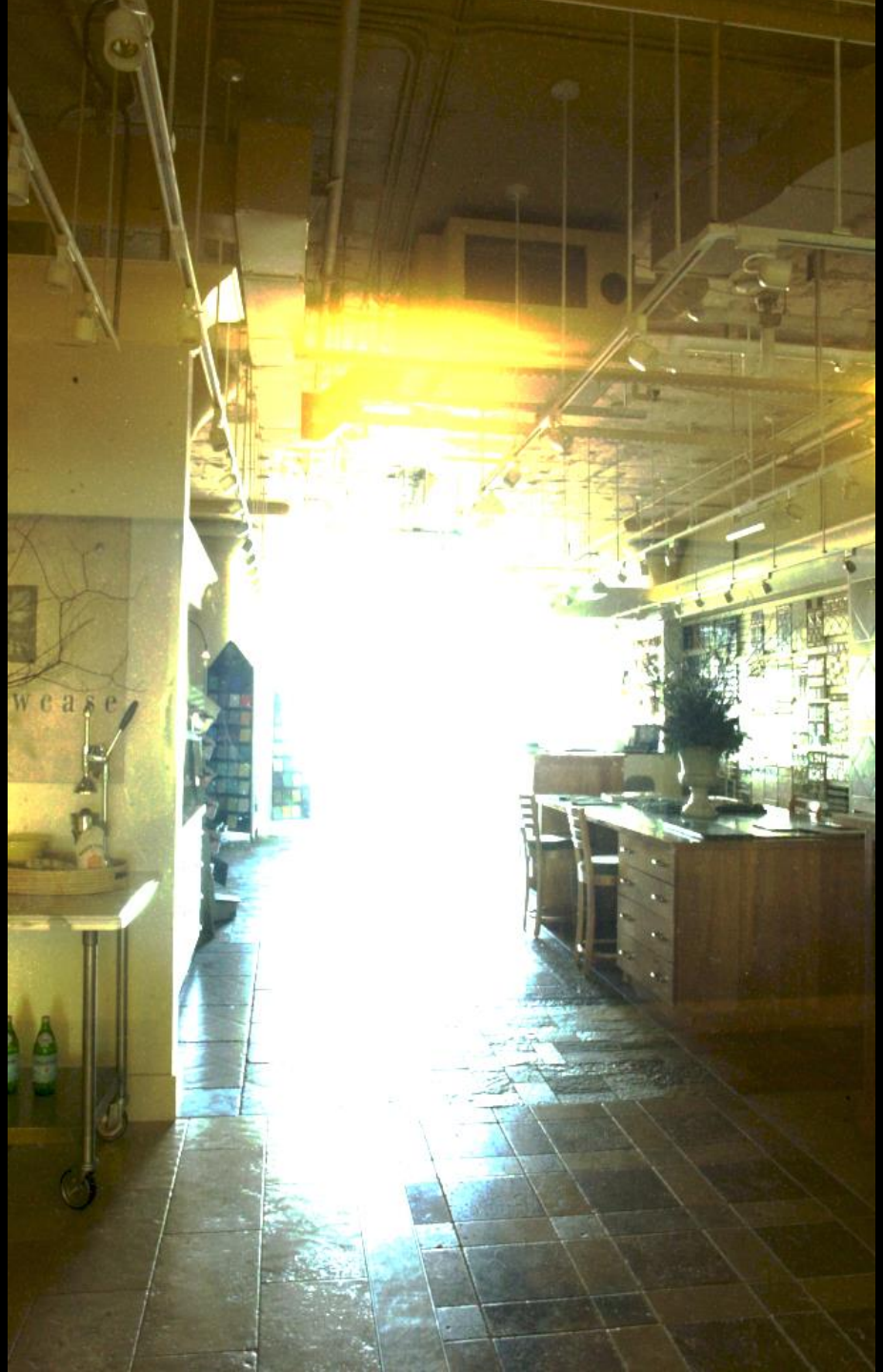

UNITED
STATES

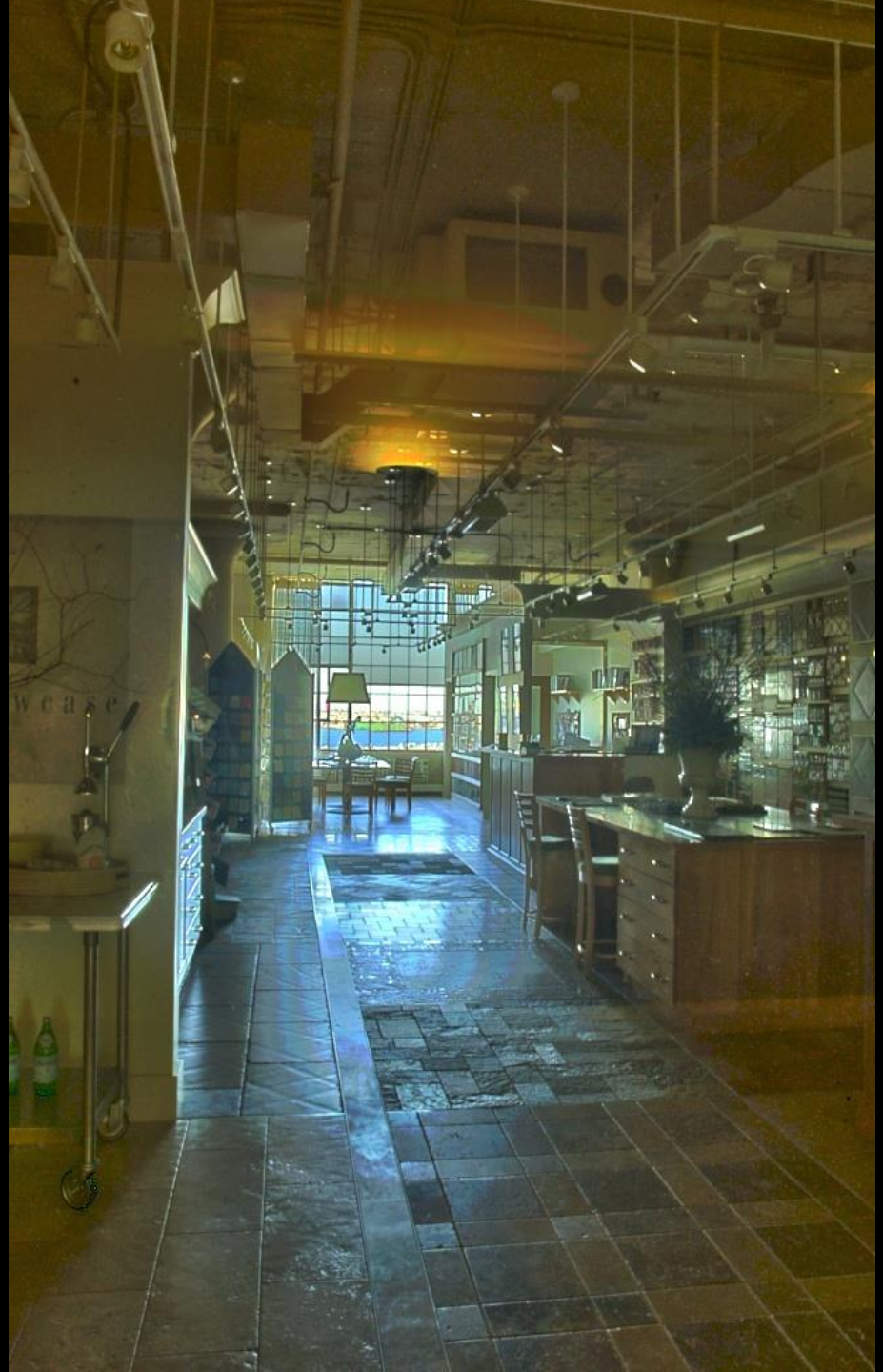

(c) 2012, http://mc.posvete.cz


YASHICA


Canon
NIKON

Cameras are Everywhere



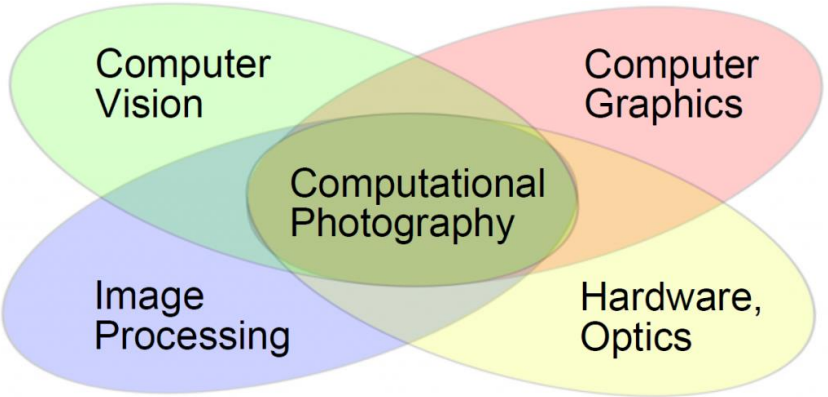


WHAT IS COMPUTATIONAL PHOTOGRAPHY?

Computational Photography

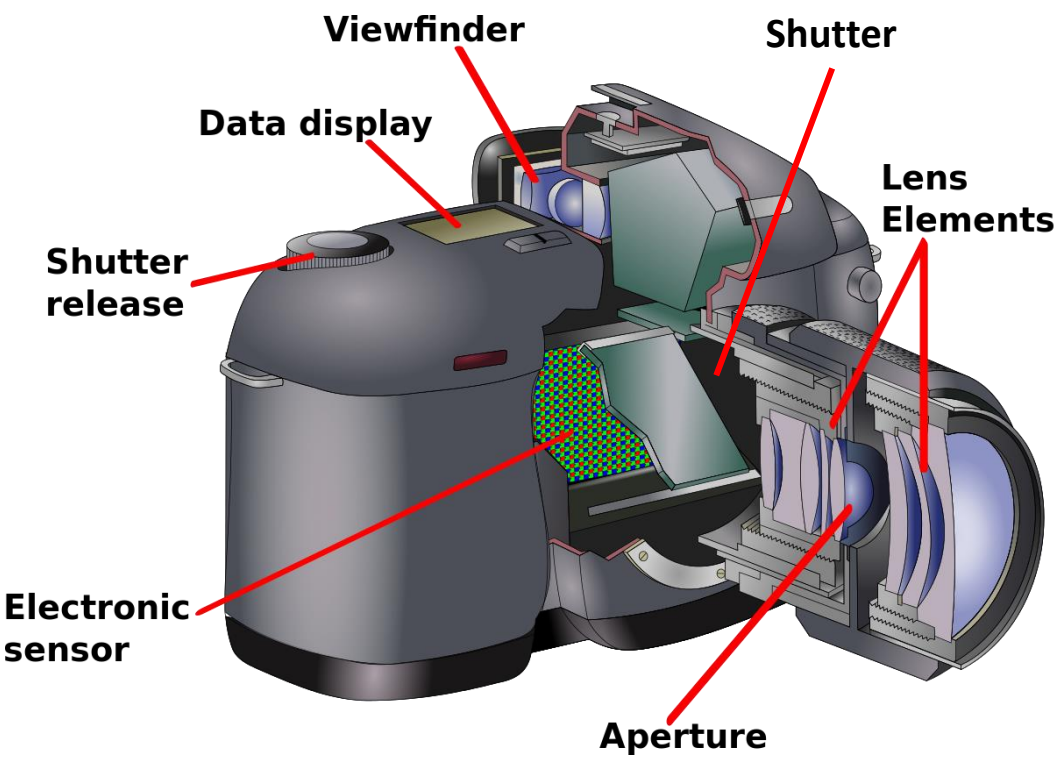
– Photography + computations = better pictures
– Images that go beyond the capabilities of traditional imaging systems

– Conferences
– Books
– Courses…



Photography Once Upon a Time

Photography Crash Course



- Lens and viewpoint determine perspective
- Aperture and shutter speed determine exposure
- Aperture and other effects determine depth of field
- Sensor records image

Photography Today

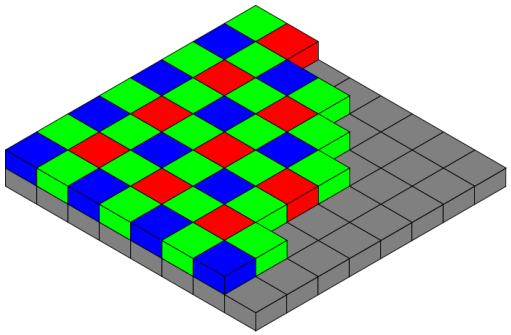
$$X = Lt$$

HOW COMPUTATIONAL PHOTOGRAPHY?

Cameras

- Optics + sensing + computation

- Already quite some computation (one may not be aware of)
  - De-mosaicing (Bayer pattern)
  - Blurring (to avoid moiré and aliasing)
  - Geometric corrections
  - …



HOW COMPUTATIONAL PHOTOGRAPHY: MULTIPLE EXPOSURES

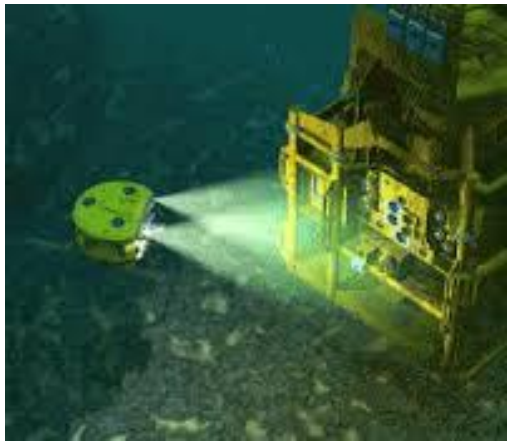
Field of View

- Human FOV = 200 x 135°
- Virtual wide-angle camera

[Panoramic San Francisco, 1851]

Underwater Imaging

- Mosaicking



Spherical Panorama

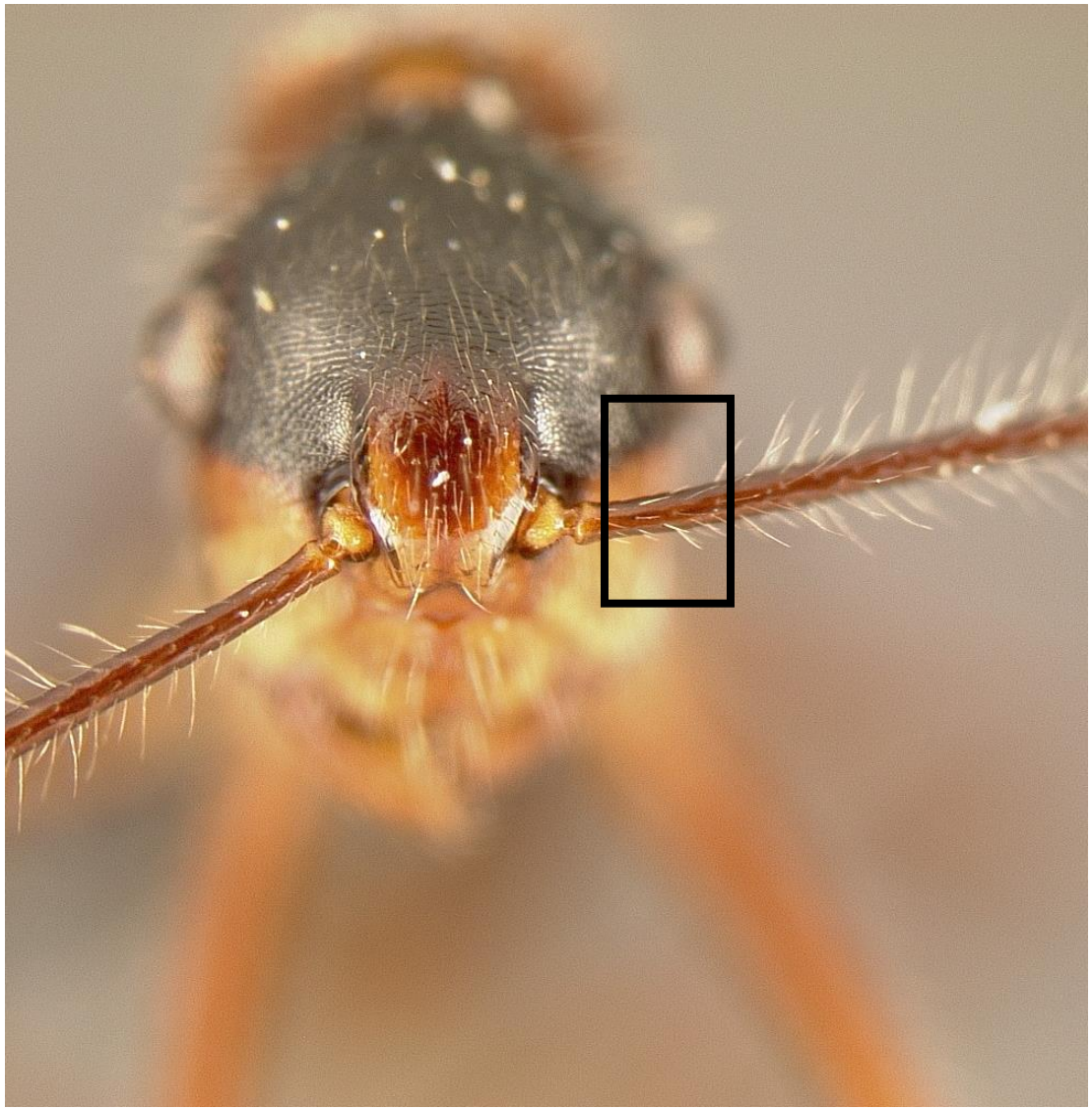
- http://www.fit.vutbr.cz/~cadik/VYF/lecture2018.html

Panorama Stitching Software

- Hugin
  - http://hugin.sourceforge.net/

- Panorama Tools
  - https://sourceforge.net/projects/panotools/

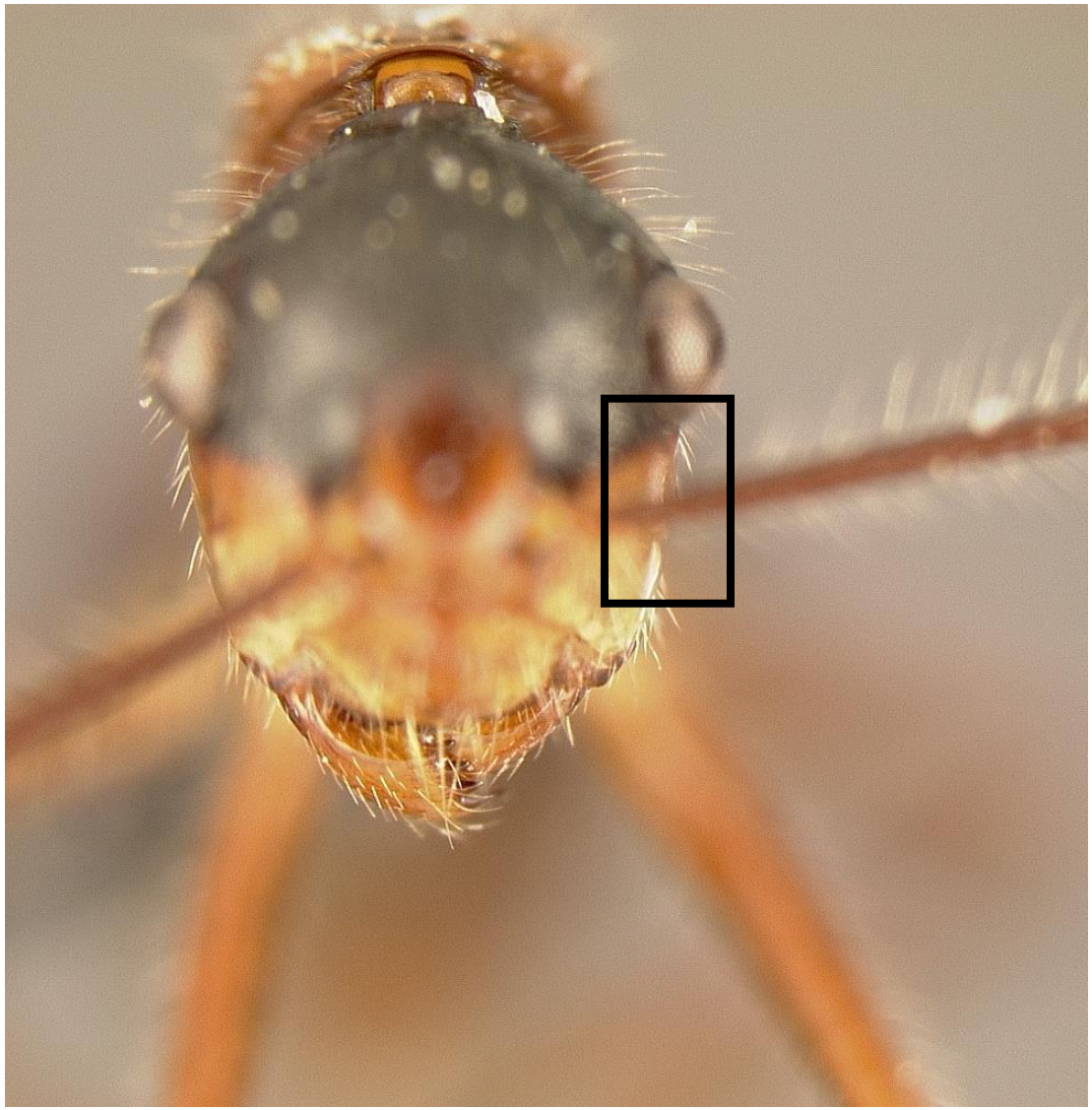
Depth of Field



[Agrawala et al., 2004]

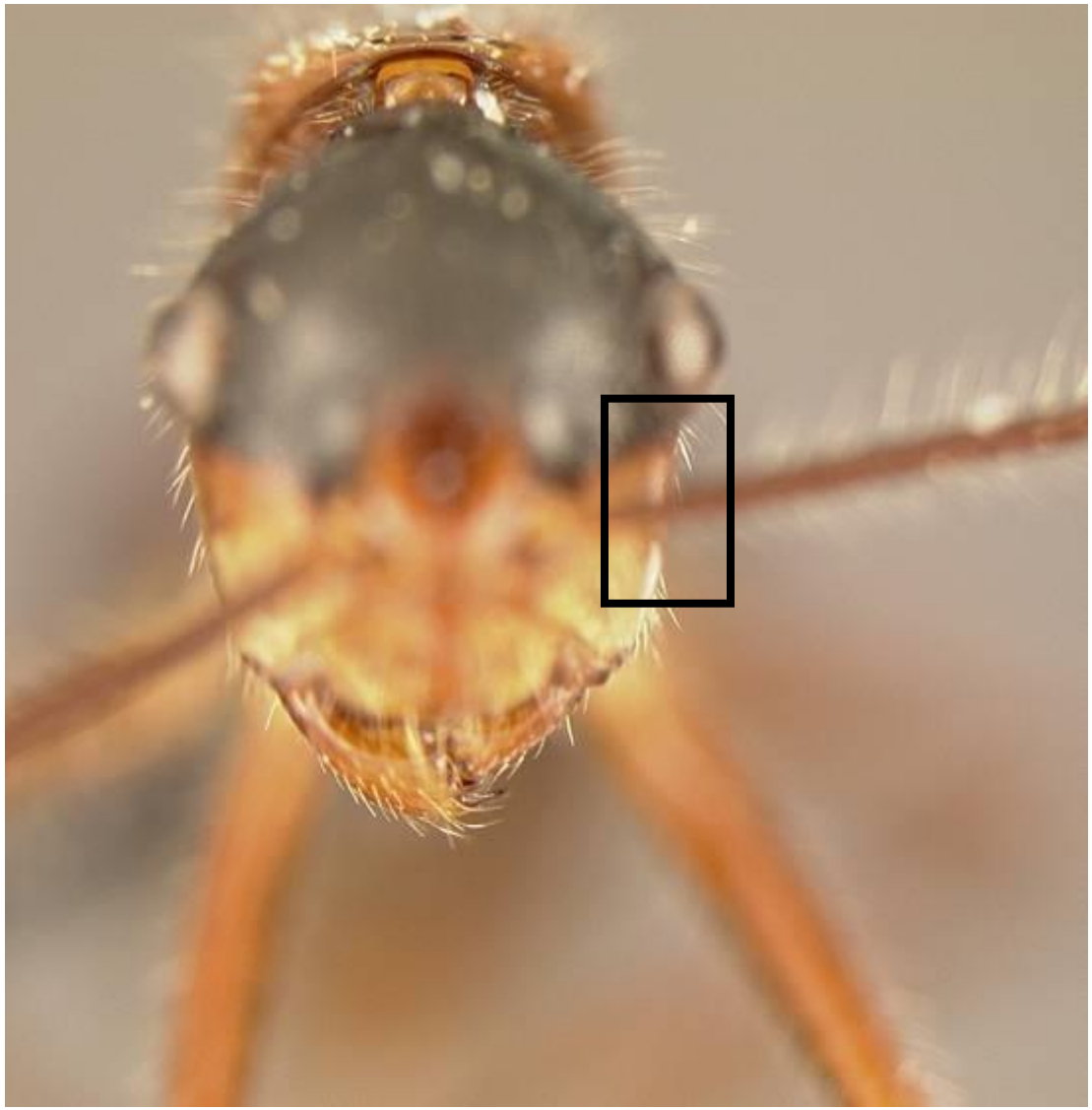
Near

Depth of Field



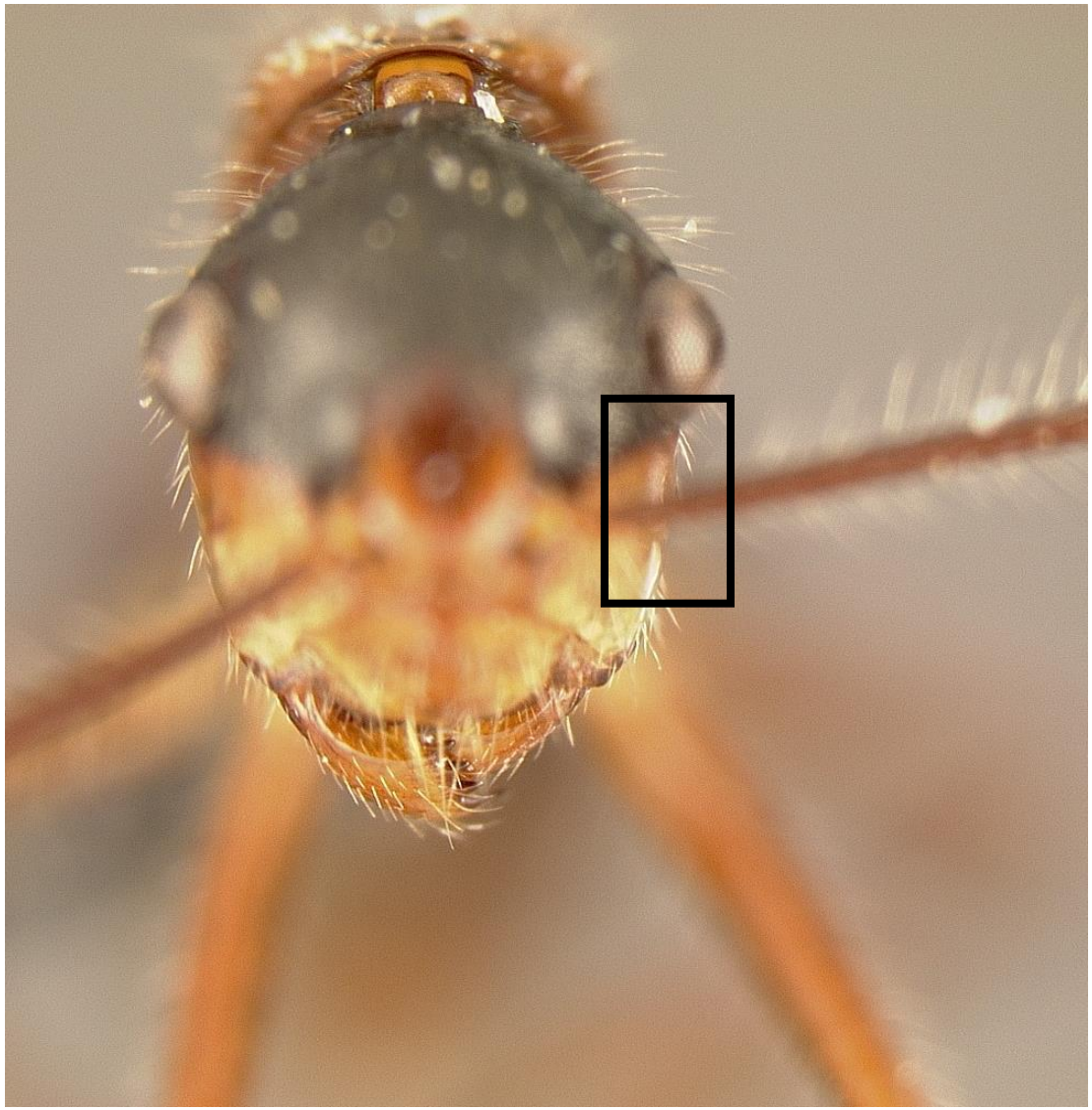
Far

Depth of Field



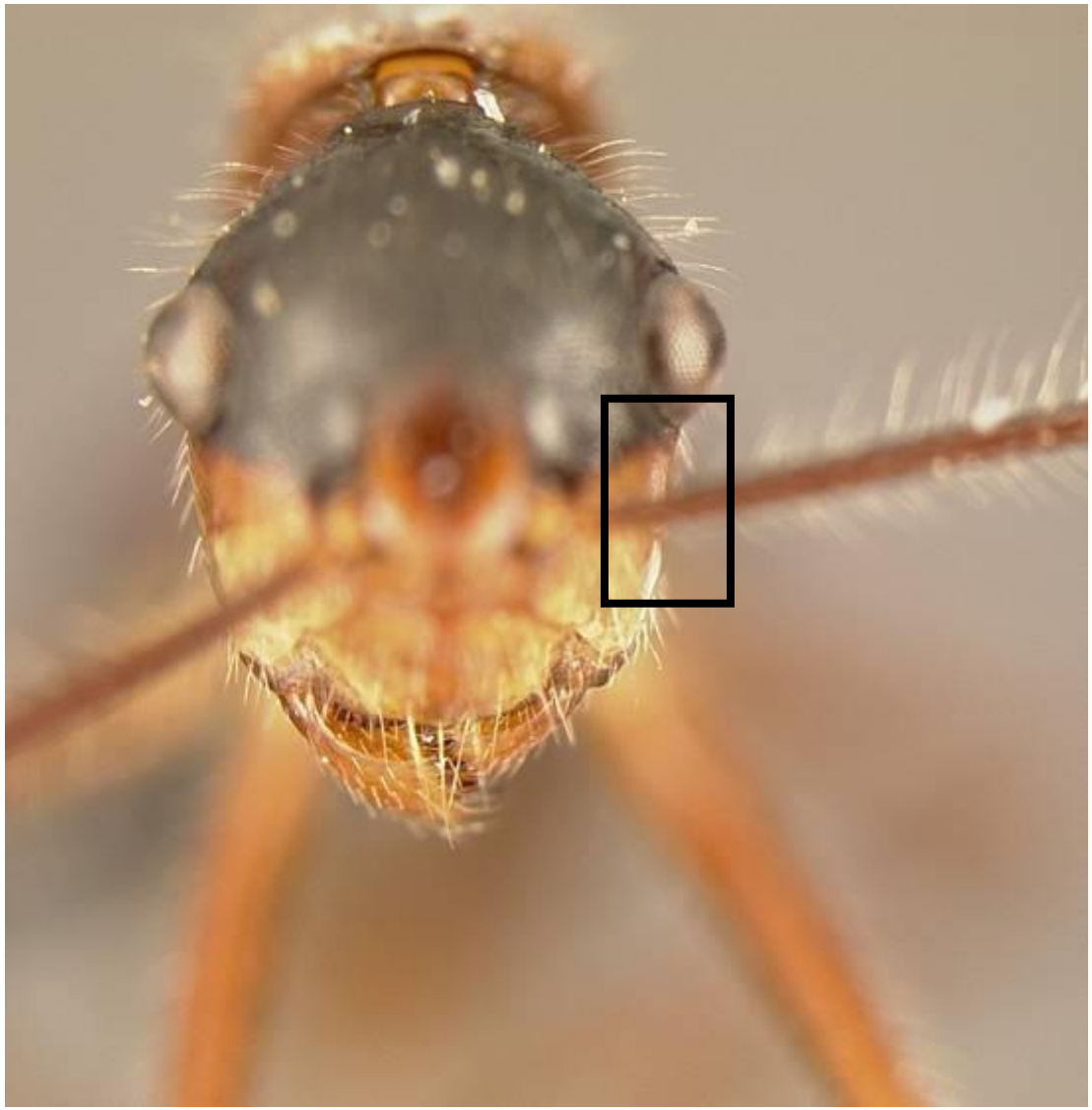
global maximum contrast image objective

Depth of Field



global maximum contrast image objective

Depth of Field



global maximum contrast image objective

Depth of Field

global maximum contrast image objective

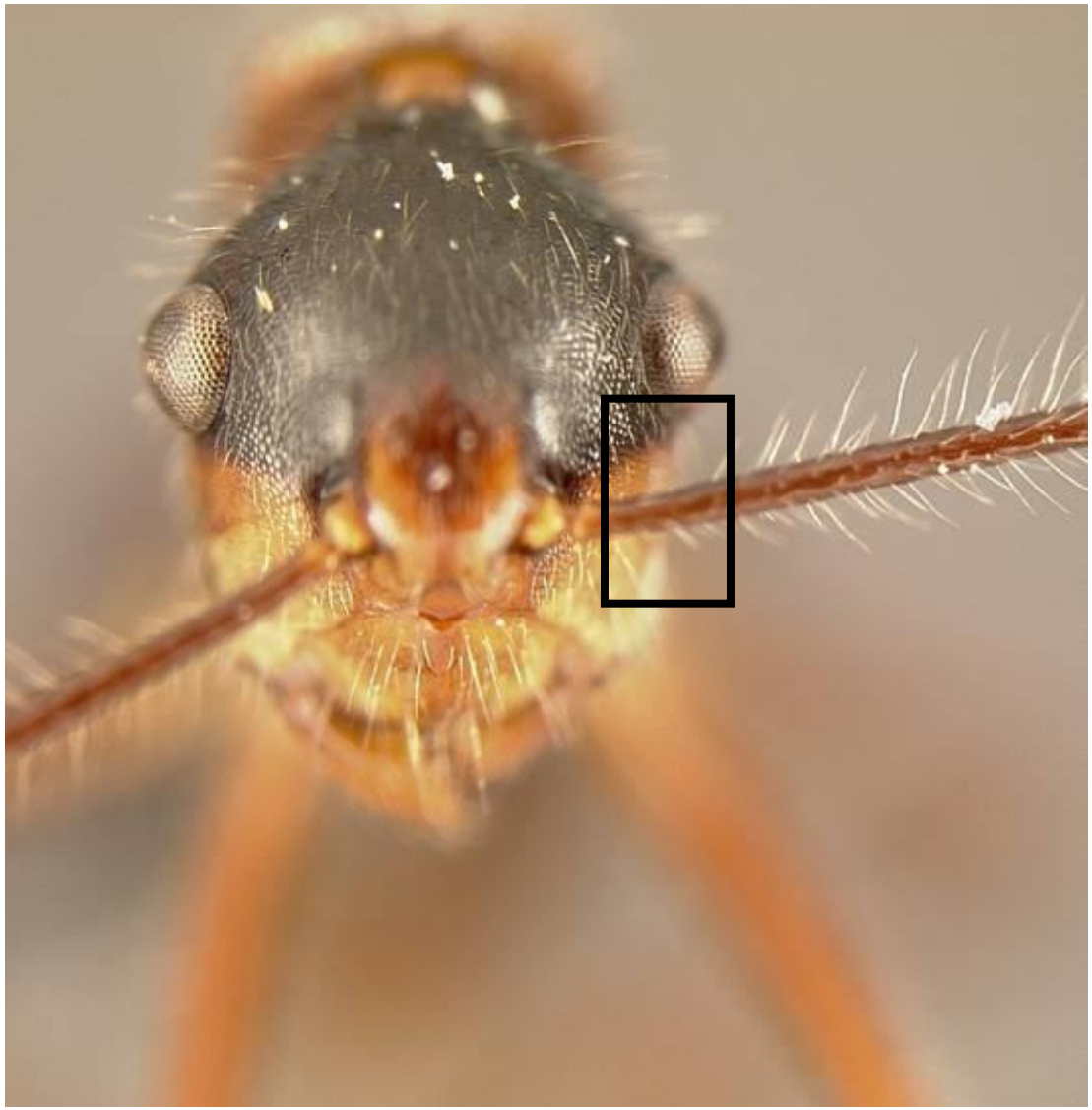
Depth of Field

global maximum contrast image objective

Depth of Field

global maximum contrast image objective

Depth of Field

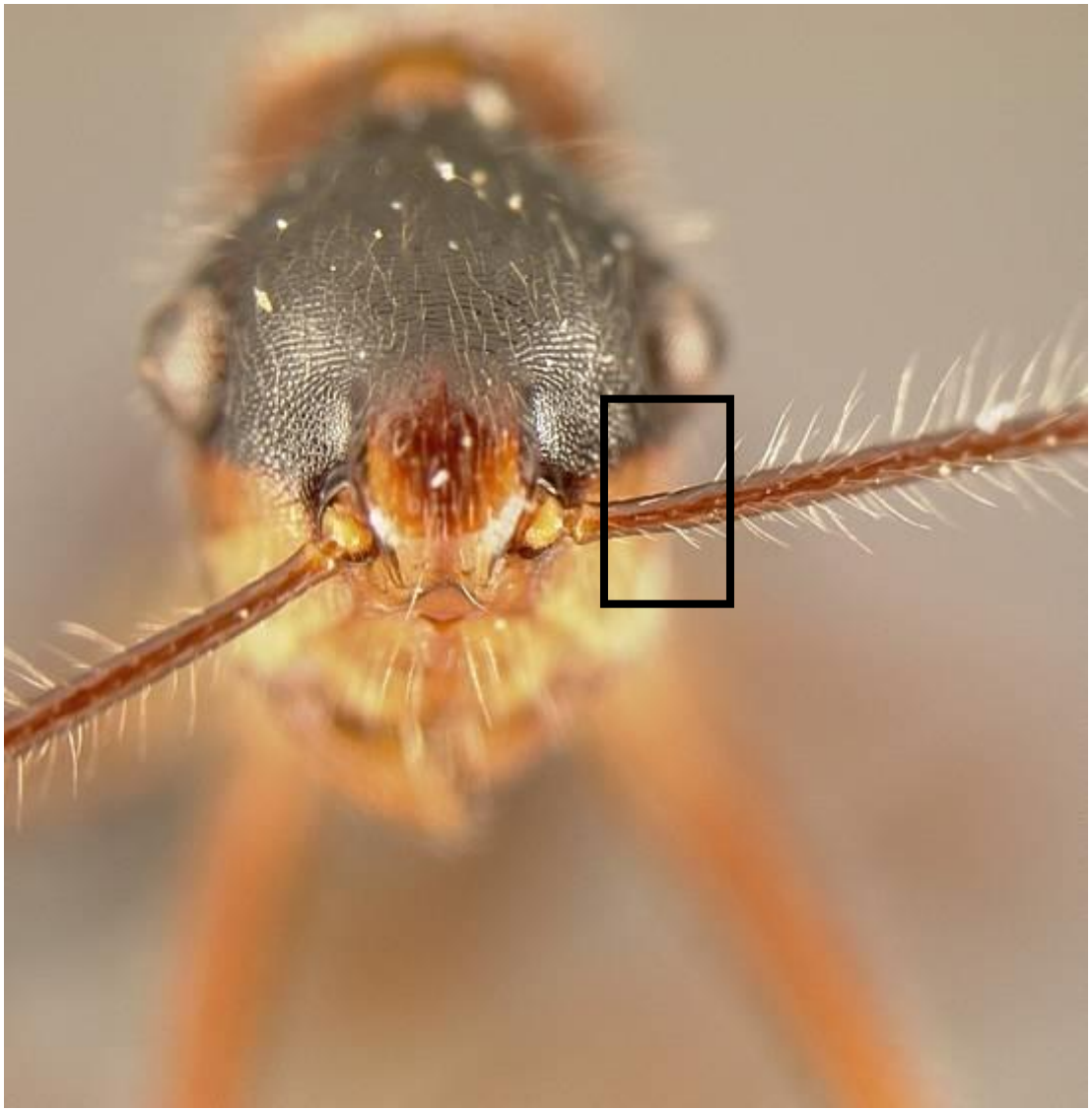


global maximum contrast image objective

Depth of Field

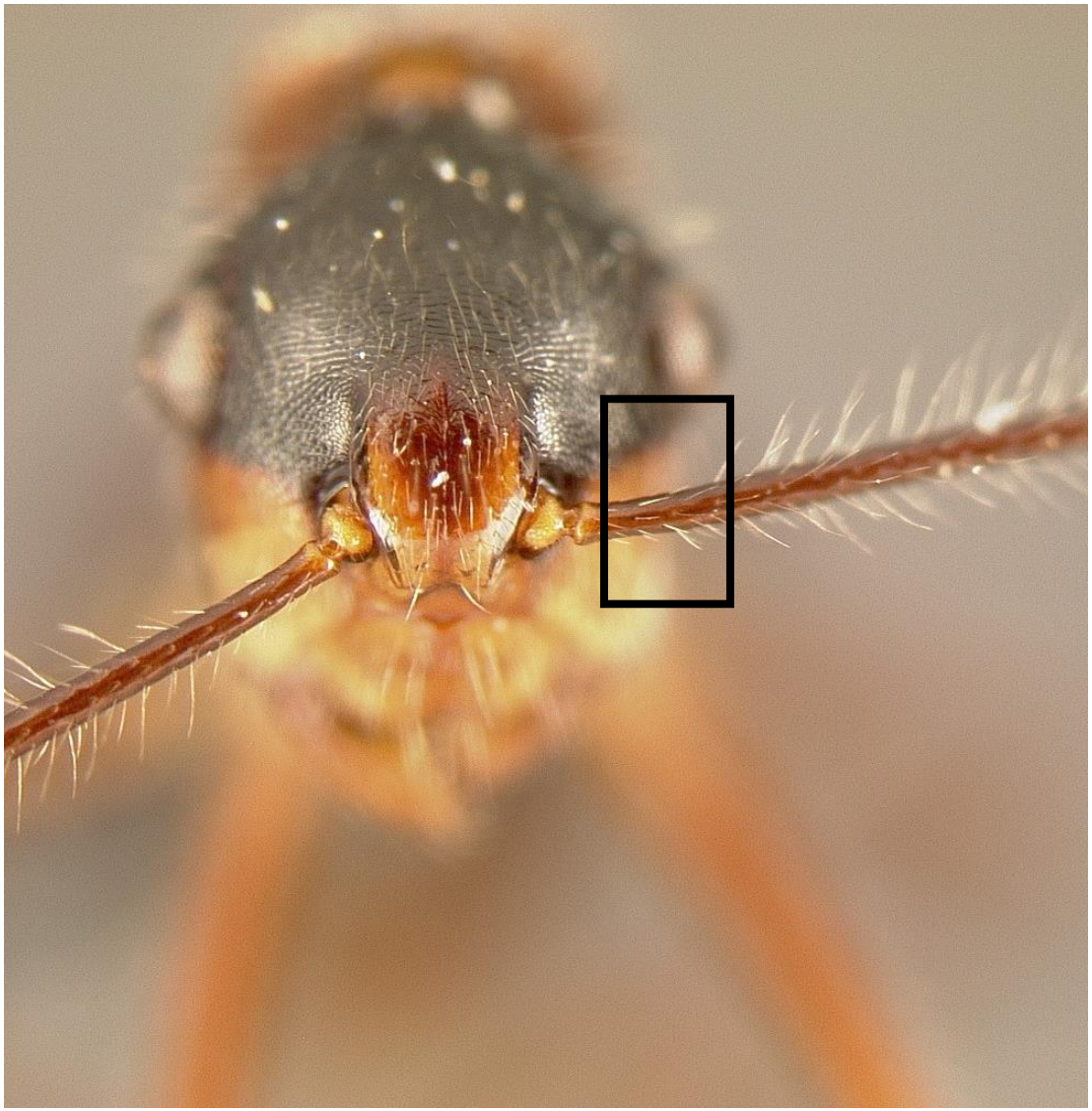
global maximum contrast image objective

Depth of Field



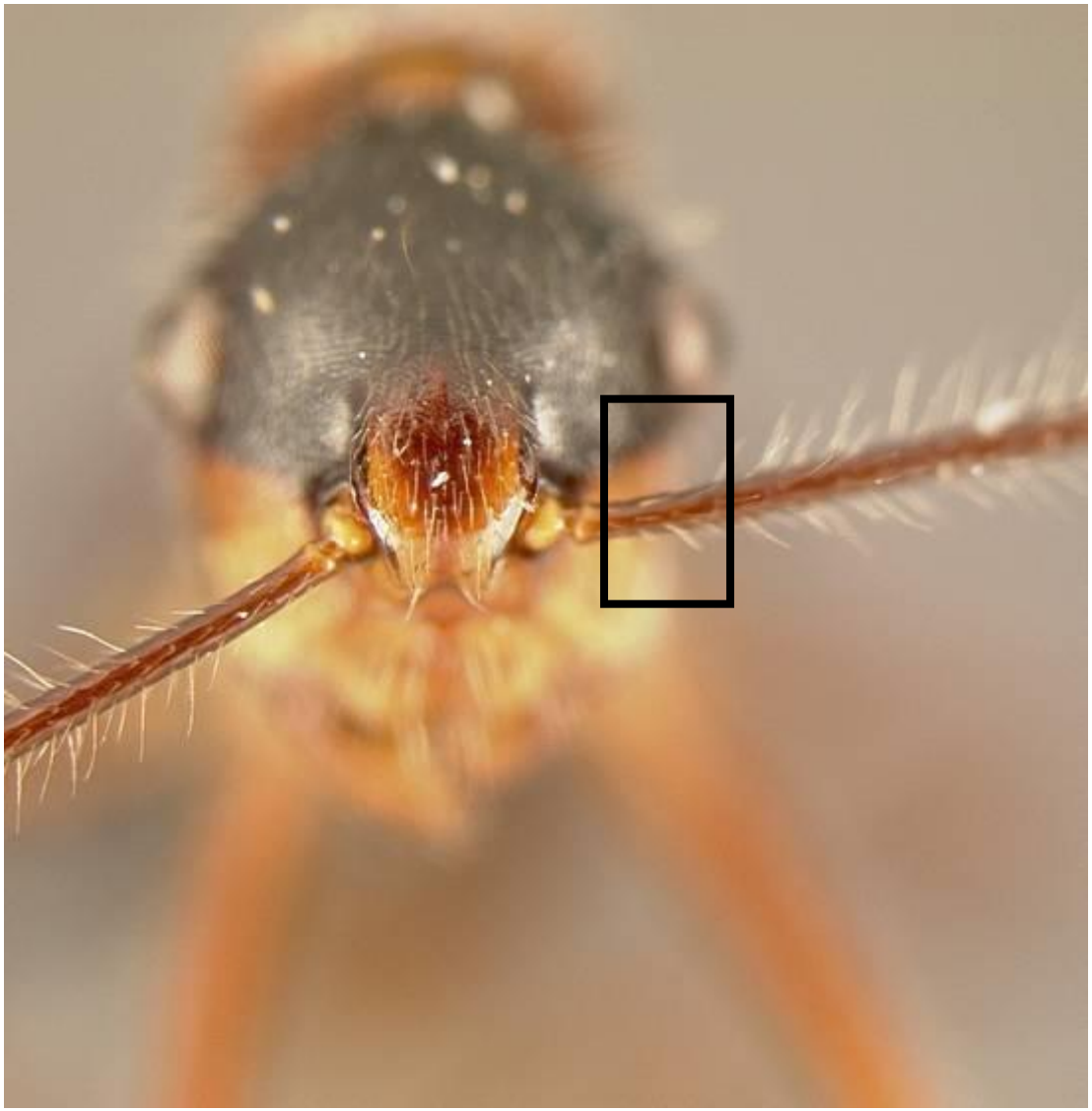
global maximum contrast image objective

Depth of Field



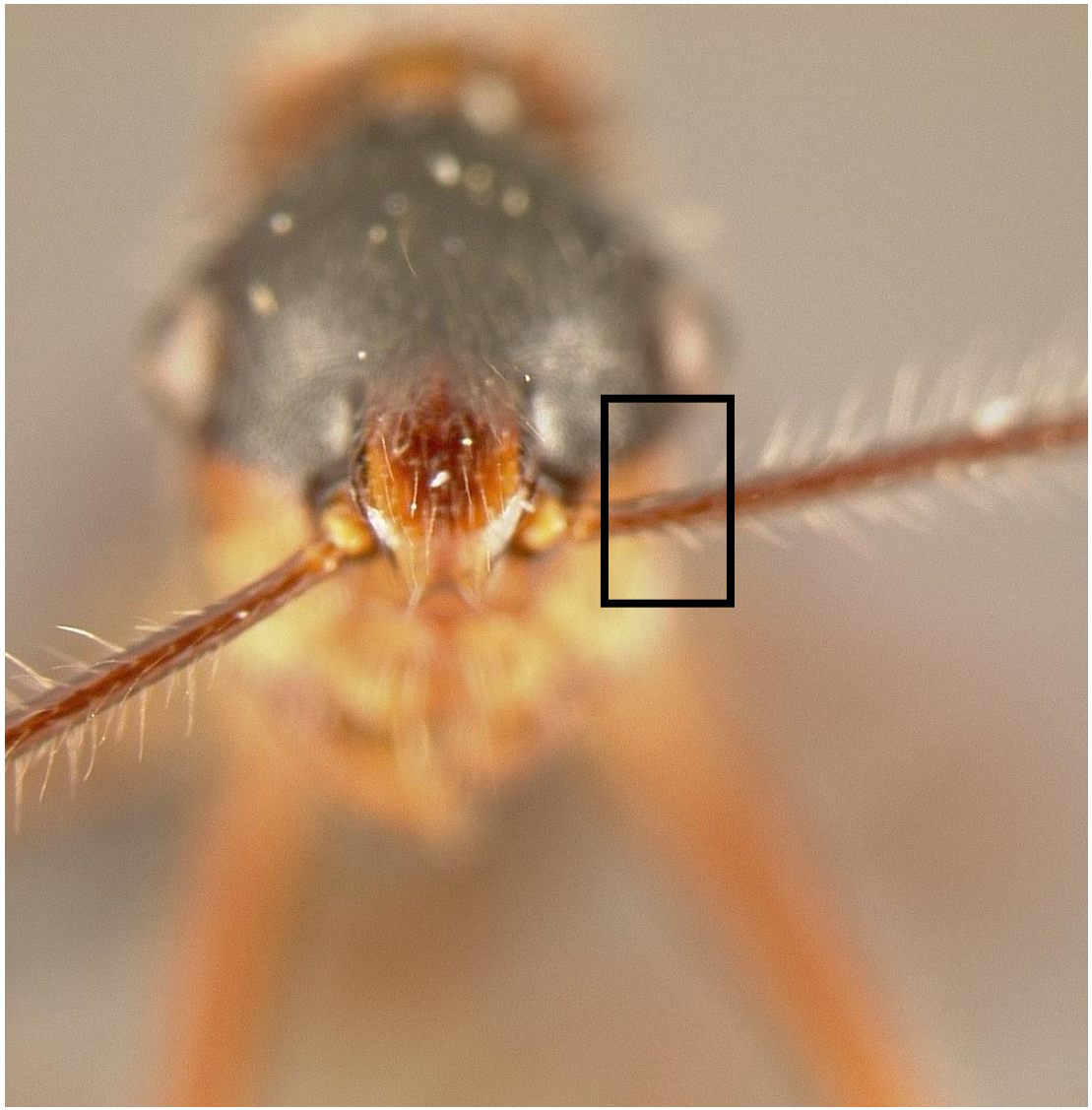
global maximum contrast image objective

Depth of Field

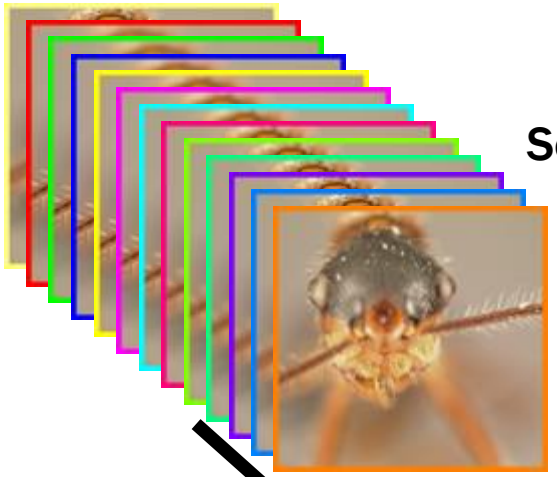


global maximum contrast image objective

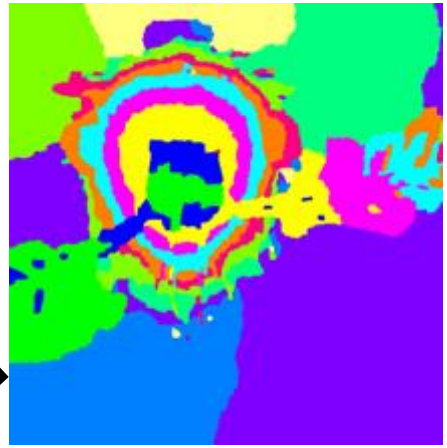
Depth of Field



global maximum contrast
image objective



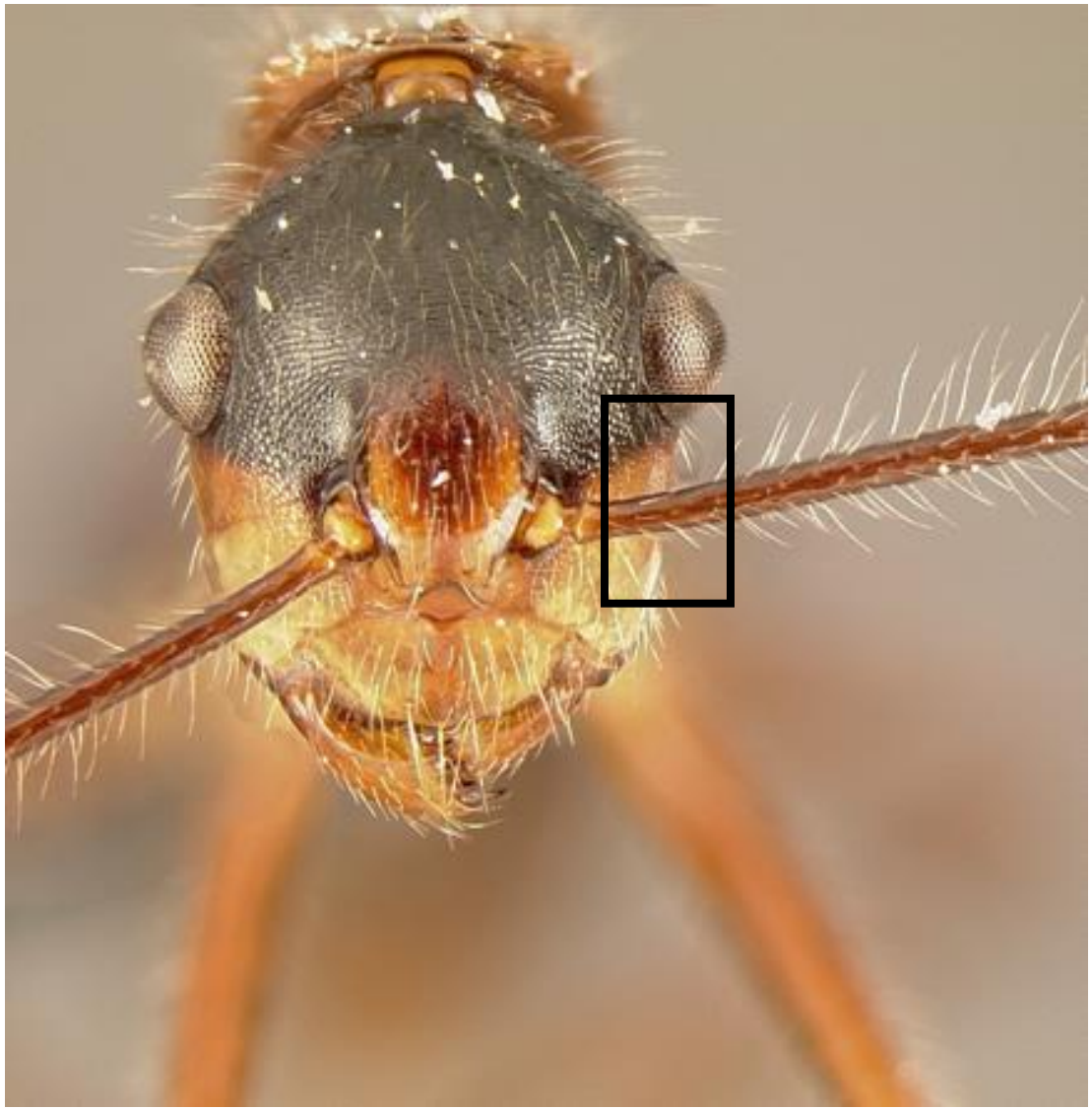
Source images



‘Graph Cuts’ Solution
(global maximum contrast image objective)

Gradient-Domain fusion

Depth of Field

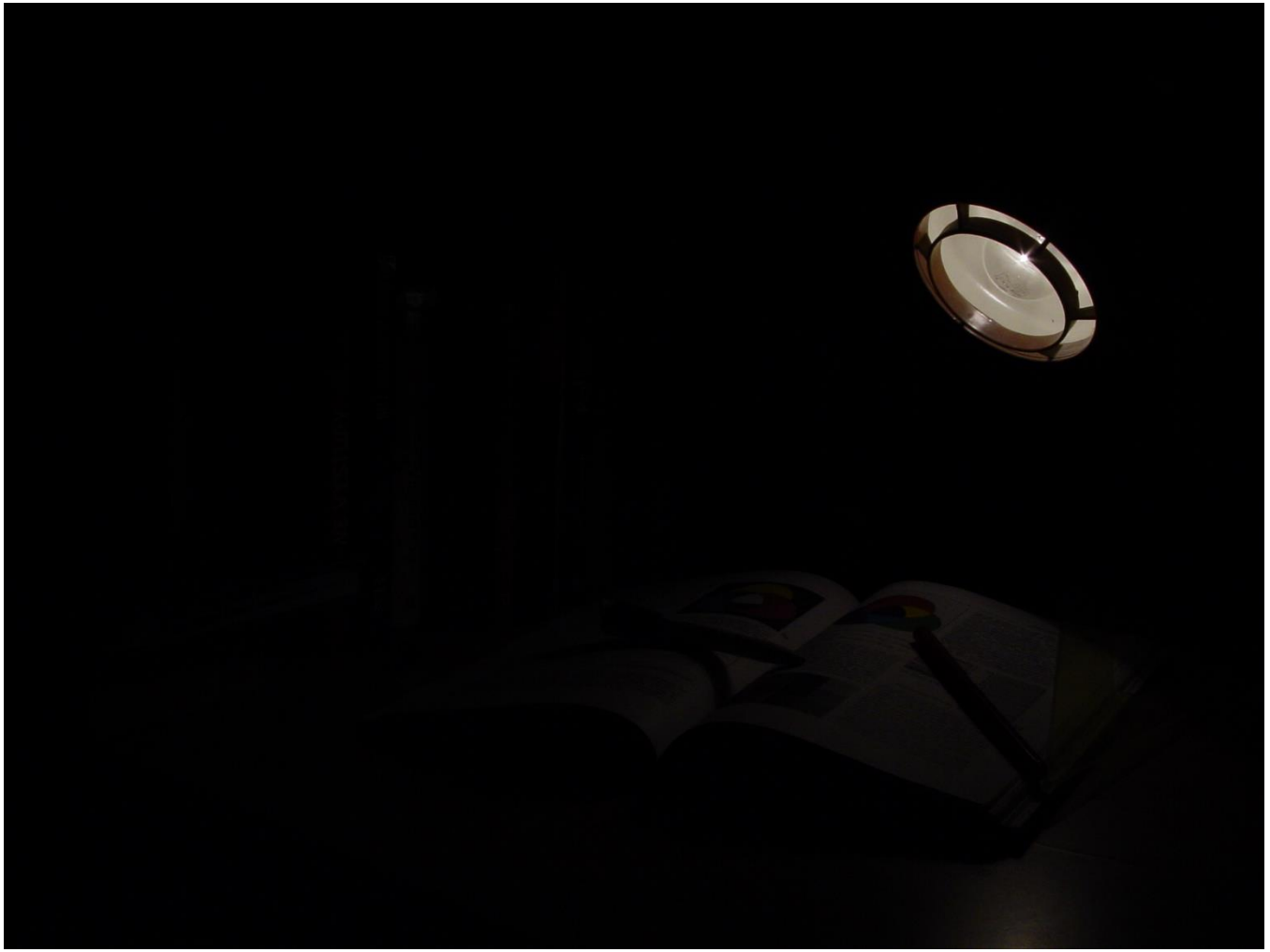


global maximum contrast image objective

Result

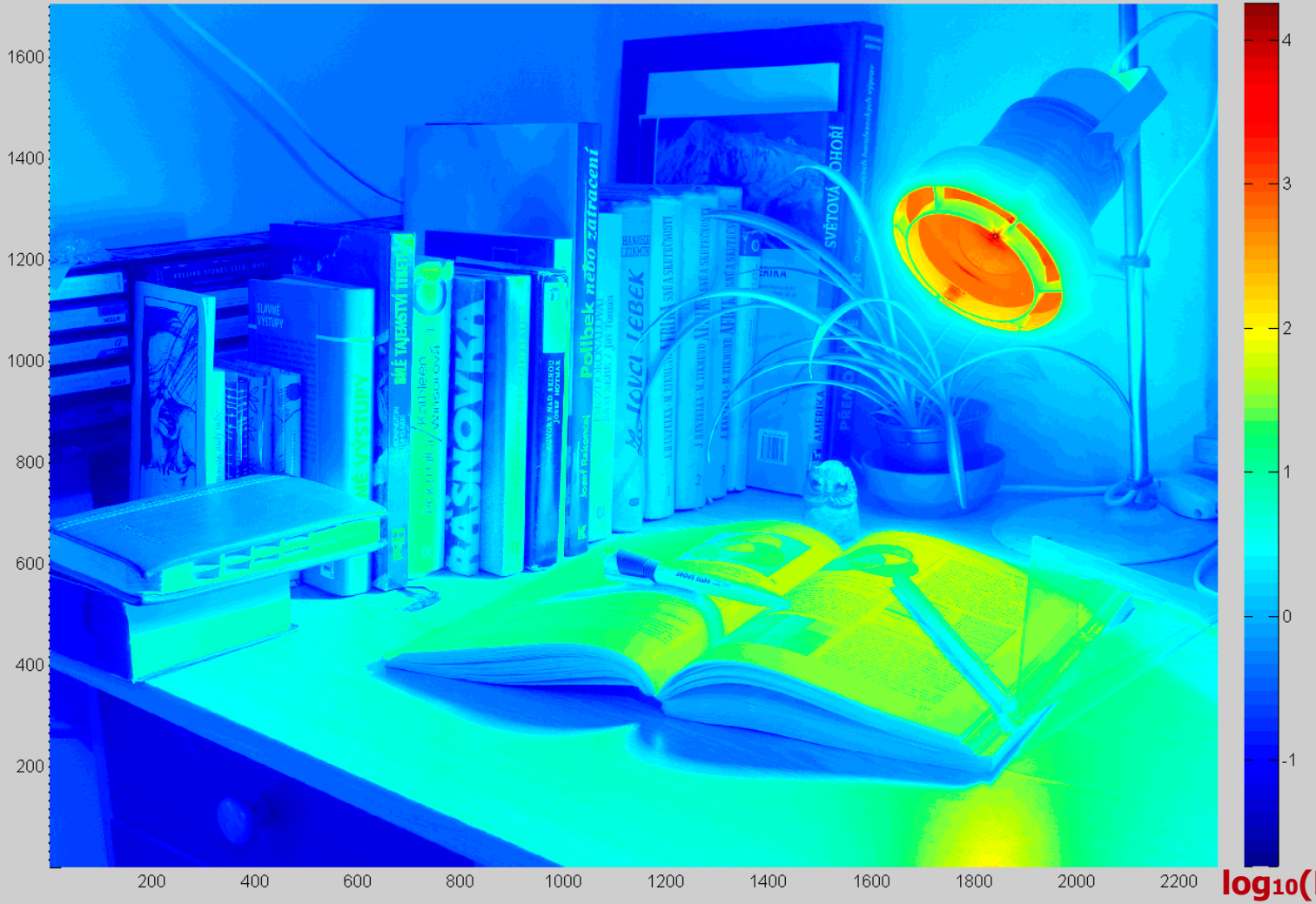
Limited Exposure Range

Limited Exposure Range



Limited Exposure Range

High Dynamic Range of Luminance



Multi-exposure Technique

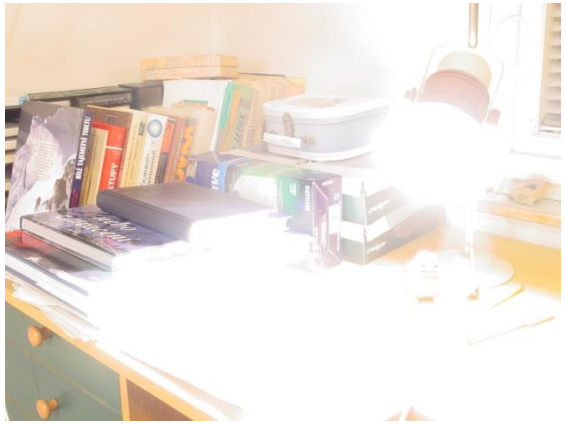
f/5.6, 1/1000s

f/5.6, 1/250s

f/5.6, 1/30s

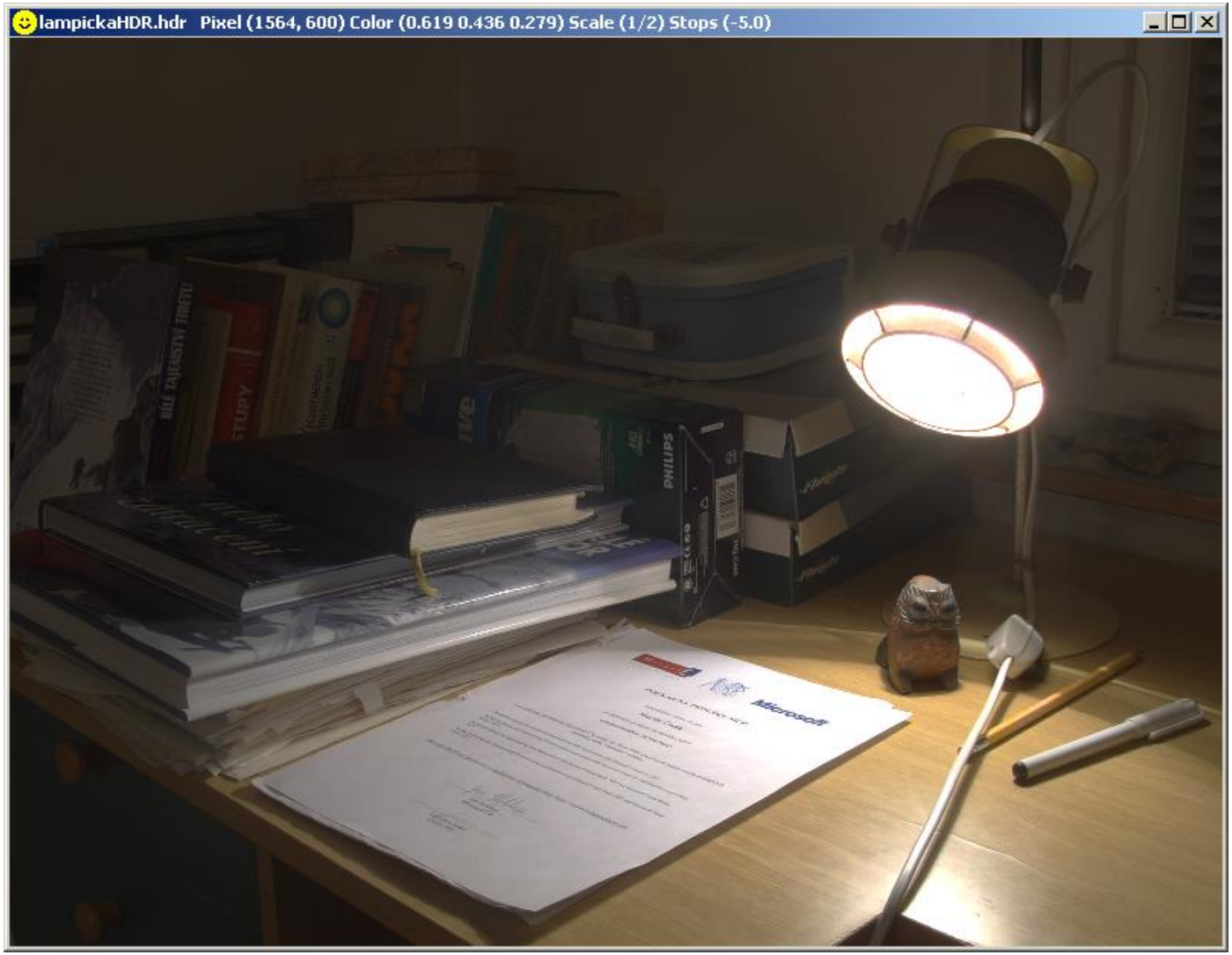
f/5.6, 1/4s

f/5.6, 2s



f/5.6, 8s

HDR Image


lampickaHDR.hdr Pixel (1564, 600) Color (0.619 0.436 0.279) Scale (1/2) Stops (-5.0)
PHILIPS
Microsoft

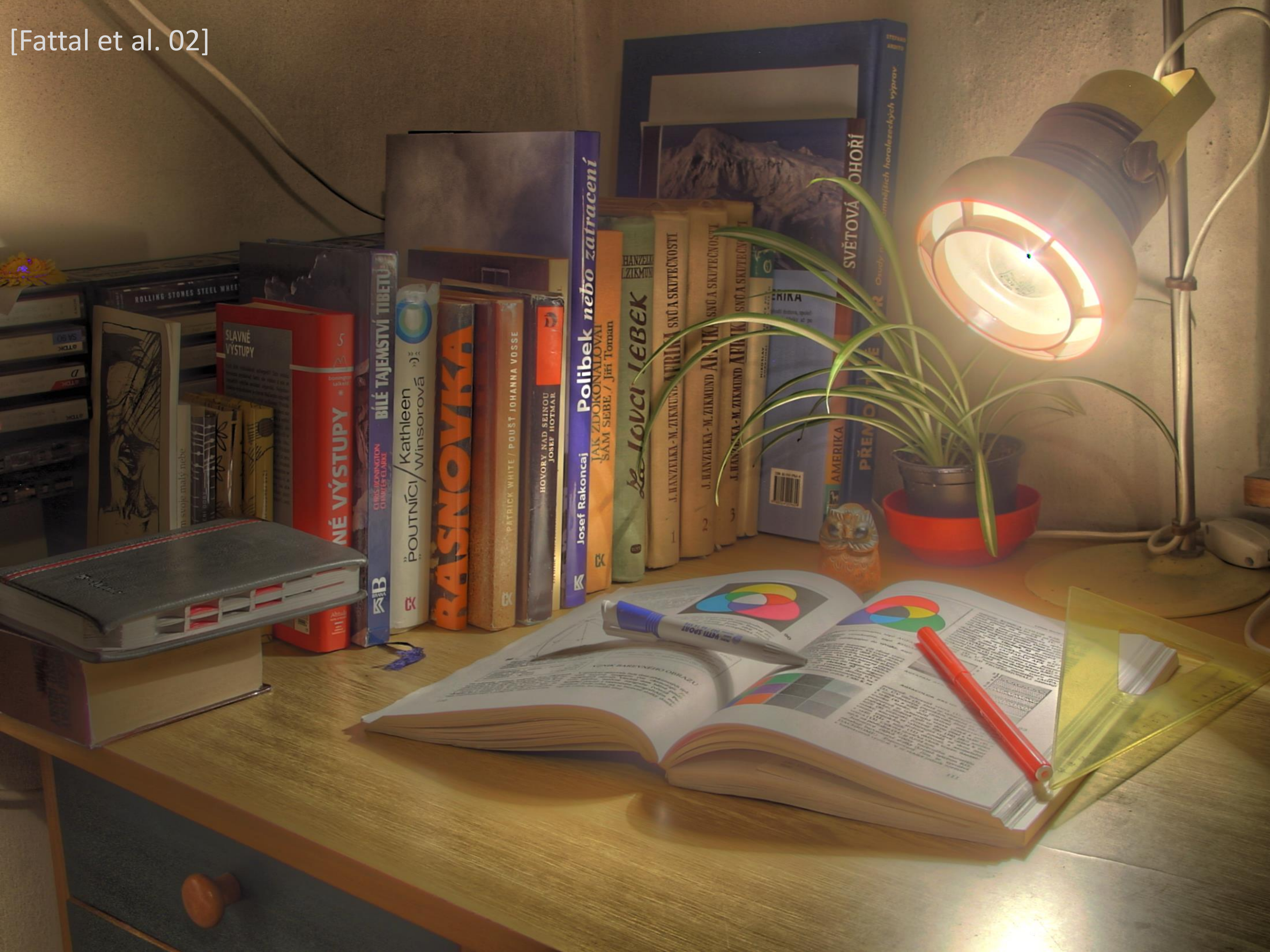
HDR is a “digital negative”


[single exposure]
SLAVNÉ VÝSTUPY
BÍLÉ TAJEMSTVÍ TIBETU
POUTNÍCI Kathleen Winsorová
PATRICK WHITE / POUŠŤ JOHANNA VOSSE
HOVORY NAD SEINOU JOSEF HOTMAR
Polibek nebo zatracení
Josef Rakoncaj
JAK ZDOKONALOVAT SÁM SEBE / Jiří Toman
Lovci lebek
SVĚTOVÁ HORY
AMERIKA

[Čadík 07]


SLAVNÉ VÝSTUPY
BÍLÉ TAJEMSTVÍ TIBETU
Kathleen Winsorová
RÁSNOVKA
Josef Rakoncaj
Polibek nebo zatracení
Le loví lebek
SVĚTOVÁ
OHOŘÍ
AMERIKA


[Pattanaik et al. 00]



[Fattal et al. 02]

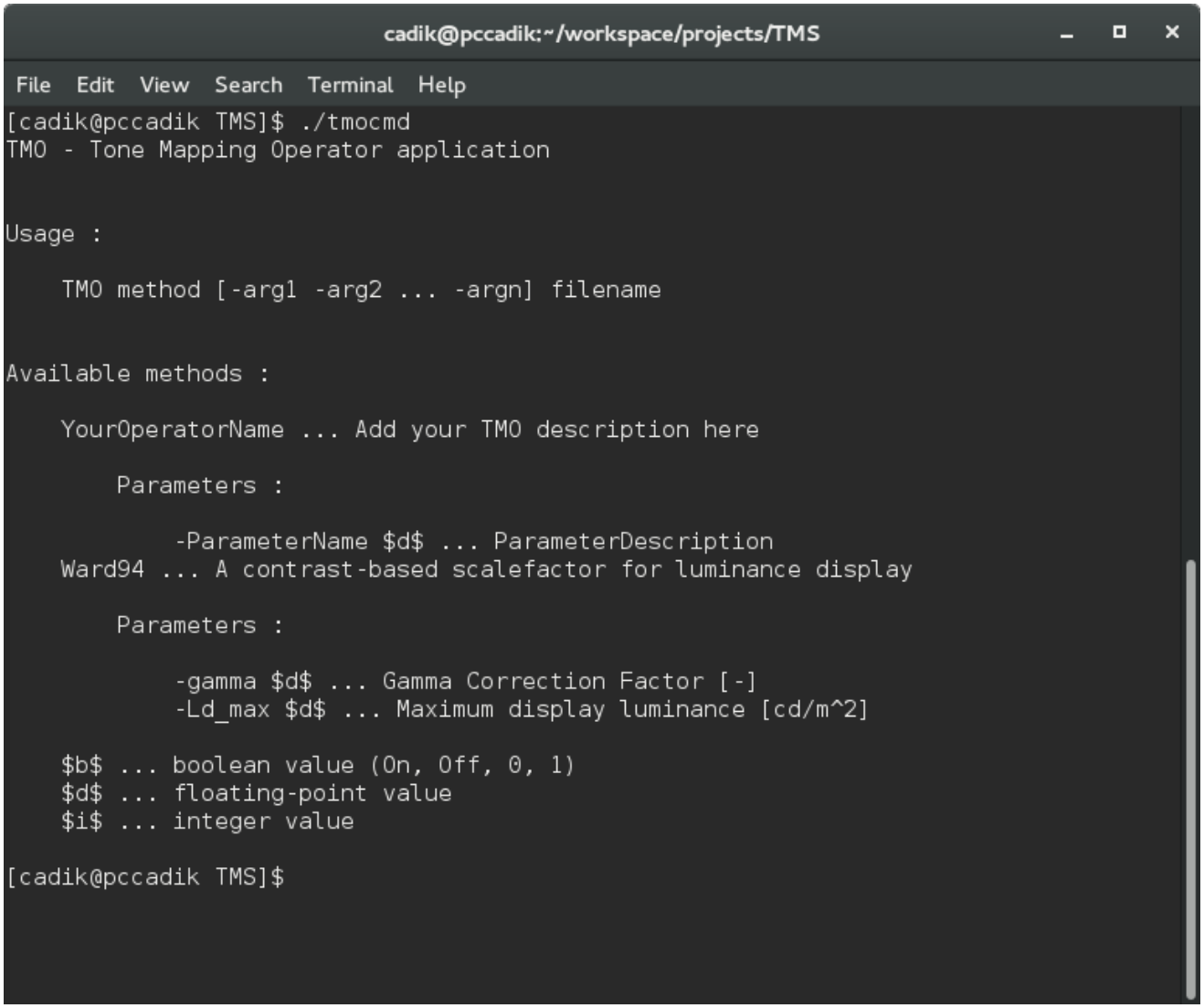

[Paris et al. 11,
Aubry et al. 15]

Tone Mapping Studio

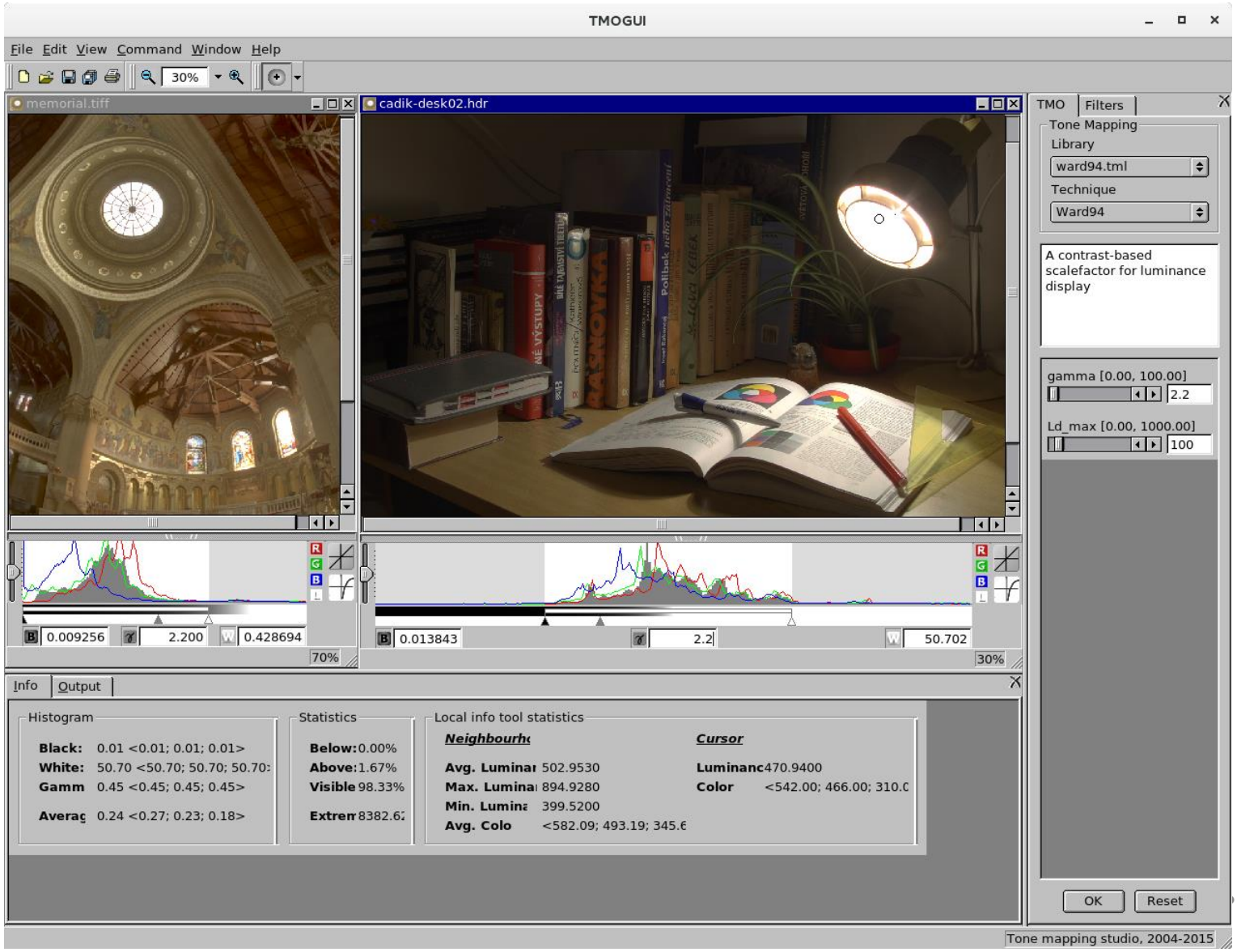
- tmolib: library for HDR image processing
  - loading/storing most of HDR file formats
  - color conversions
  - image processing functions
- tmocmd
- tmogui
- plug-ins

- https://github.com/cadik/TMS
- c++, linux/windows

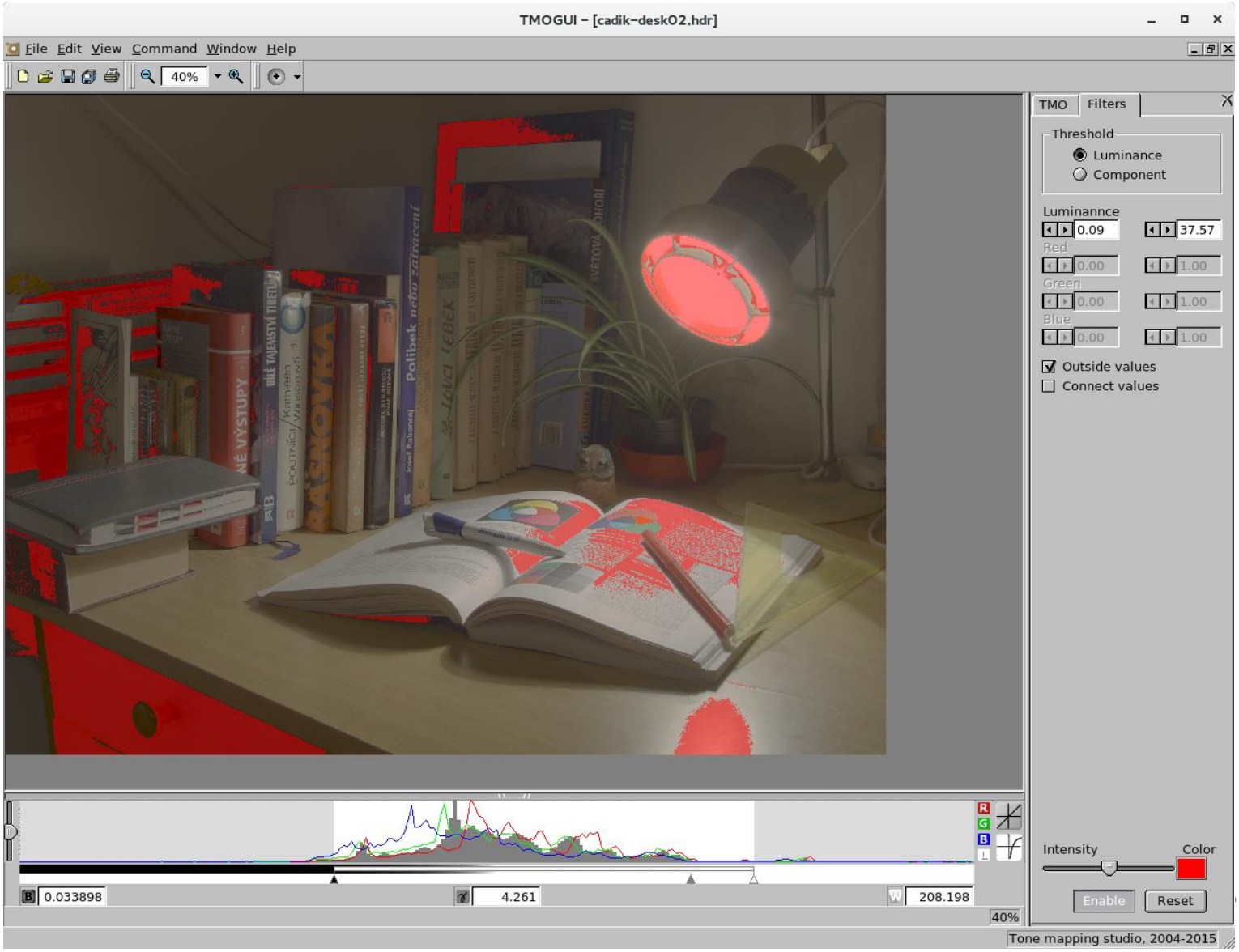
tmocmd


cadik@pccadik:~/workspace/projects/TMS
File Edit View Search Terminal Help
[cadik@pccadik TMS]$ ./tmocmd
TMO - Tone Mapping Operator application
Usage :
TMO method [-arg1 -arg2 ... -argn] filename
Available methods :
YourOperatorName ... Add your TMO description here
Parameters :
-ParameterName d ... ParameterDescription
Ward94 ... A contrast-based scalefactor for luminance display
Parameters :
-gamma d ... Gamma Correction Factor [-]
-Ld_max d ... Maximum display luminance [cd/m^2]
b ... boolean value (On, Off, 0, 1)
d ... floating-point value
i ... integer value
[cadik@pccadik TMS]$

tmogui


TMOGUI
File Edit View Command Window Help
30%
memorial.tiff
cadik-desk02.hdr
TMO
Filters
Tone Mapping
Library
ward94.tml
Technique
Ward94
A contrast-based scalefactor for luminance display
gamma [0.00, 100.00]
2.2
Ld_max [0.00, 1000.00]
100
0.009256
2.200
0.428694
70%
0.013843
2.2
50.702
30%
Info
Output
Histogram
Black: 0.01 <0.01; 0.01; 0.01>
White: 50.70 <50.70; 50.70; 50.70>
Gamm 0.45 <0.45; 0.45; 0.45>
Averag 0.24 <0.27; 0.23; 0.18>
Statistics
Below:0.00%
Above:1.67%
Visible 98.33%
Extrem 8382.67
Local info tool statistics
Neighbourh
Cursor
Avg. Lumina 502.9530
Max. Lumina 894.9280
Min. Lumina 399.5200
Avg. Colo <582.09; 493.19; 345.6
Luminanc 470.9400
Color <542.00; 466.00; 310.0
OK
Reset
Tone mapping studio, 2004-2015

tmogui


TMOGUI – [cadik-desk02.hdr]
File Edit View Command Window Help
40%
TMO
Filters
Threshold
Luminance
Component
Luminannce
0.09
37.57
Red
0.00
1.00
Green
0.00
1.00
Blue
0.00
1.00
Outside values
Connect values
Intensity
Color
Enable
Reset
0.033898
4.261
208.198
40%
Tone mapping studio, 2004-2015

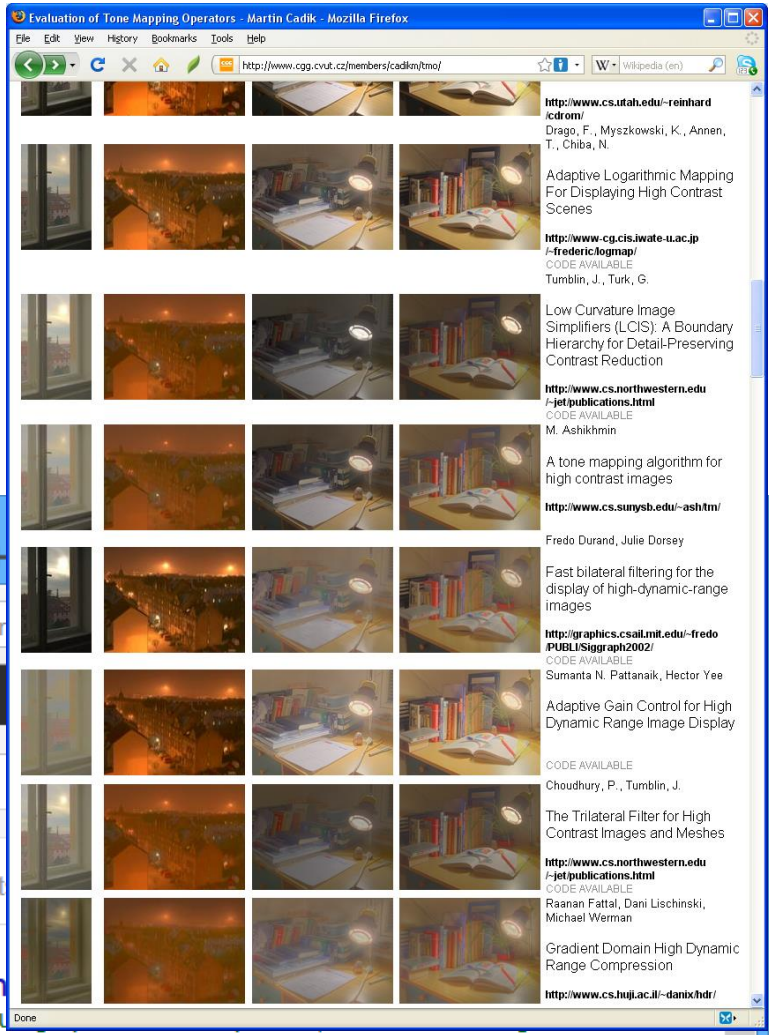
plug-in

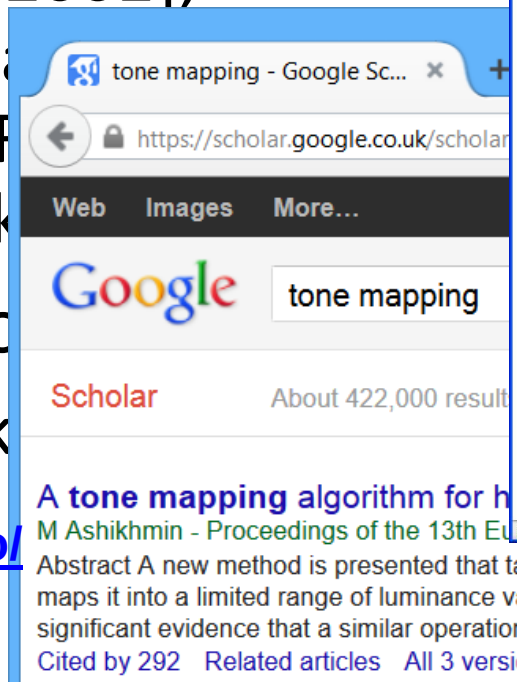
```cpp
/* TMOYourOperatorName.cpp: implementation of the TMOYourOperatorName class.   */

#include "TMOYourOperatorName.h"

/* Constructor serves for describing a technique and input parameters          */
TMOYourOperatorName::TMOYourOperatorName()
{
    SetName(L"YourOperatorName");                       // TODO - Insert operator name
    SetDescription(L"Add your TMO description here");   // TODO - Insert description

    dParameter.SetName(L"ParameterName");               // TODO - Insert parameters names
    dParameter.SetDescription(L"ParameterDescription"); // TODO - Insert parameter descriptions
    dParameter.SetDefault(1);                           // TODO - Add default values
    dParameter=1.;
    dParameter.SetRange(-1000.0,1000.0);                // TODO - Add acceptable range if needed
    this->Register(dParameter);
}

TMOYourOperatorName::~TMOYourOperatorName()
{
}

/* This overloaded function is an implementation of your tone mapping operator */
TMOYourOperatorName::Transform()
{
    // Source image is stored in local parameter pSrc
    // Destination image is in pDst

    // Initialy images are in RGB format, but you can
    // convert it into other format
    pSrc->Convert(TMO_Yxy);                             // This is format of Y as luminance
    pDst->Convert(TMO_Yxy);                             // x, y as color information

    double* pSourceData = pSrc->GetData();              // You can work at low level data
    double* pDestinationData = pDst->GetData();         // Data are stored in form of array
                                                        // of three doubles representing
                                                        // three colour components
    double pY, px, py;

    for (int j = 0; j < pSrc->GetHeight(); j++)
    {
        pSrc->ProgressBar(j, pSrc->GetHeight());    // You can provide progress bar
        for (int i = 0; i < pSrc->GetWidth(); i++)
        {
            pY = *pSourceData++;
            px = *pSourceData++;
            py = *pSourceData++;

            // Here you can use your transform
            // expressions and techniques...
            pY *= dParameter;                           // Parameters can be used like
                                                        // simple variables

            // and store results to the destination image
            *pDestinationData++ = pY;
            *pDestinationData++ = px;
            *pDestinationData++ = py;
        }
    }
    pSrc->ProgressBar(j, pSrc->GetHeight());
    pDst->Convert(TMO_RGB);
    return 0;
}
```

Many TM Methods Available

- Image TM
  - [Tumblin, Rushmeier 93], [Ward 94], [Durand, Dorsey 2002], [Drago et al., 2003], [Fattal et al. 2002], [Mantiuk et a [Čadík 07], [F [Aydin, Čadík
- [HDR video to
  - [Pajak, Čadík

http://cadik.posvete.cz/tmo/





HDR Software

- pfstools
  - http://pfstools.sourceforge.net/

- Picturenaut
  - http://www.hdrlabs.com/picturenaut/

- Photosphere
  - http://www.anyhere.com/

Other Factors

Other Factors

Other Factors

Digital Photomontage

[Agarwala et al., 2004]

Other Factors

Light L16 - Multiple Exposures

- 16 sensors
- 52 MPx
- 35-150mm

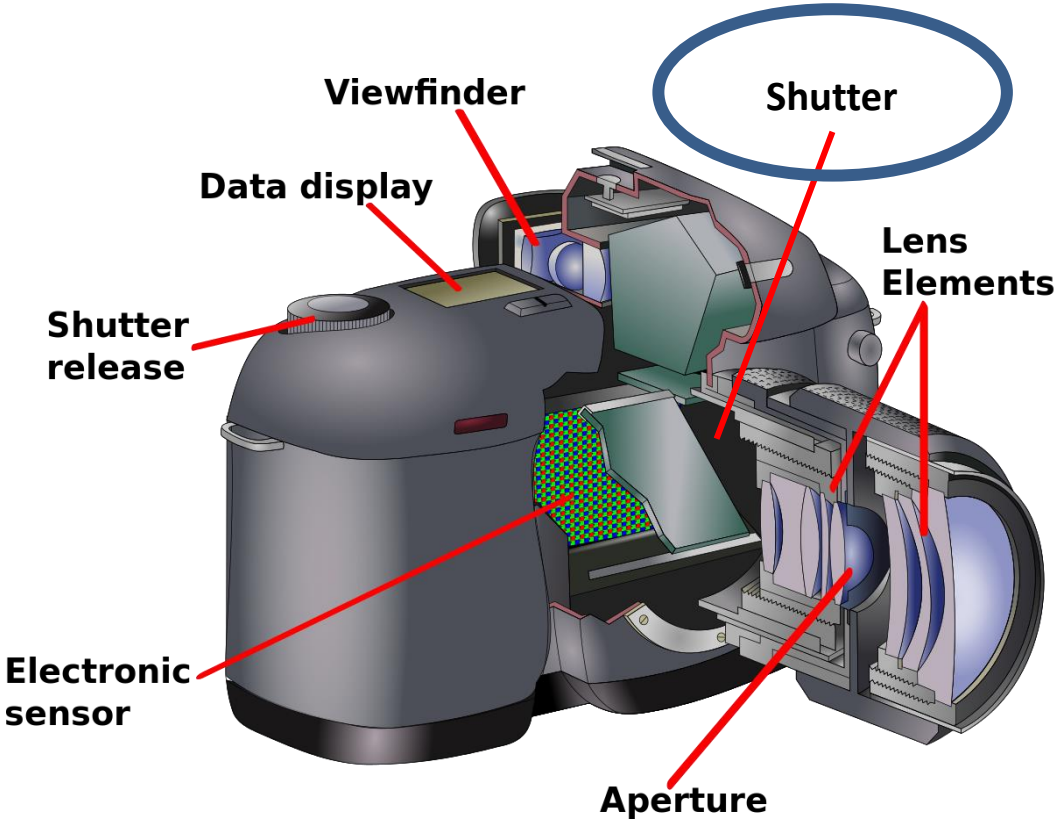
IPHONE 7S

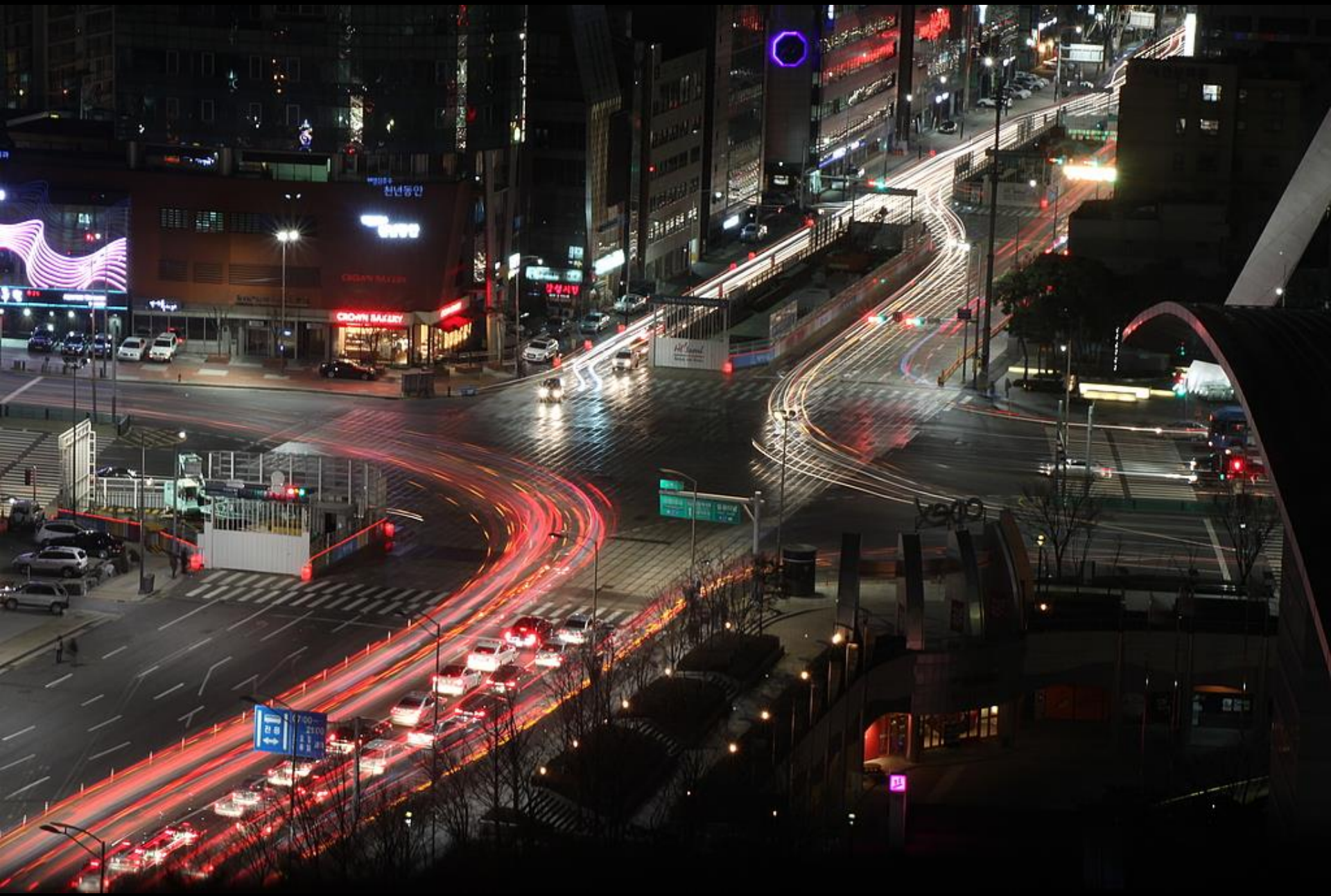
LG G6

HUAWEI P20PRO

HOW COMPUTATIONAL PHOTOGRAPHY: MODIFYING CAMERAS

Fluttered Shutter Camera

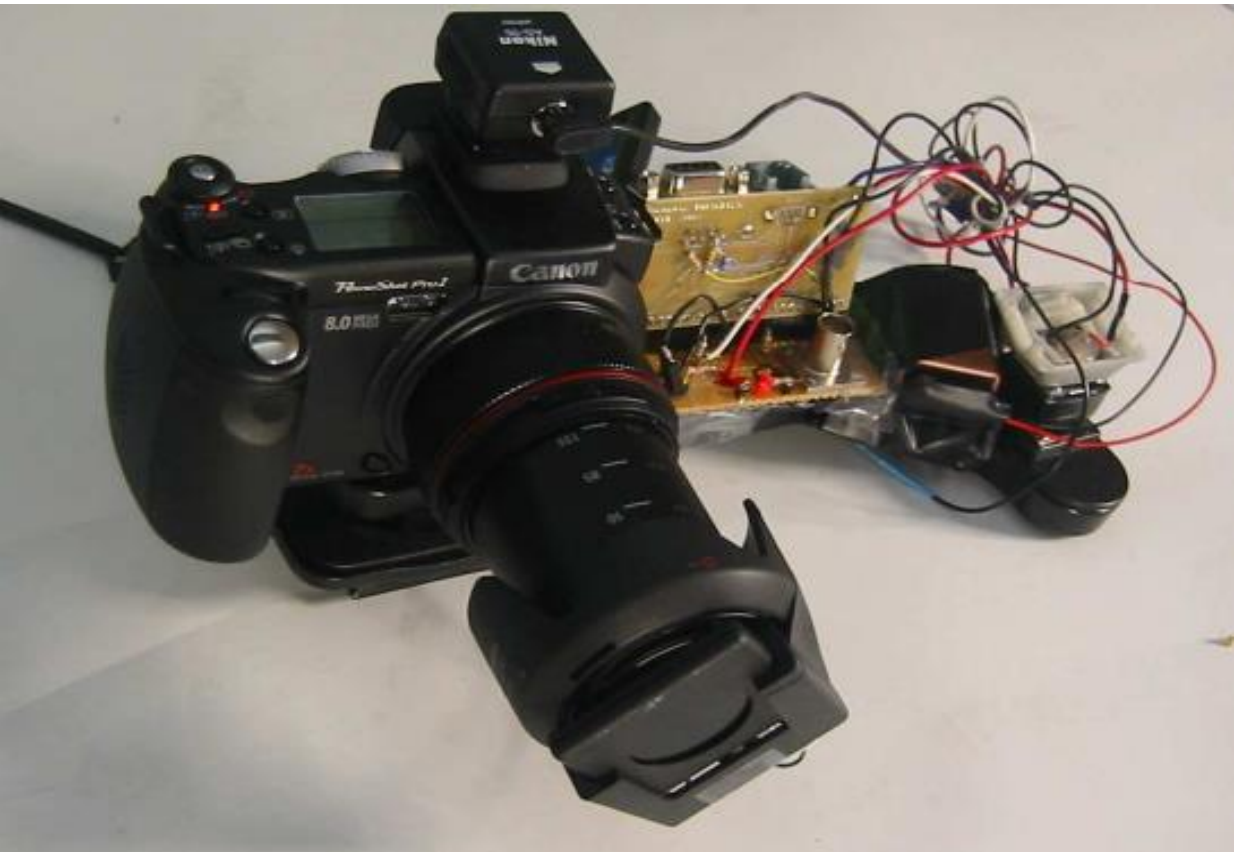


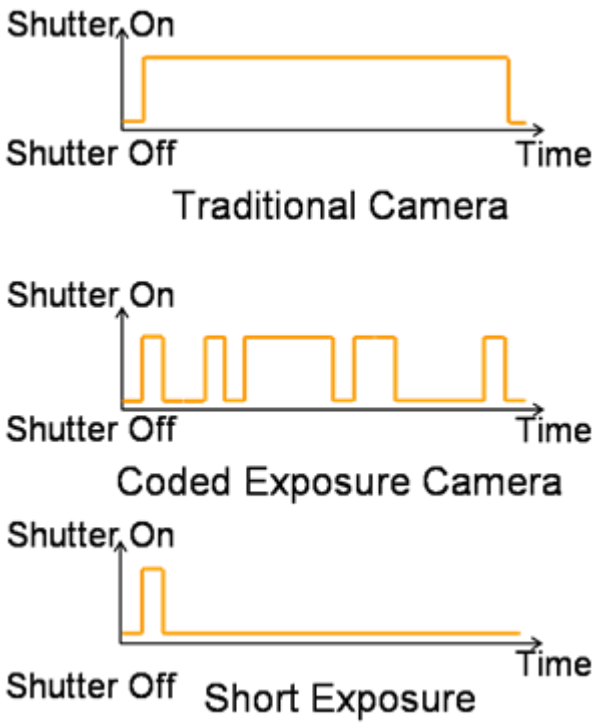

CROWN BAKERY

Motion Blur

Deblurred

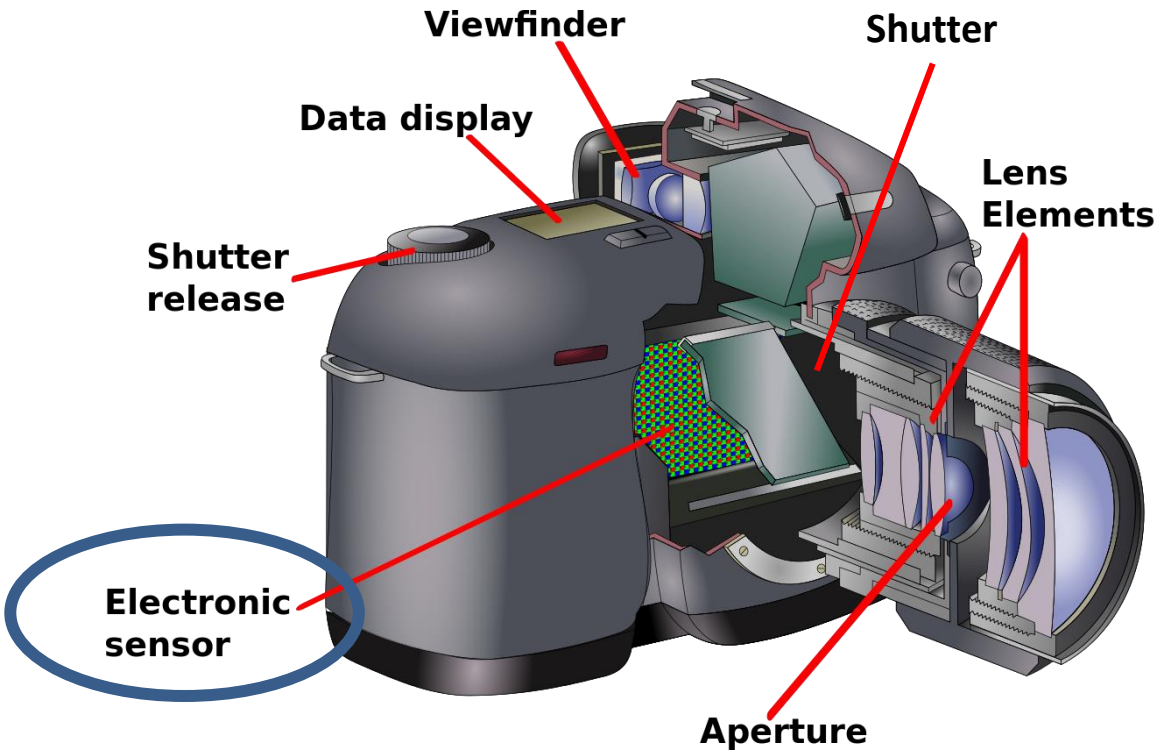
Coded Exposure Photography





[Raskar et al. 06]

Sensor – Lightfield/Lumigraph



Light Field/Lumigraph

- 4D image
- Sensor
  - Grid of many cameras
  - Microlenses
  - Coded aperture

Light Field/Lumigraph

- Applications
  - Changes of point of view


  - Changes in focus and depth of field
    - Deconvolution using depth from parallax

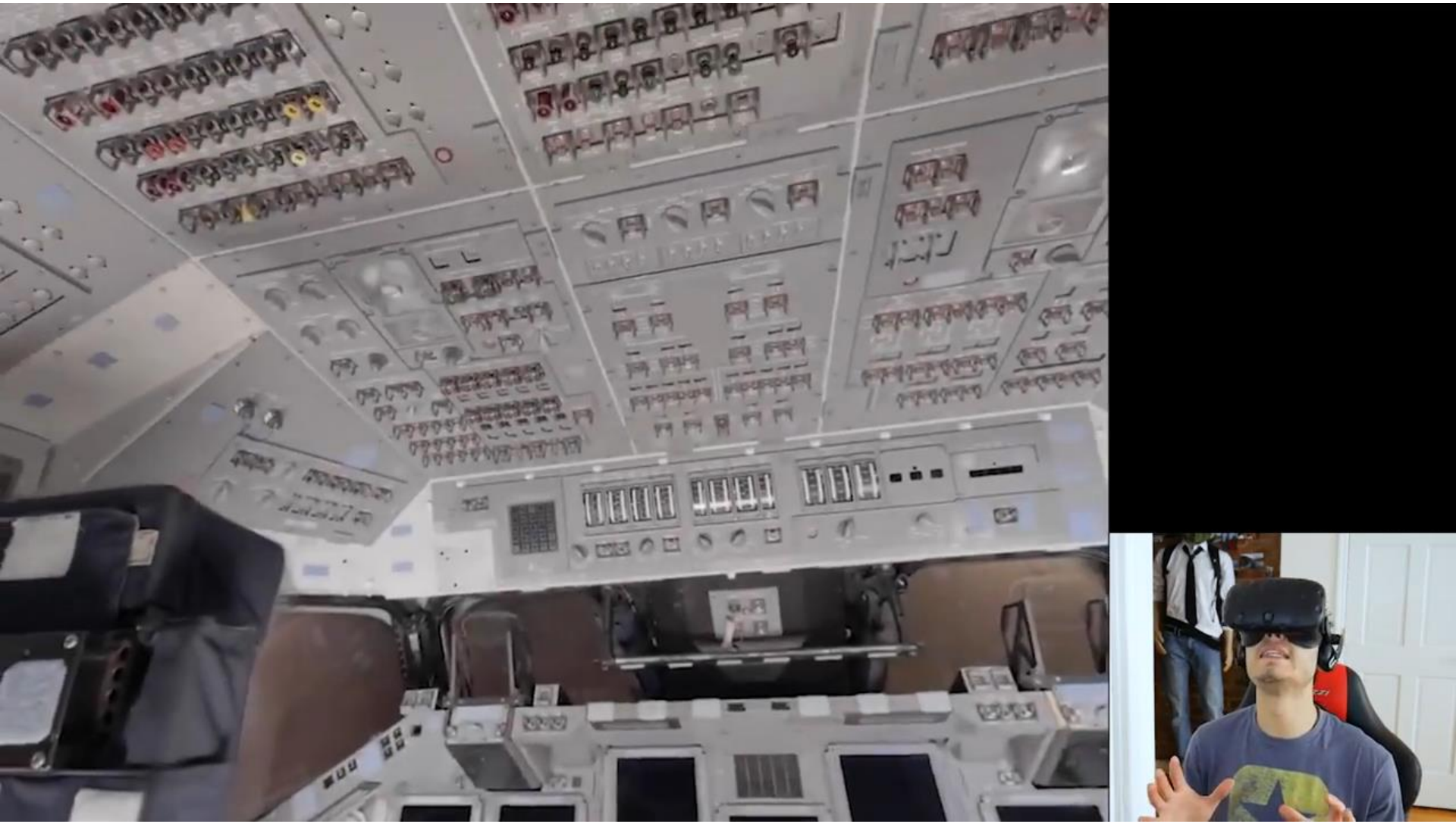




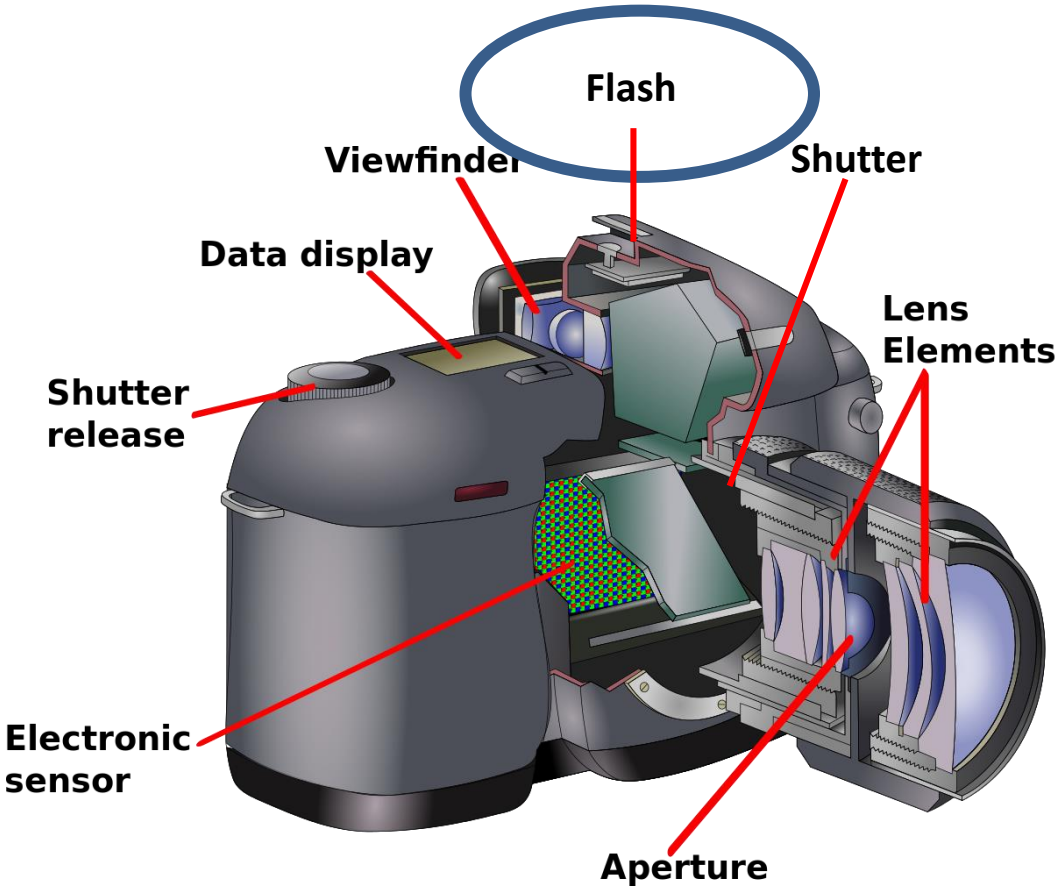
Spherical Panorama

- http://www.fit.vutbr.cz/~cadik/VYF/lecture2018.html

Light Field



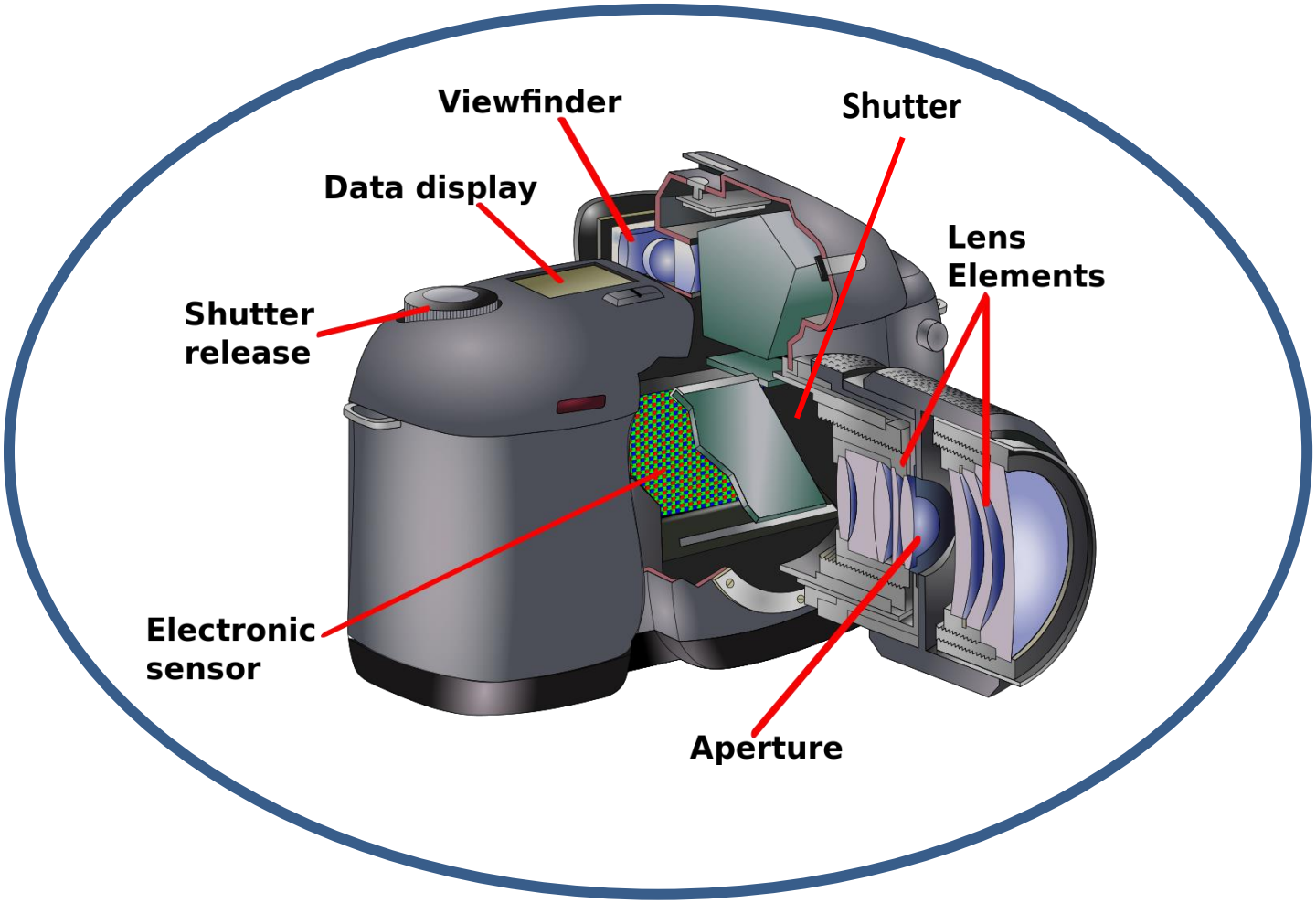
Flash/No-Flash



Flash/No-Flash

- [Nayar et al. 2006] – structured light
  - Separation of direct and global images using high frequency illumination
- [Eisemann and Durand 2004] – cross bilateral filter
- [Petschnigg et al. 2004] – joint bilateral filter

Change it All

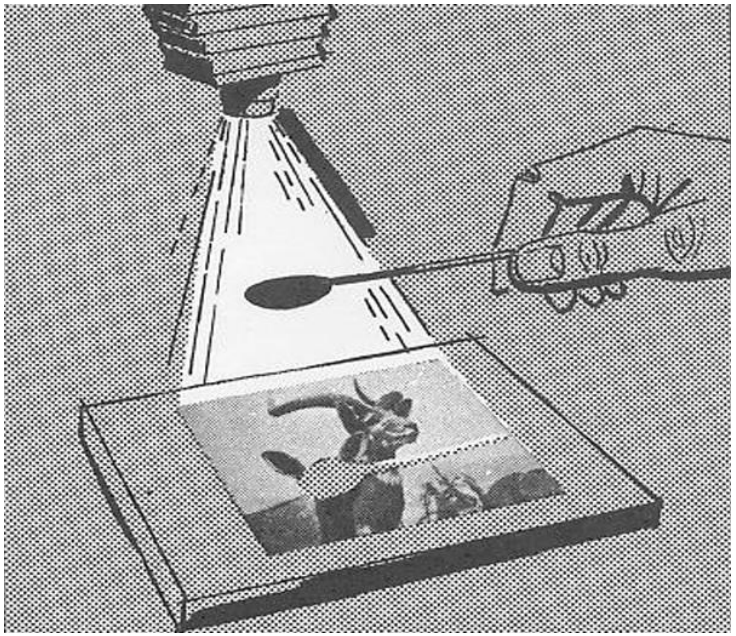


FrankenCamera

- "Open source" computational photography
  - Fcam (Stanford, ex. Nokia, nVidia) http://fcam.garage.maemo.org/
    - Complete redesign of the camera
    - Programmer has full control
    - Tailored to computational photography (contrary to std. cameras)

IMAGE EDITING

Darkroom



Digital “Darkroom”

Traditional Digital Image Editing

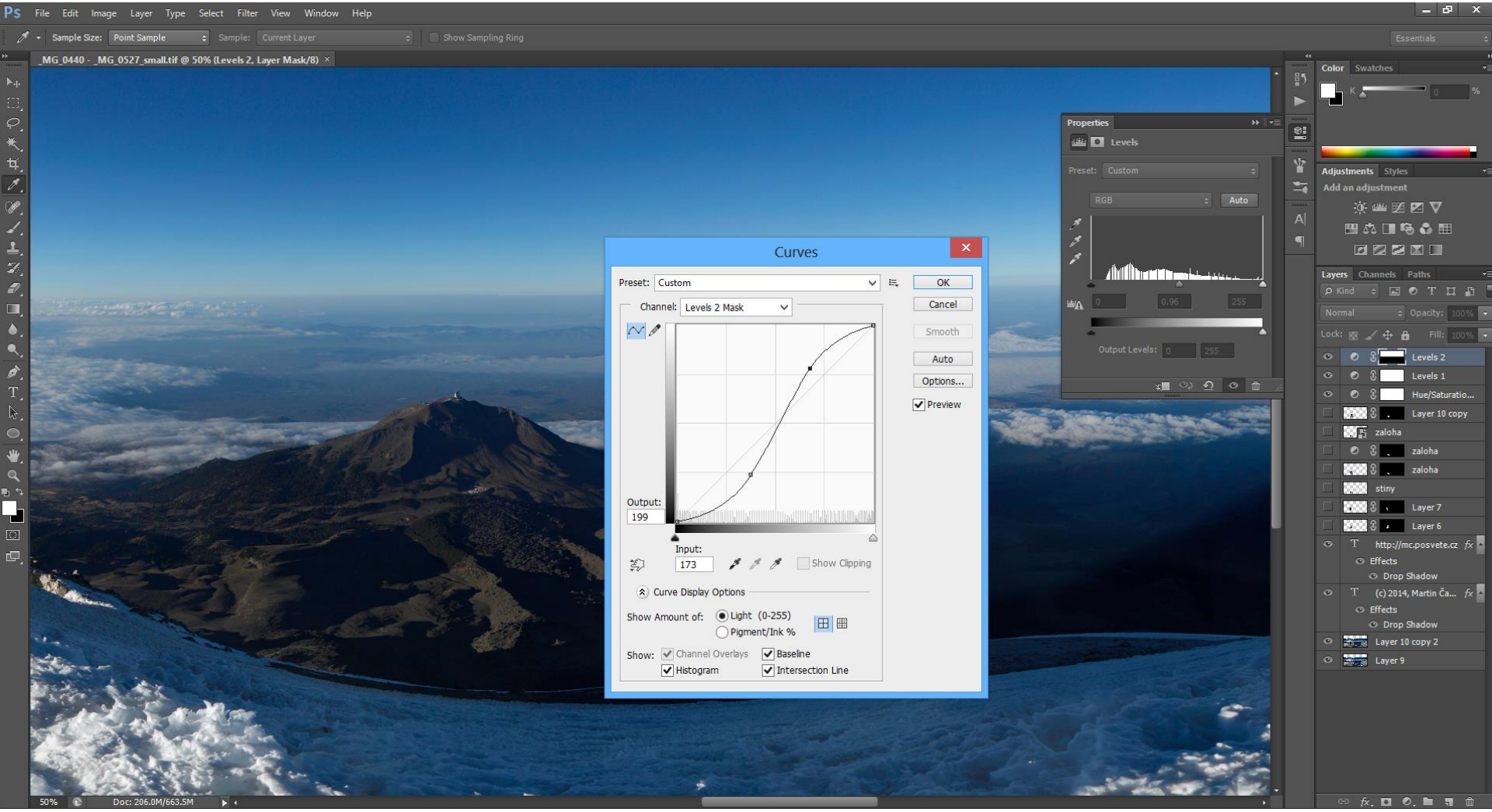
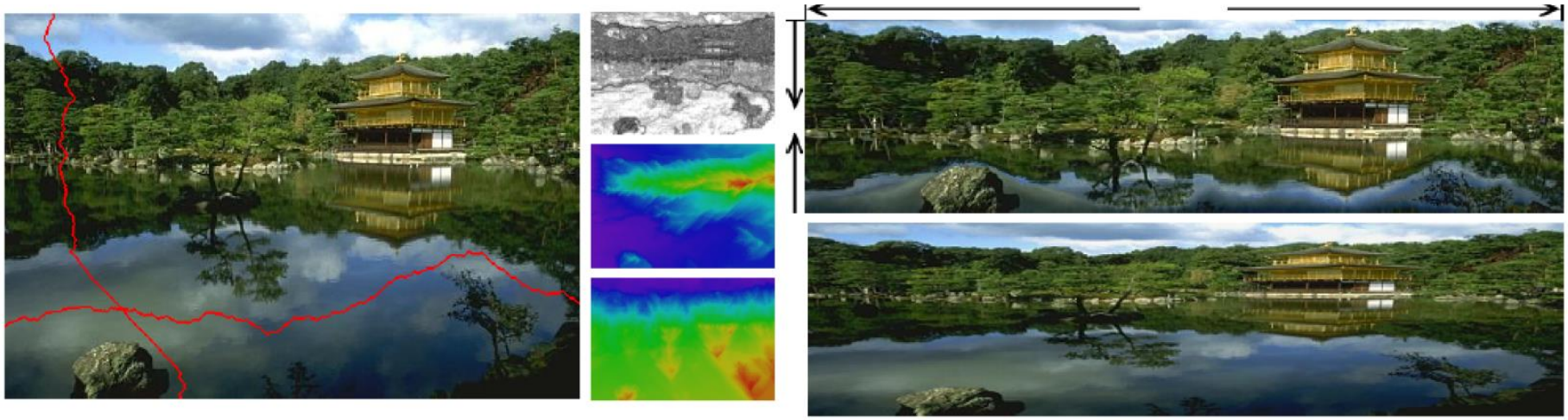


Image Resizing

- content aware image resizing
  - [Avidan, Shamir 2007]

Image Resizing

- content aware image resizing
  - [Avidan, Shamir 2007]



HDR Image Retargeting

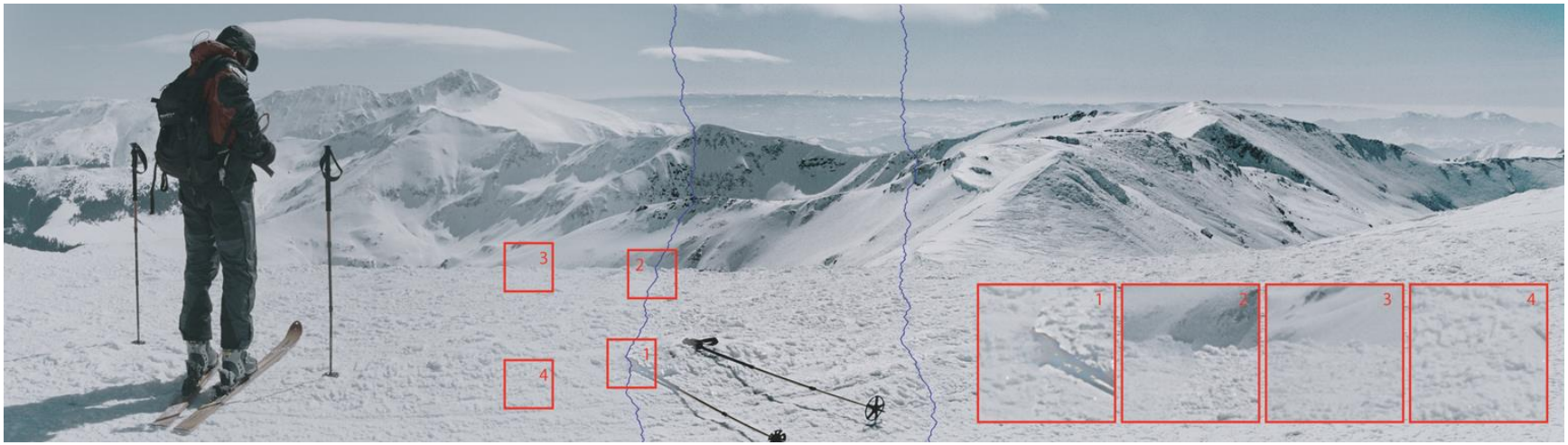
HDR source

[Avidan, Shamir 2007]

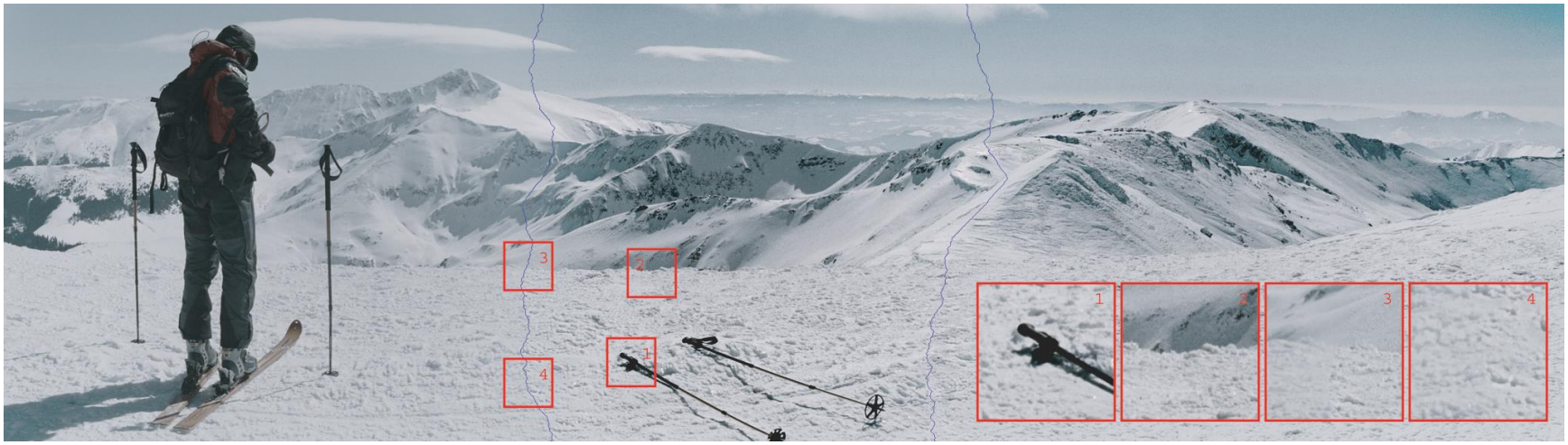
[Drago et al. 03]

[Aydin, Čadík et al. 2010]

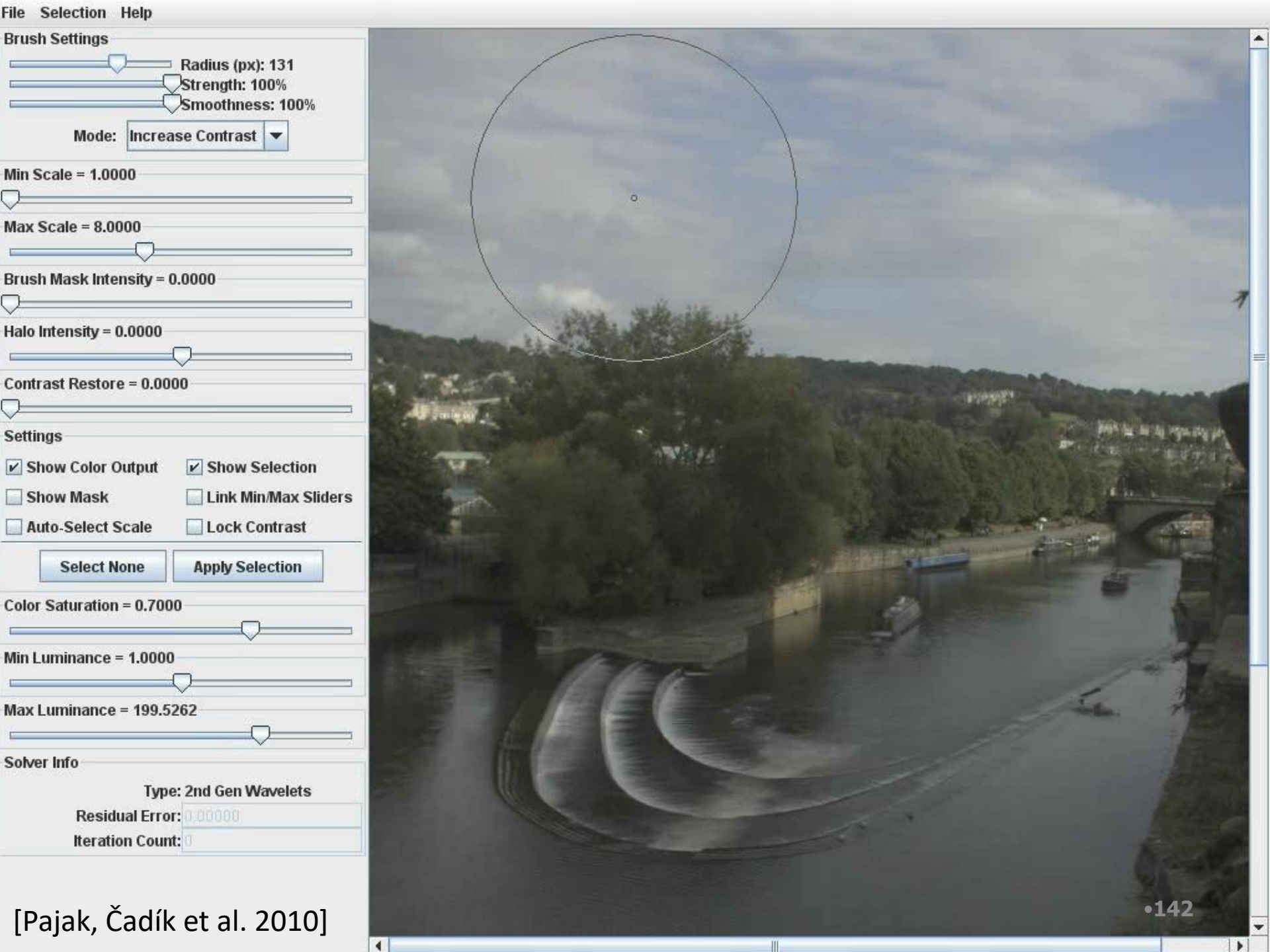
HDR Panorama Stitching



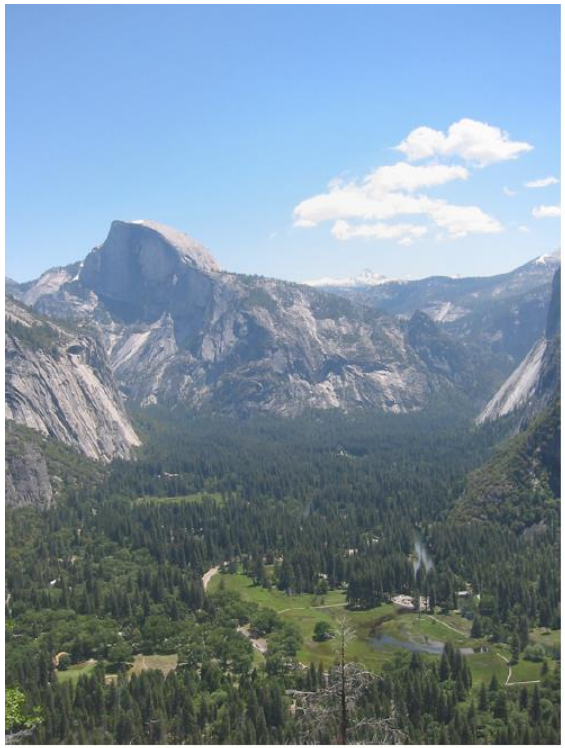
[Ward 2006]



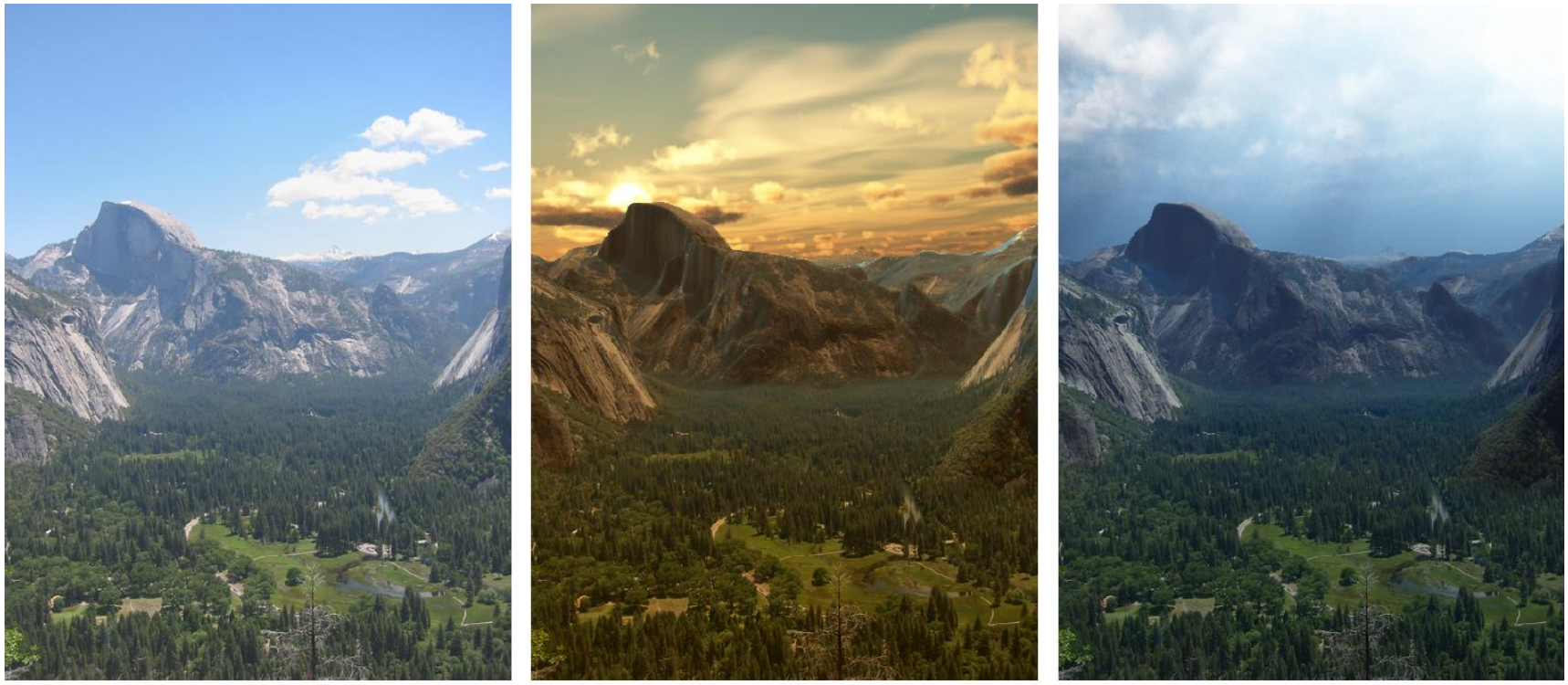
[Aydin, Čadík et al.2010]



[Pajak, Čadík et al. 2010]



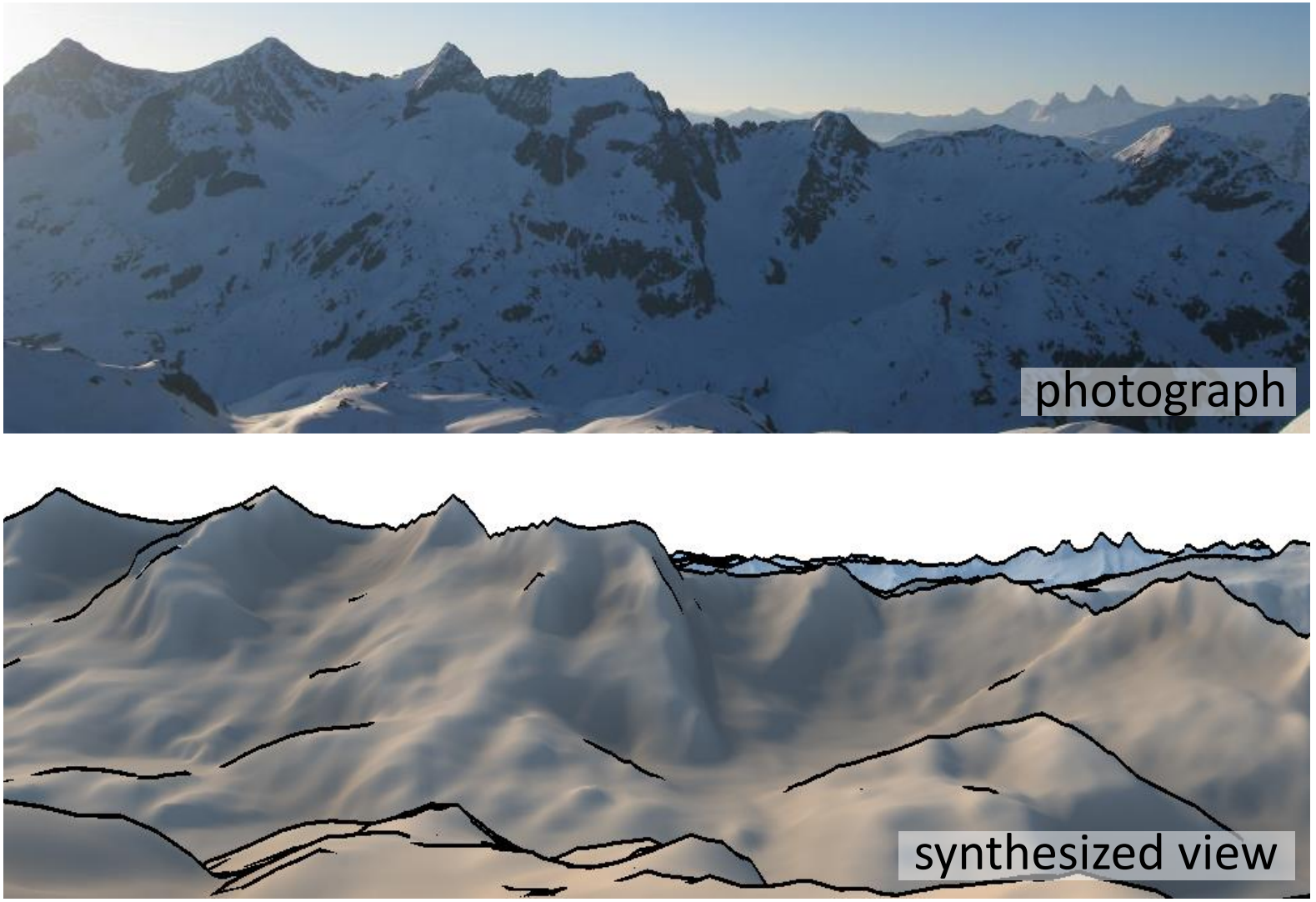
Input



Input Relighted Relighted

[Kopf et al. 2008]

3D Models & Computer Graphics

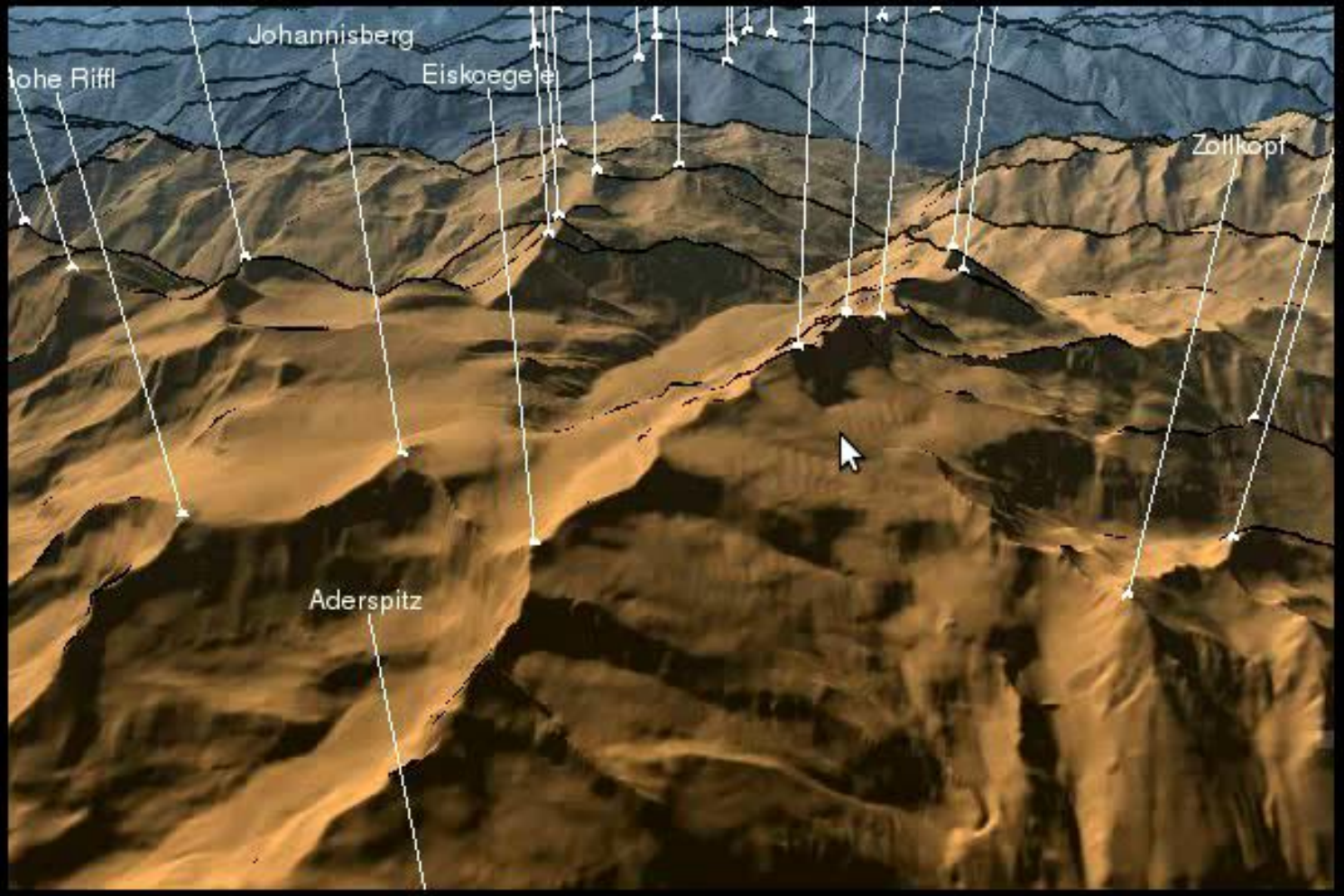


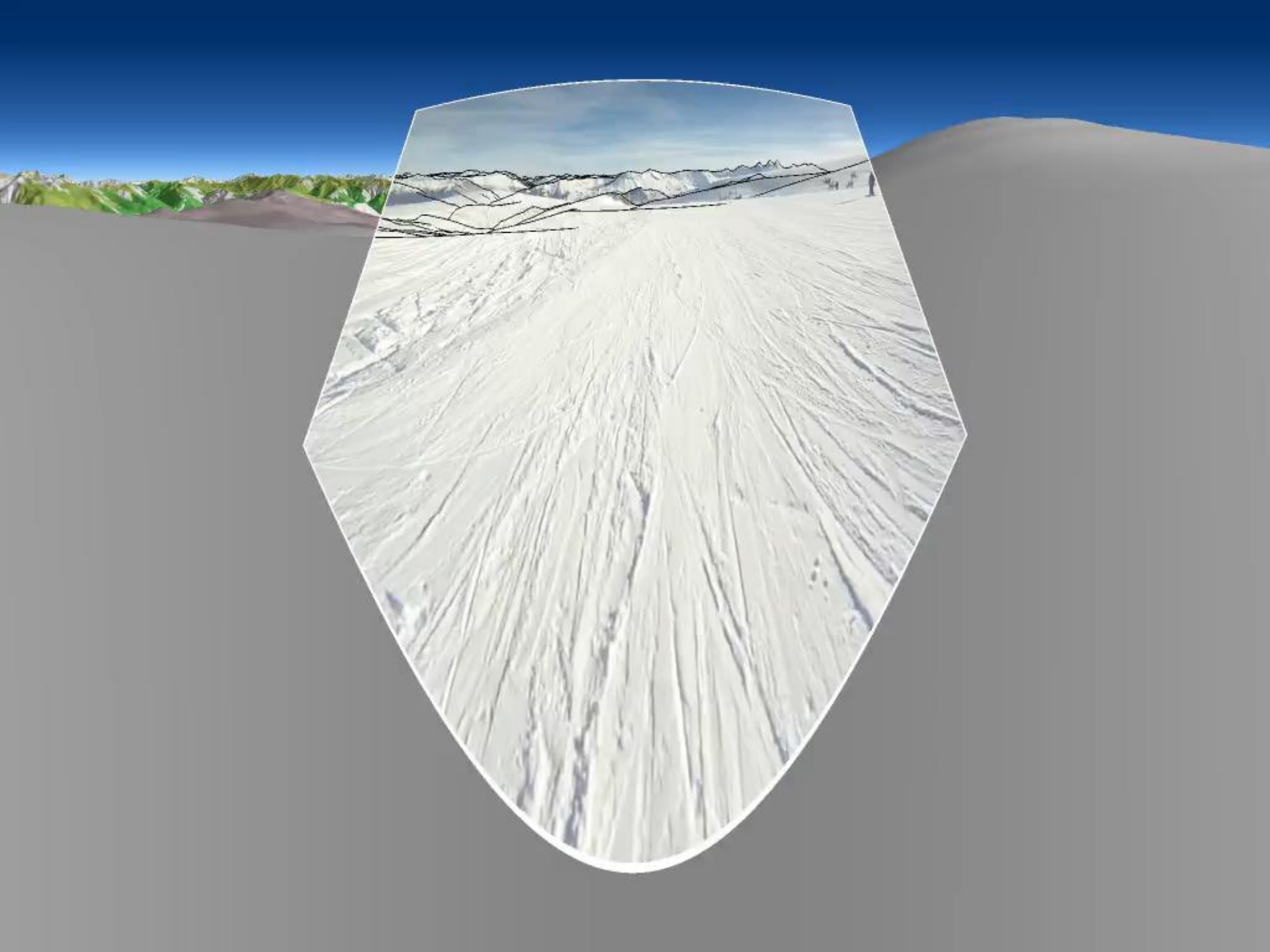
VISUAL GEO-LOCALIZATION: 3D FOR COMPUTATIONAL PHOTOGRAPHY

Image Geo-localization Task

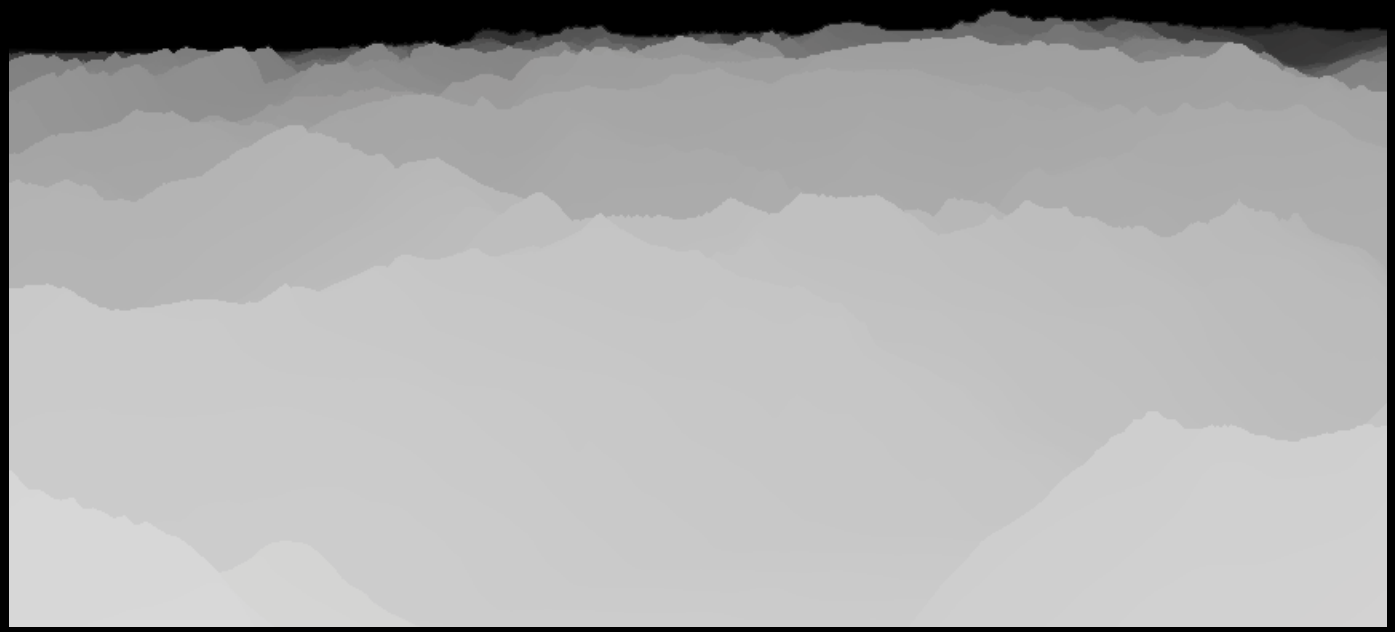
LOCATE: http://cadik.posvete.cz/locate/

Terrain model - 3D View

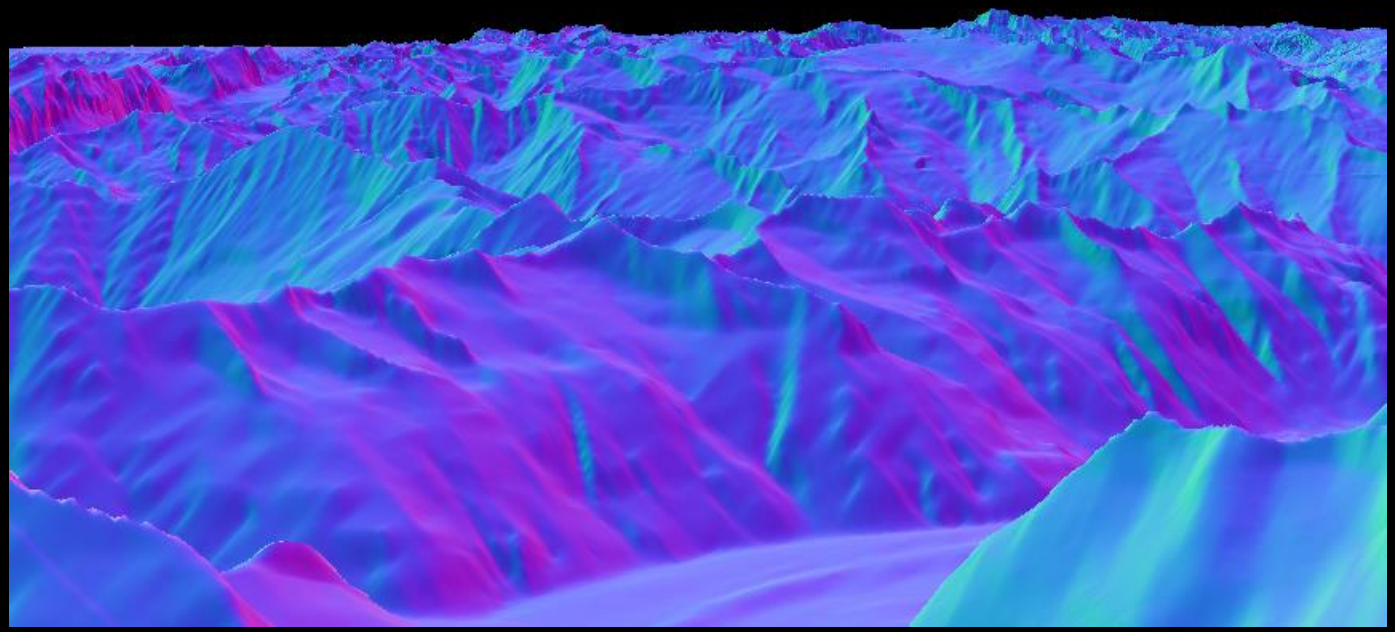




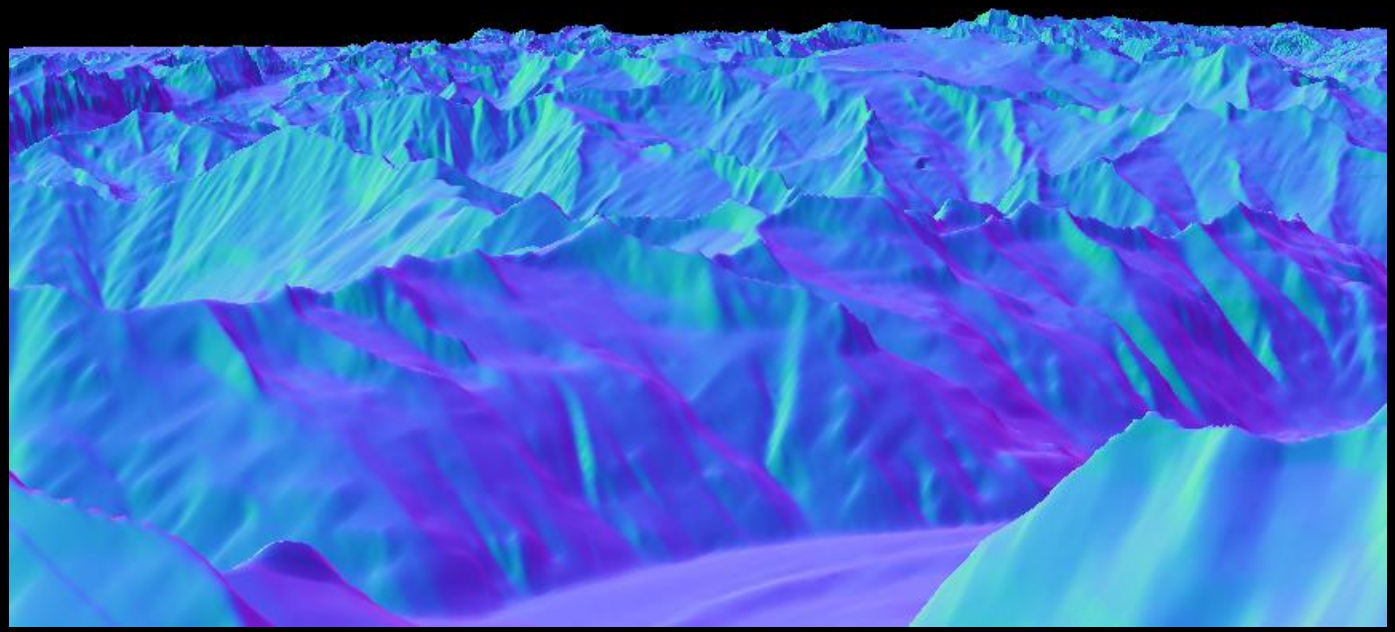
GeoPose3K - depth



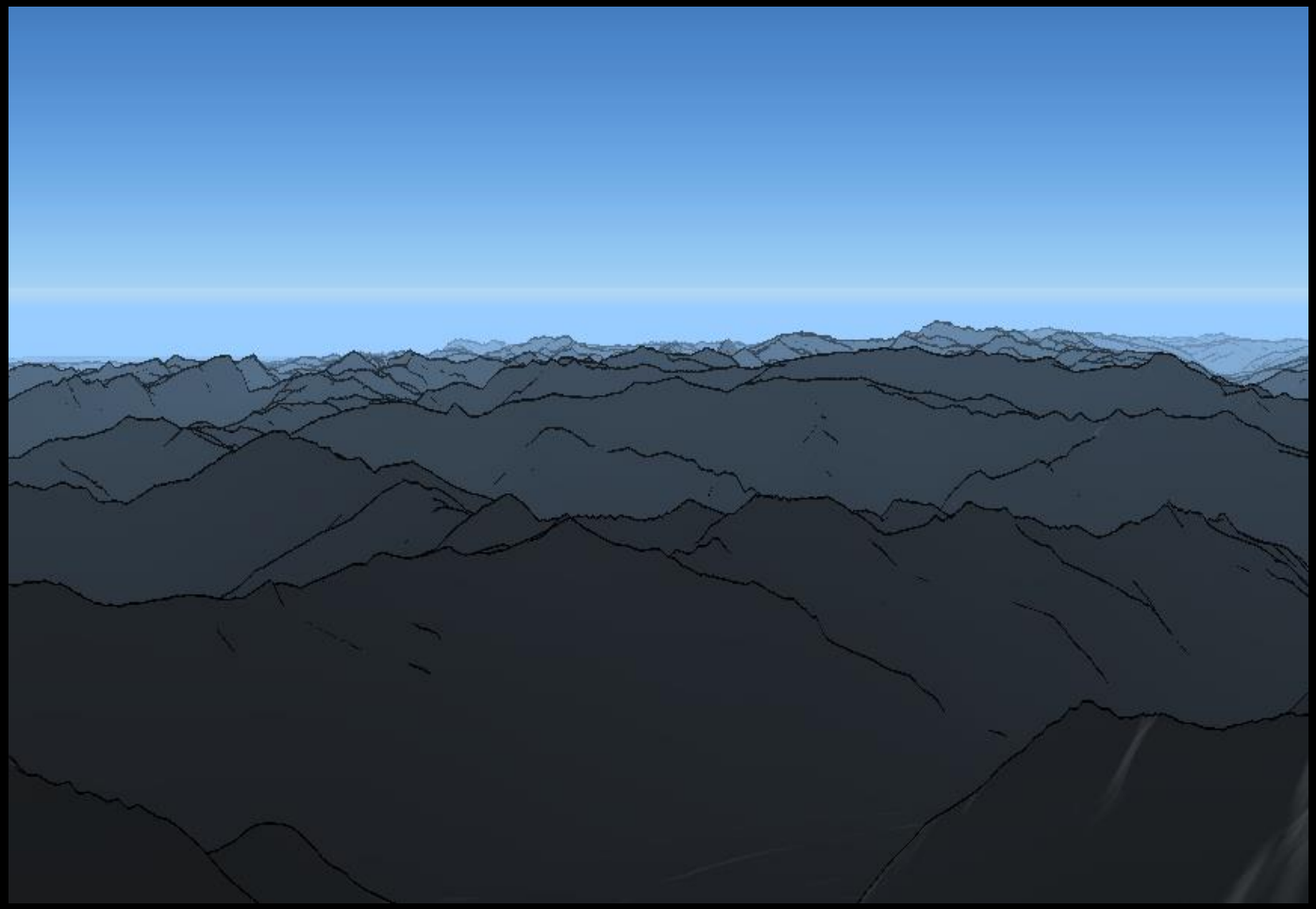
GeoPose3K - normals



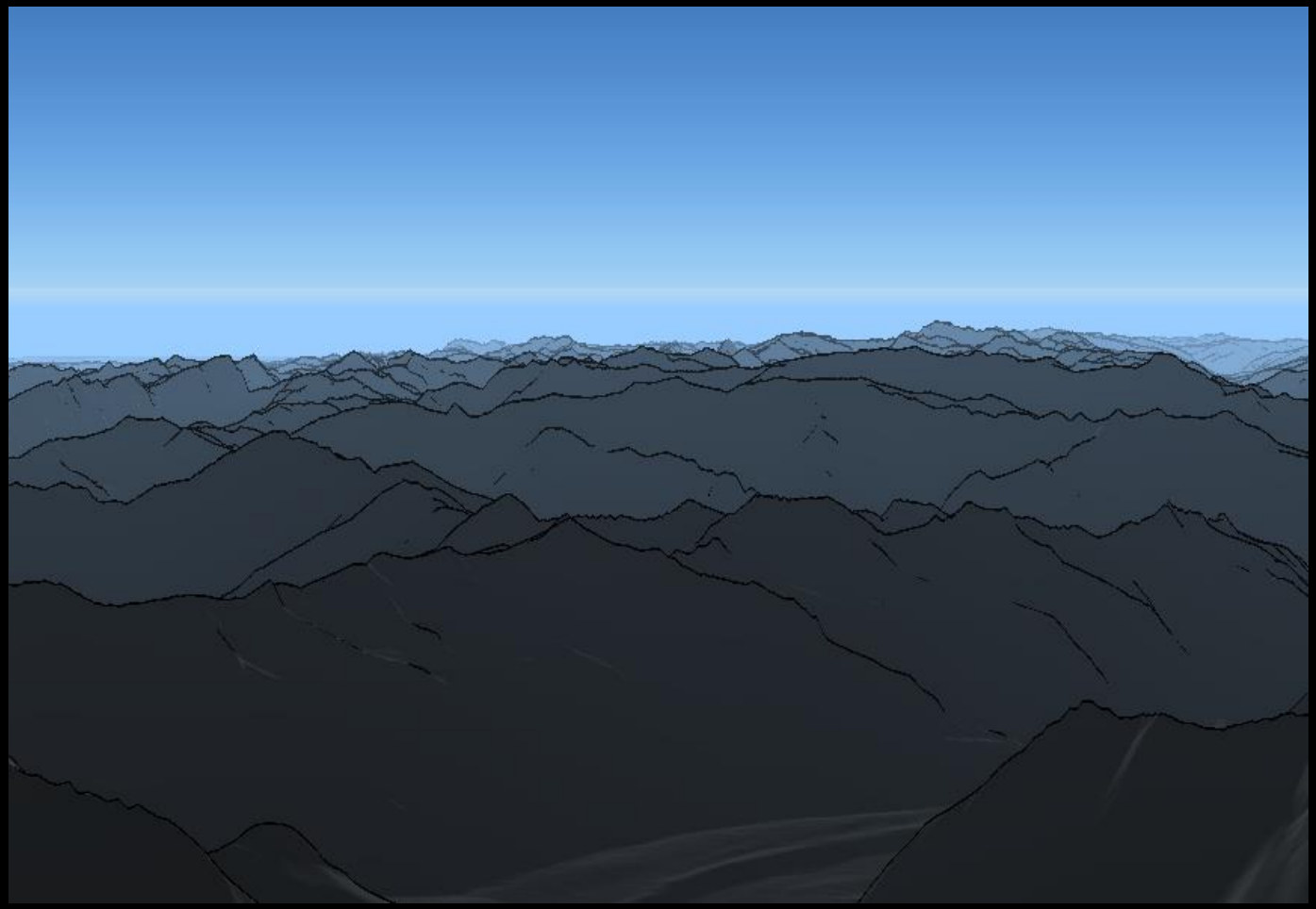
GeoPose3K - normals



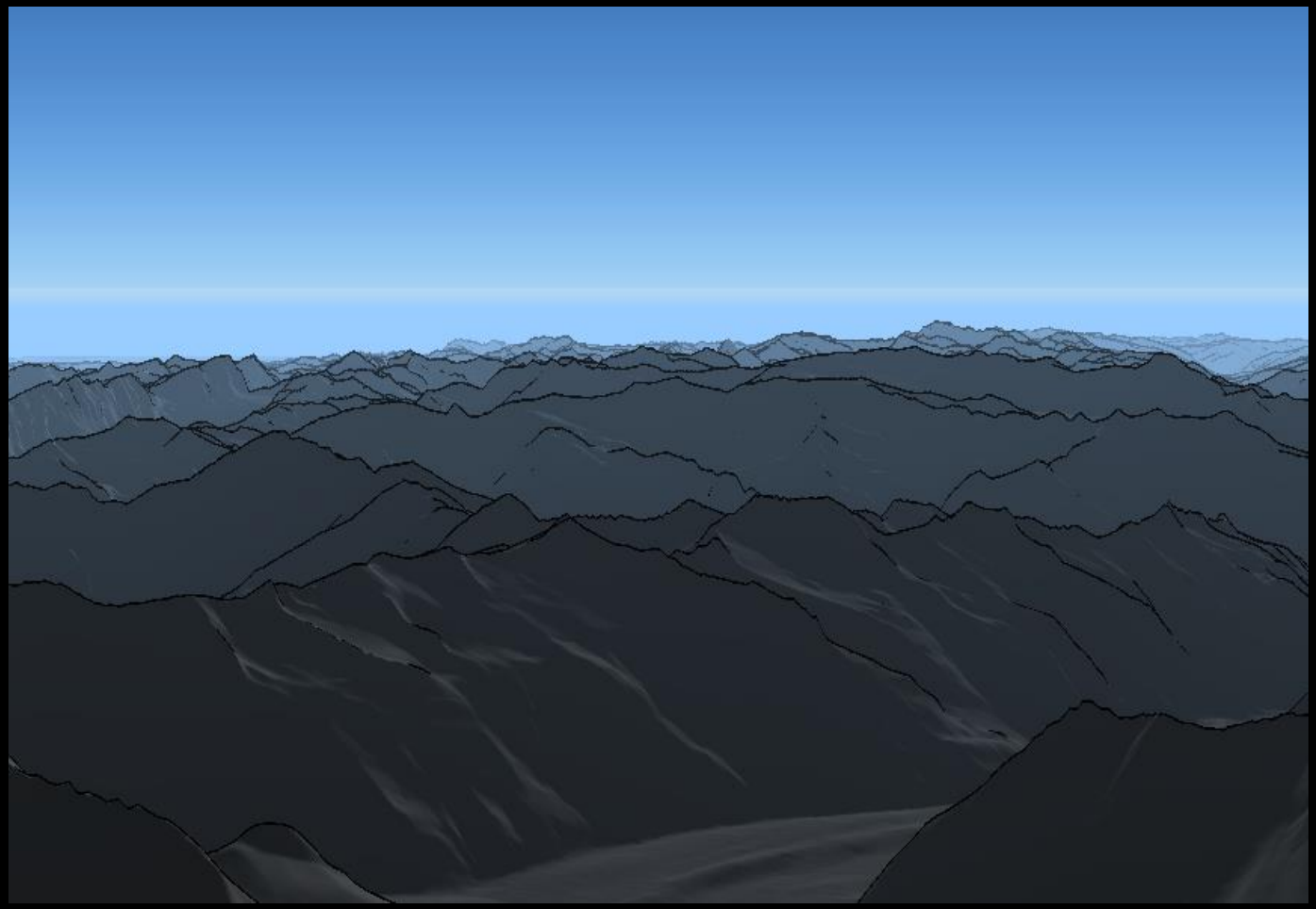
GeoPose3K - lighting



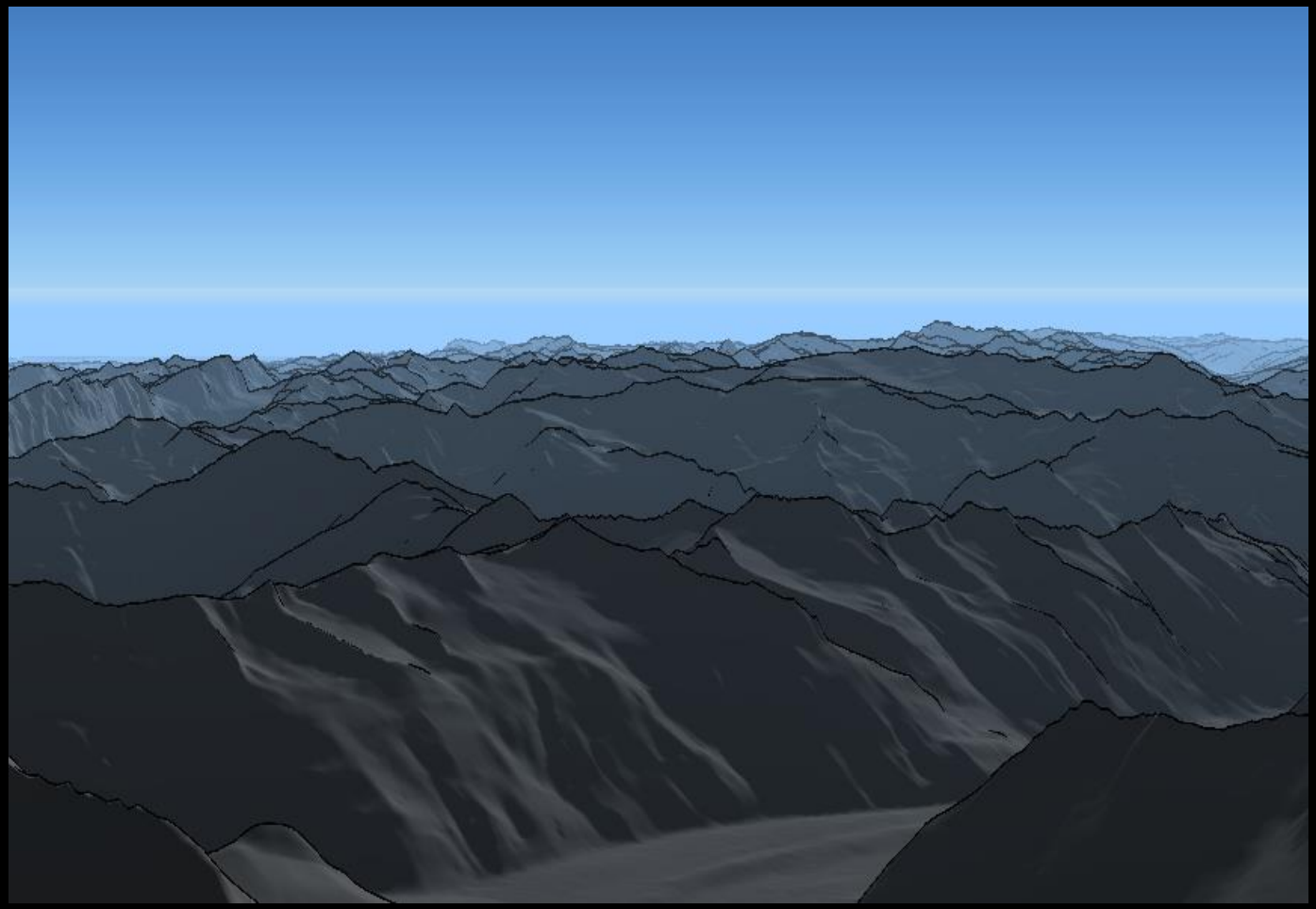
GeoPose3K - lighting



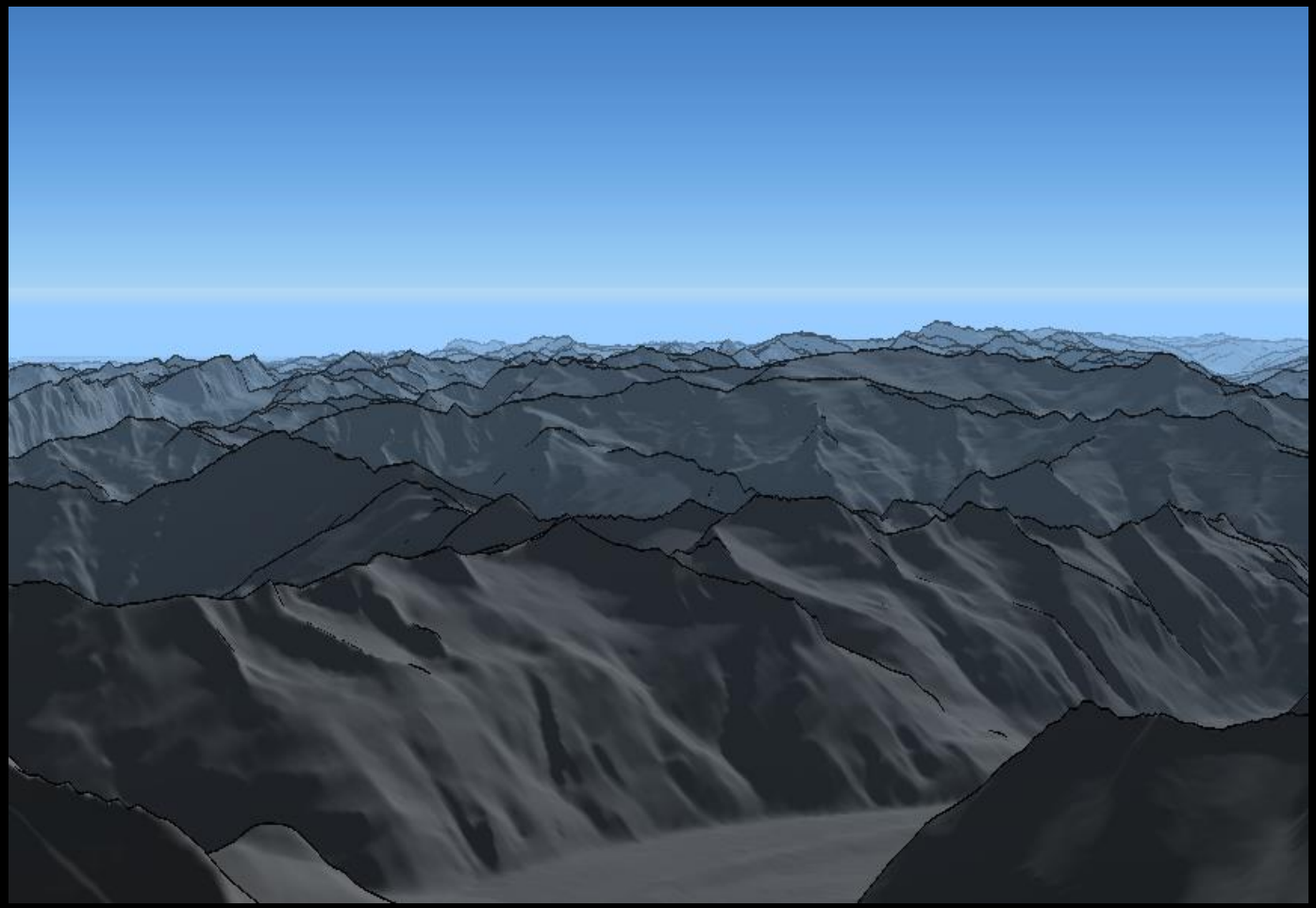
GeoPose3K - lighting



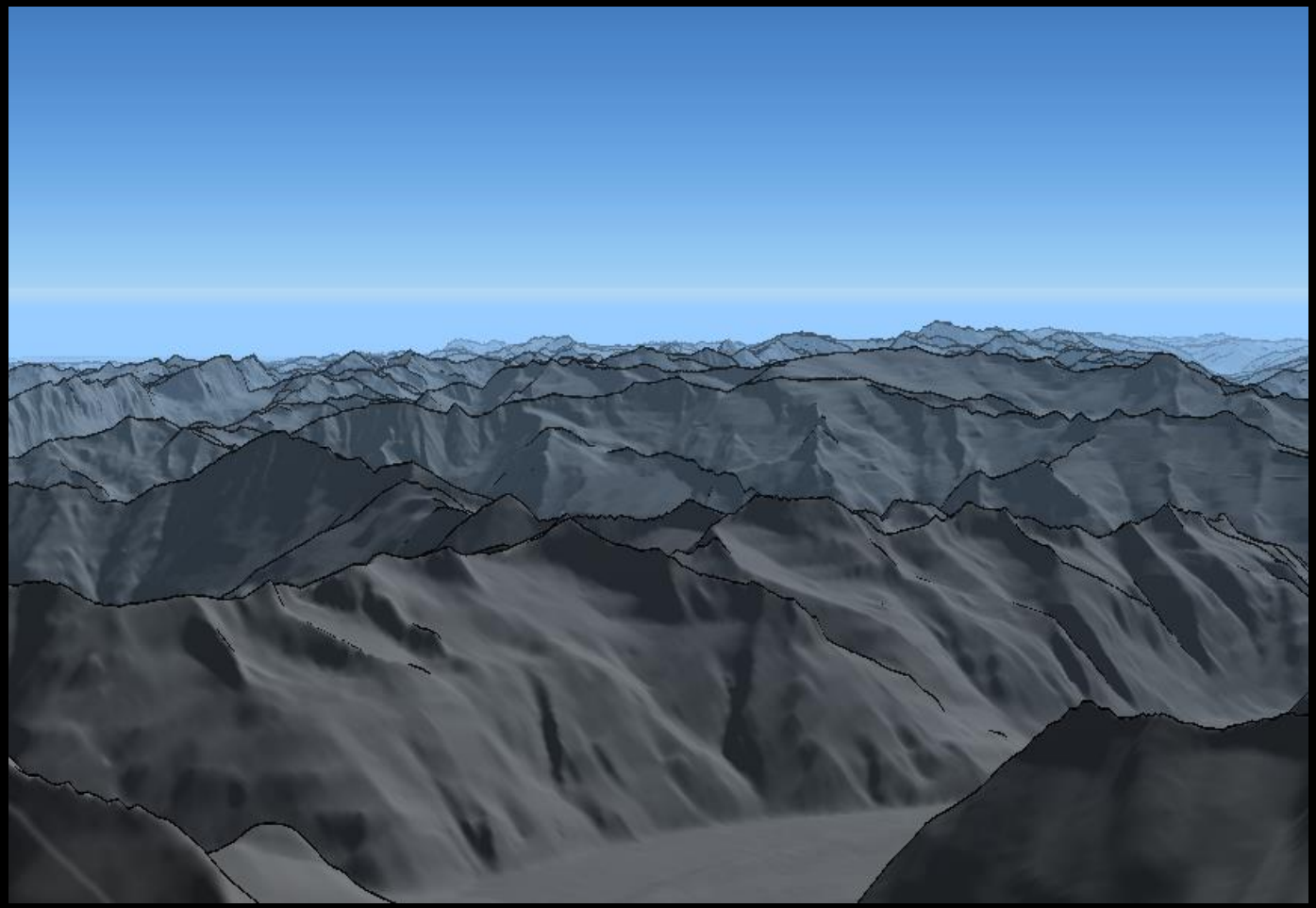
GeoPose3K - lighting



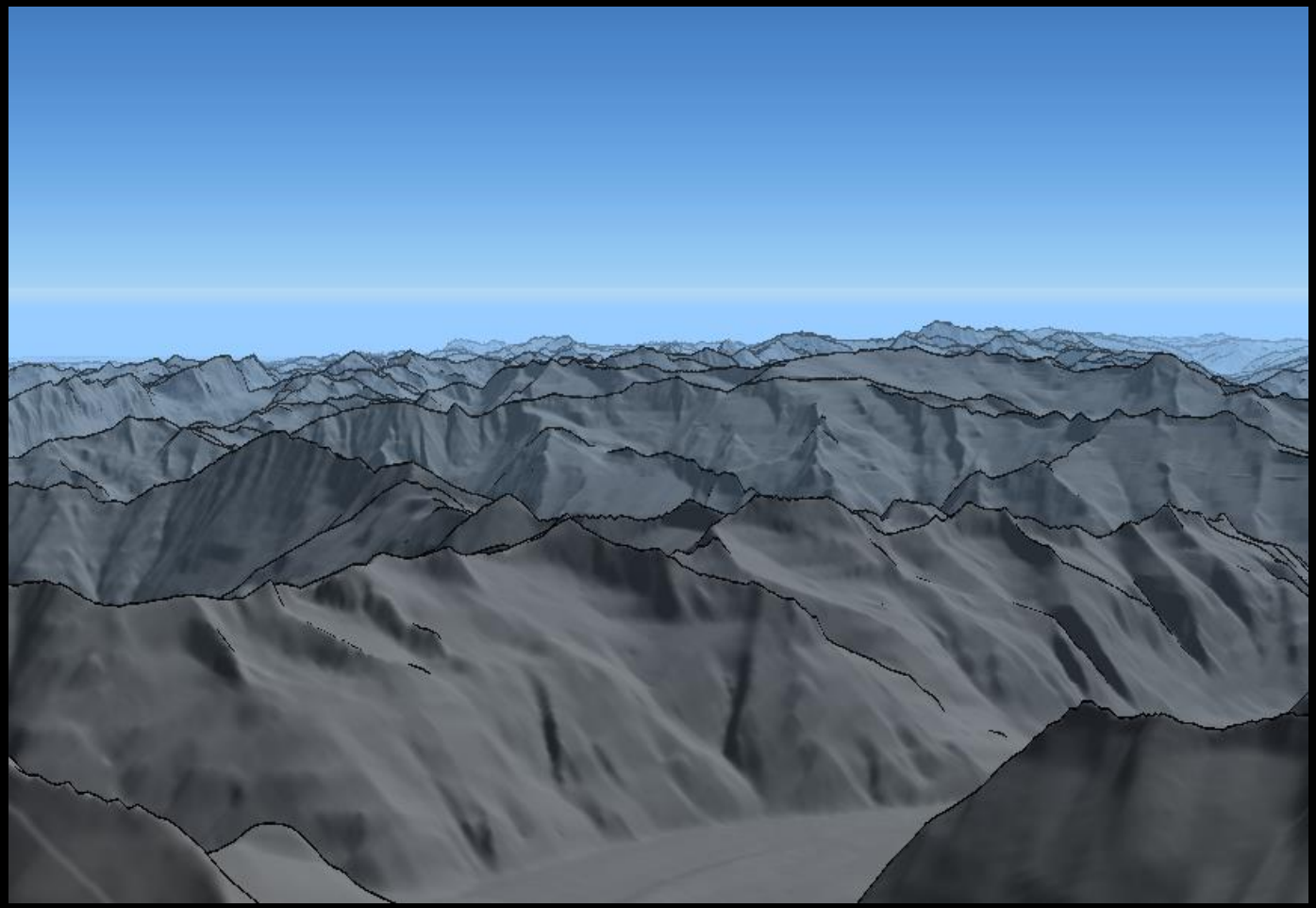
GeoPose3K - lighting



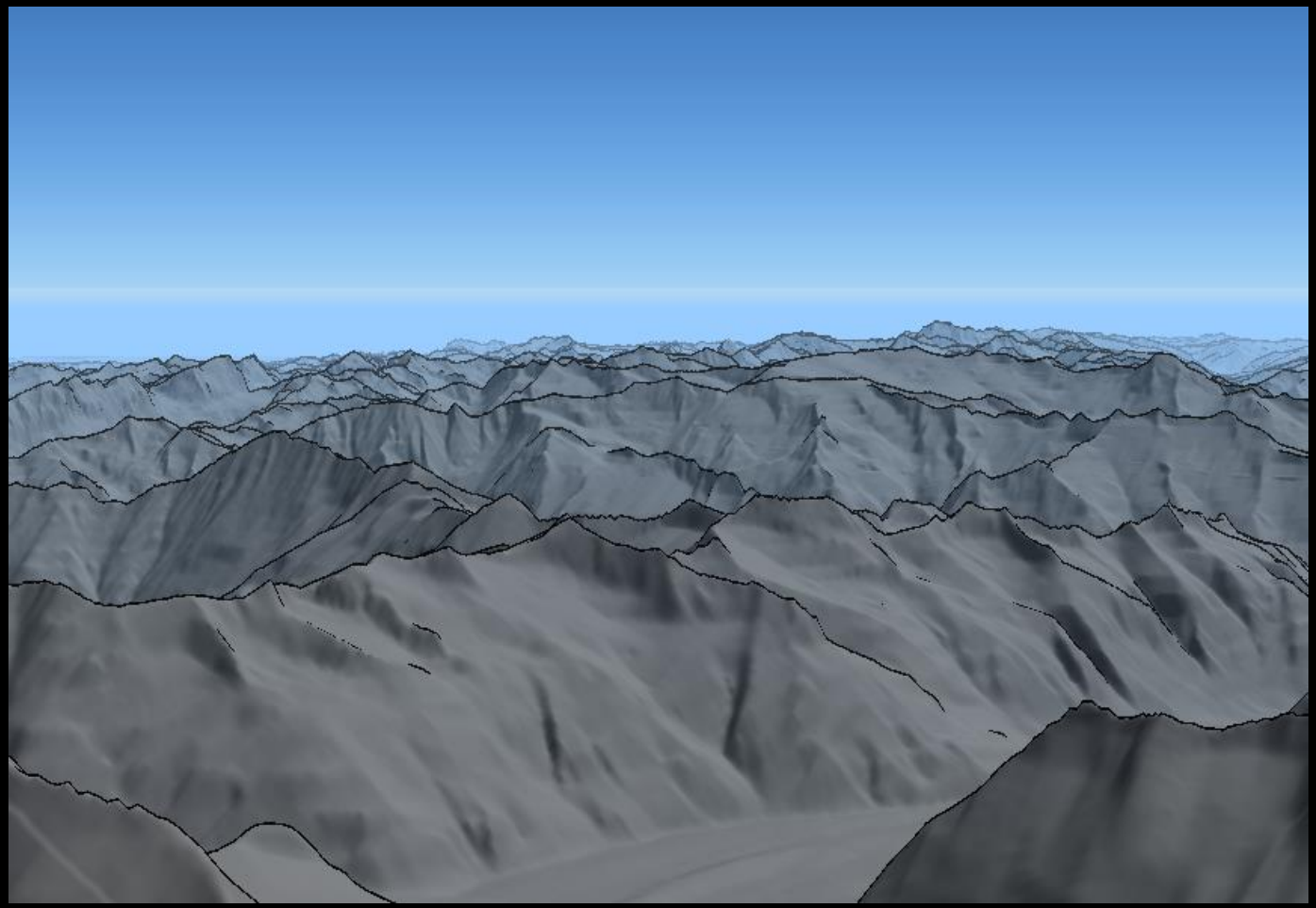
GeoPose3K - lighting



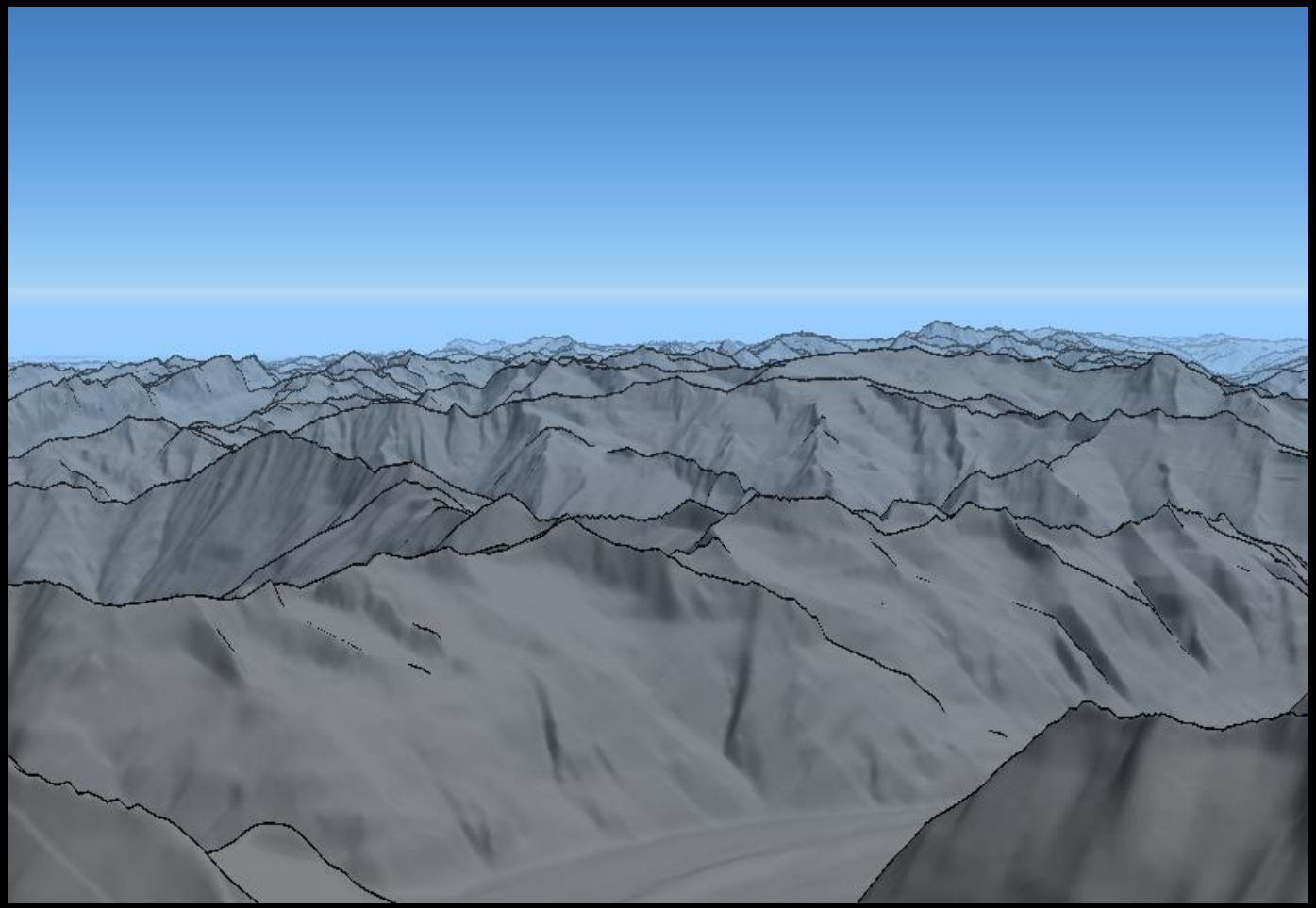
GeoPose3K - lighting



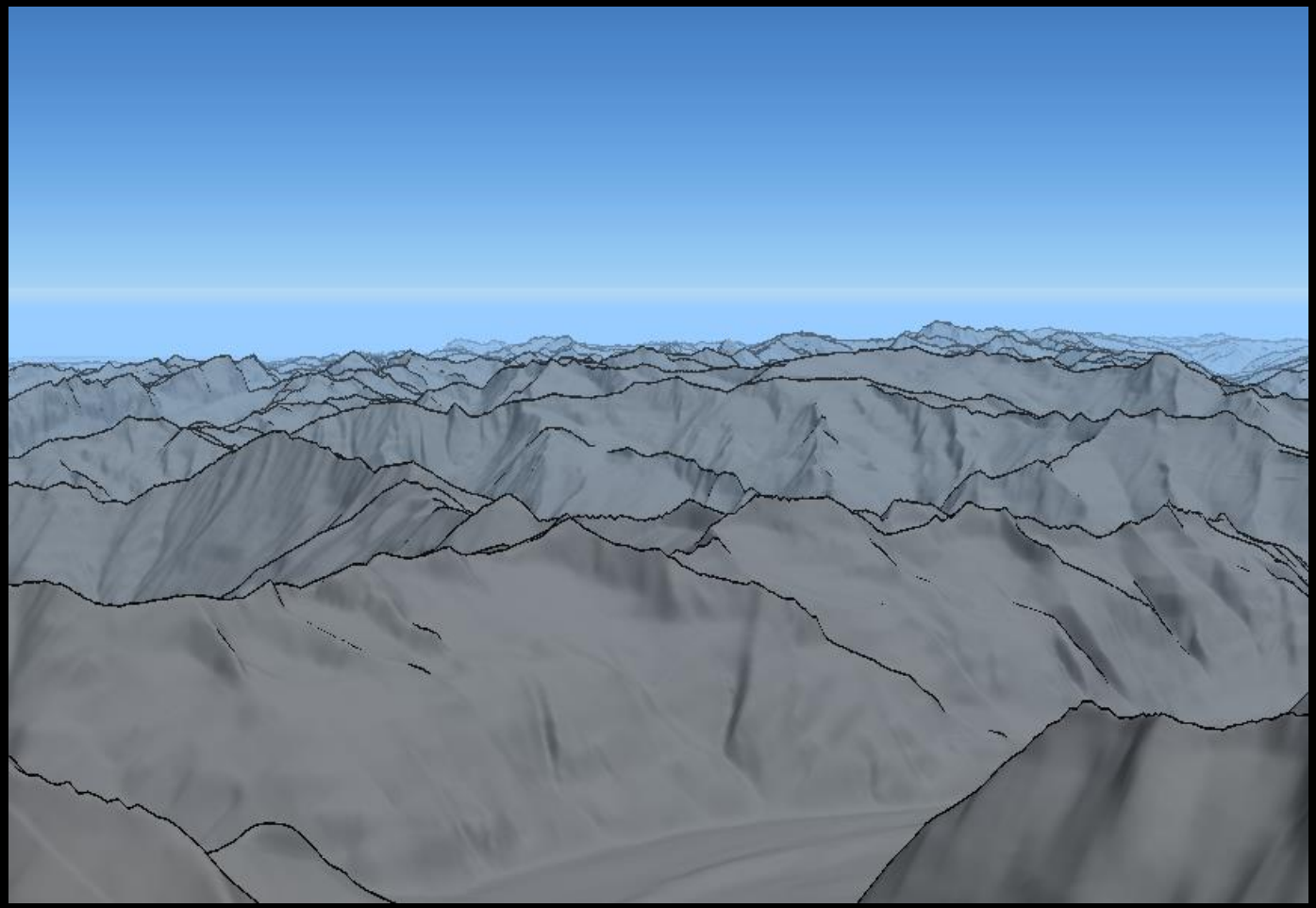
GeoPose3K - lighting



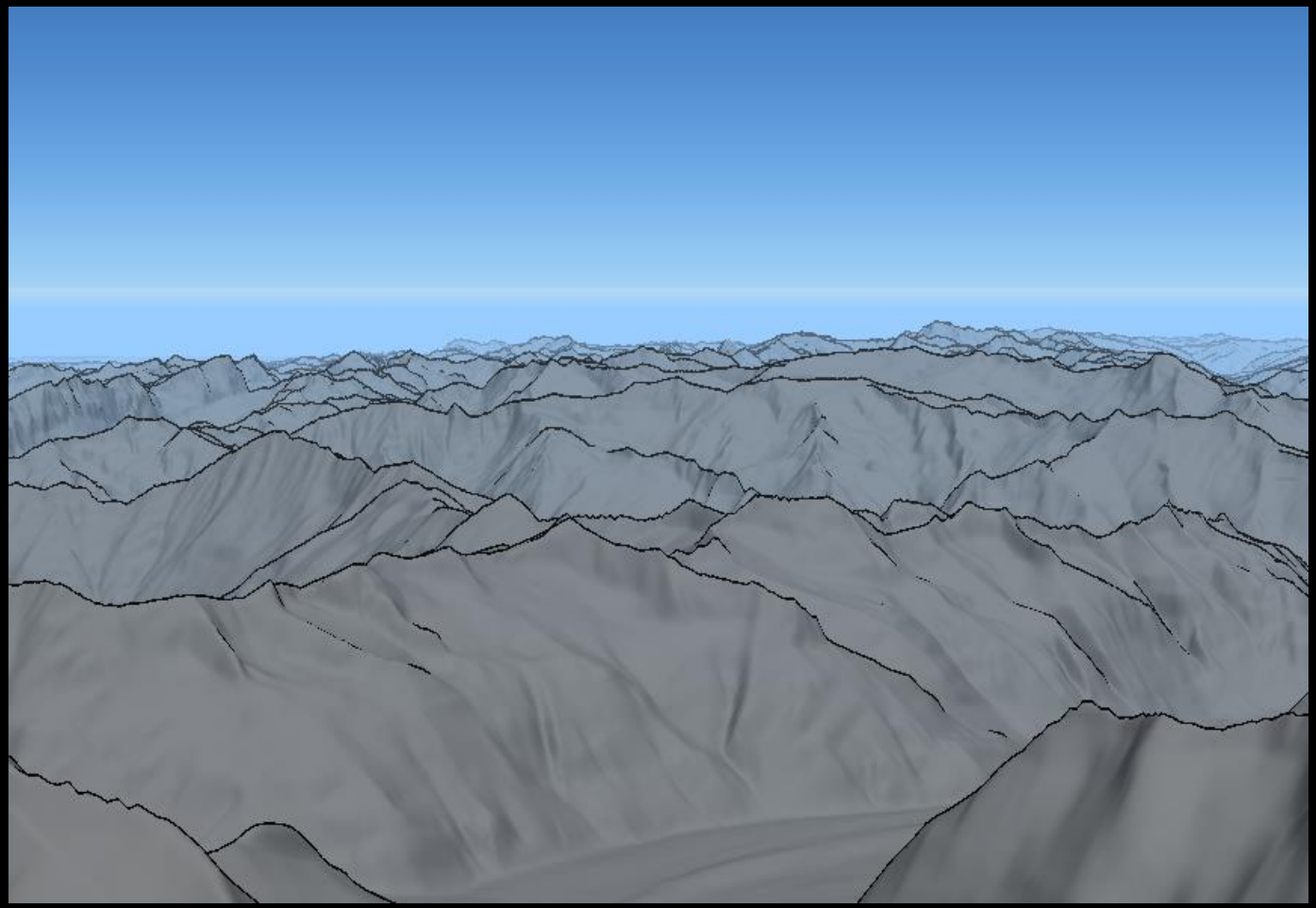
GeoPose3K - lighting



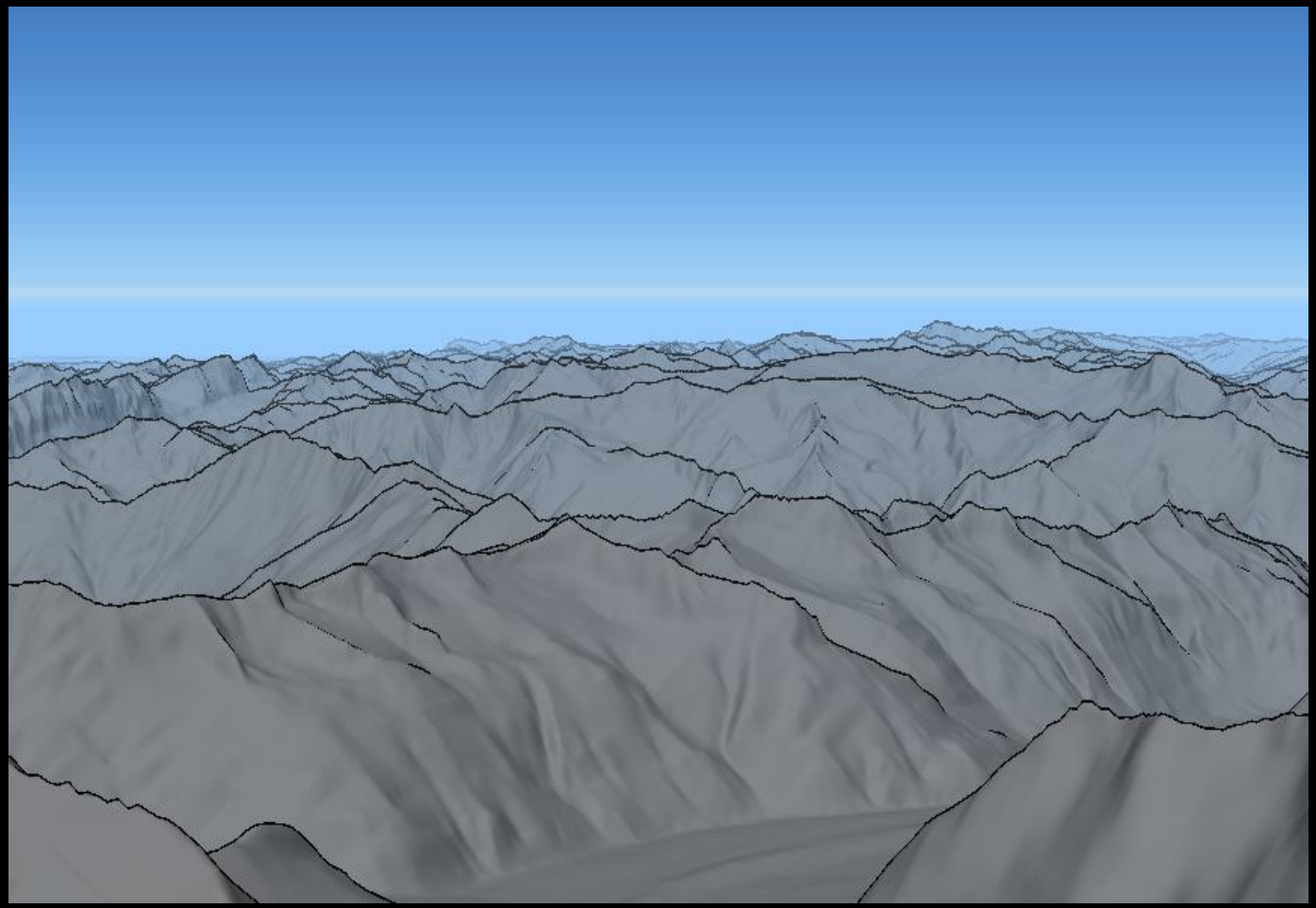
GeoPose3K - lighting



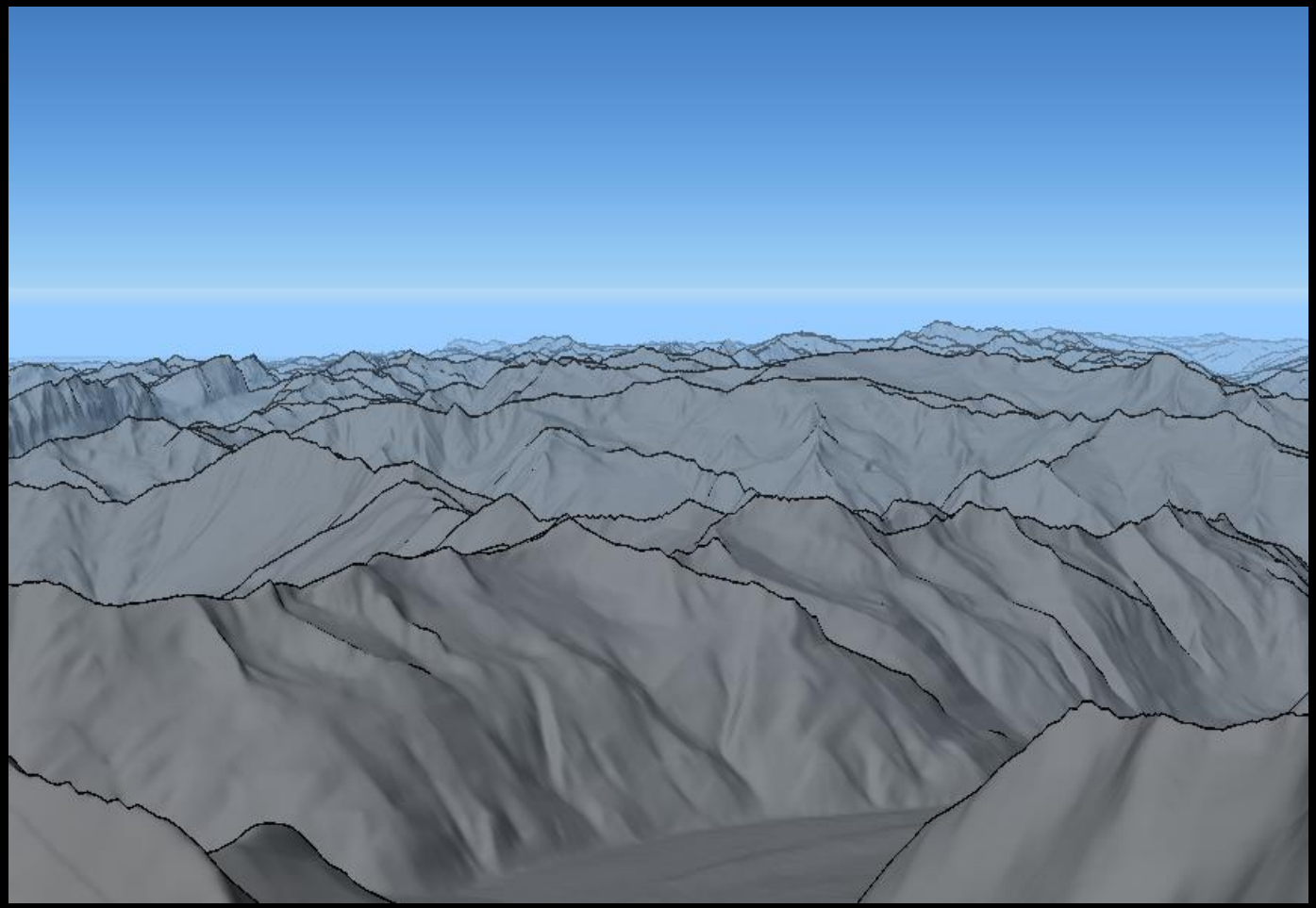
GeoPose3K - lighting



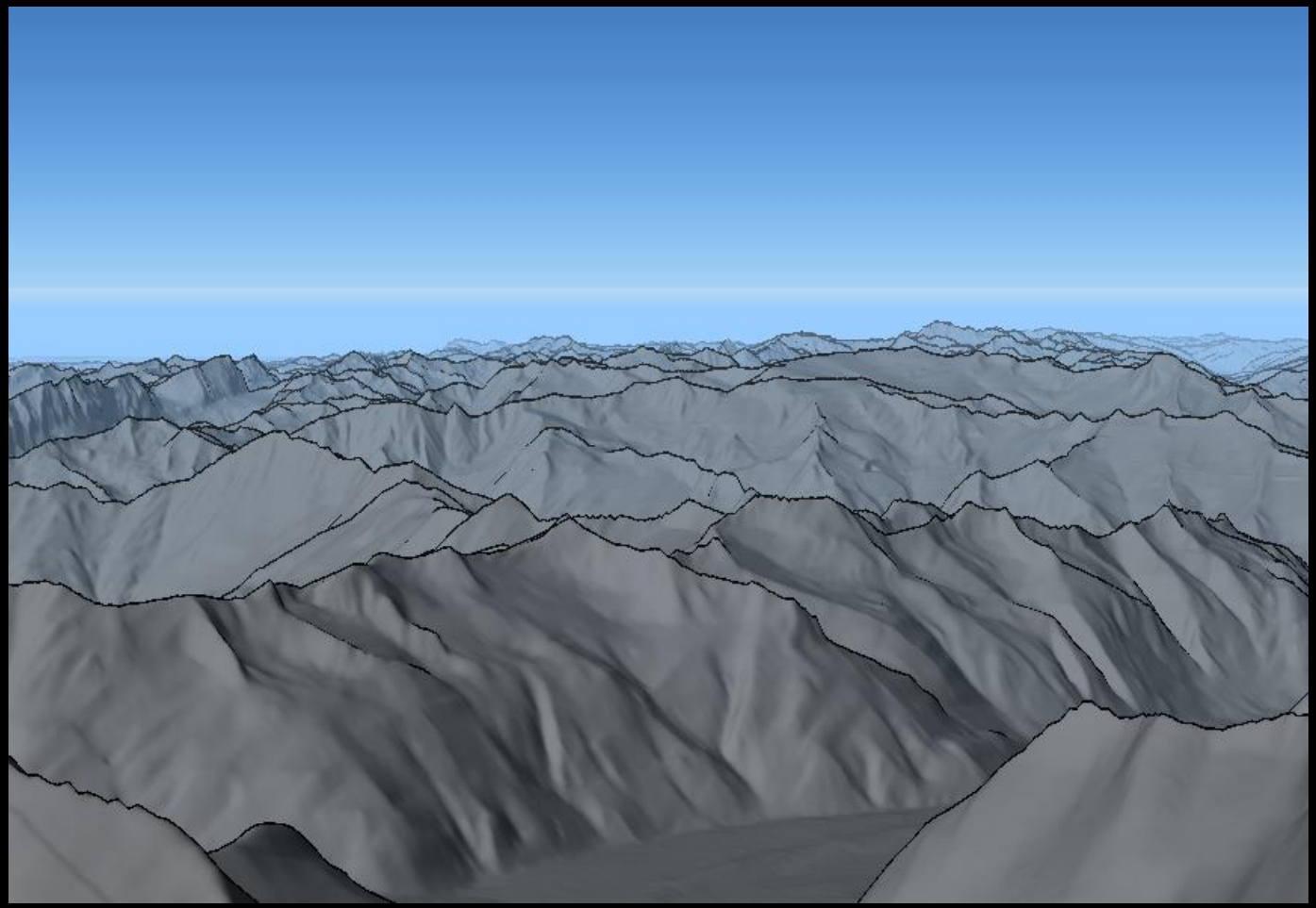
GeoPose3K - lighting



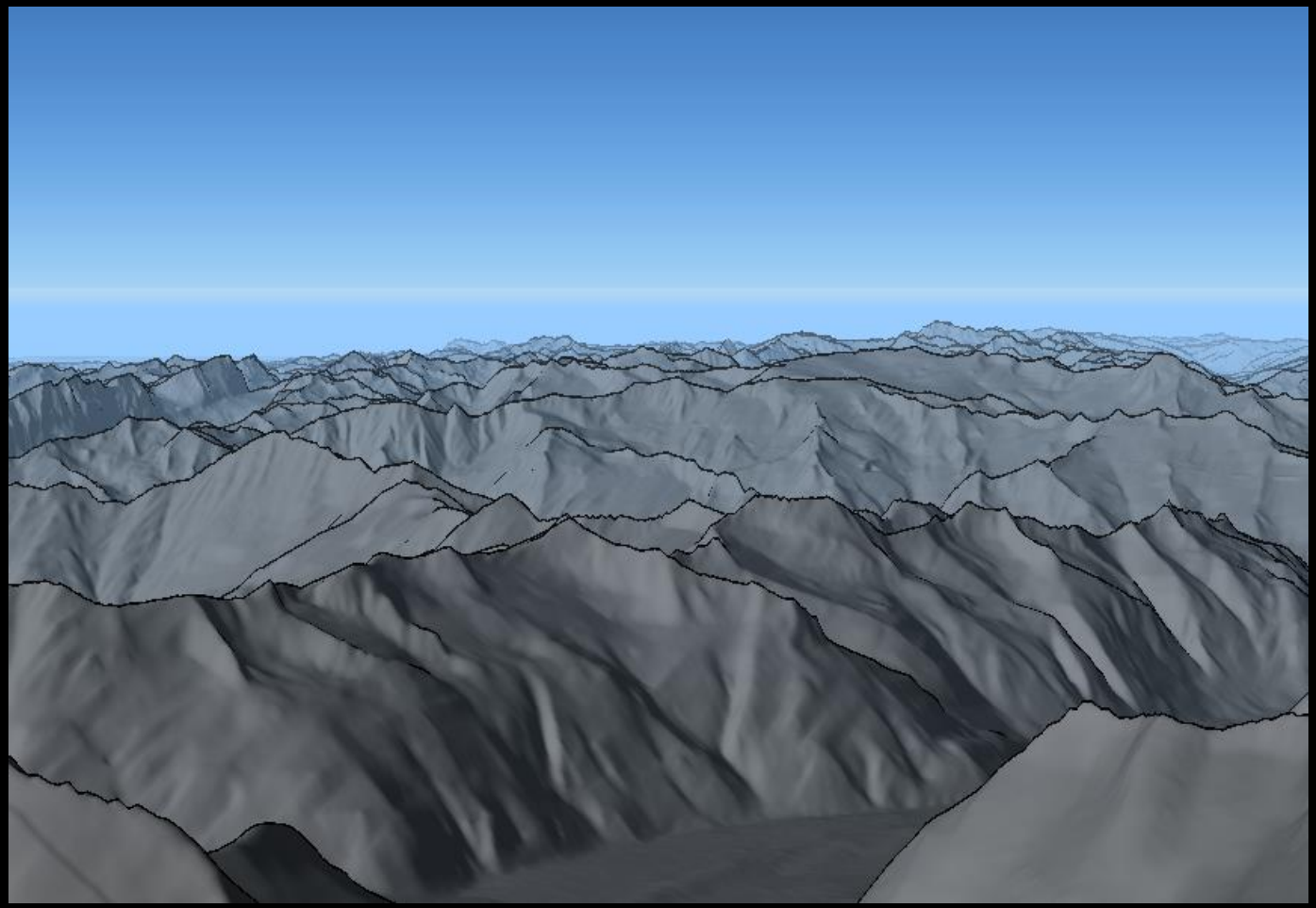
GeoPose3K - lighting



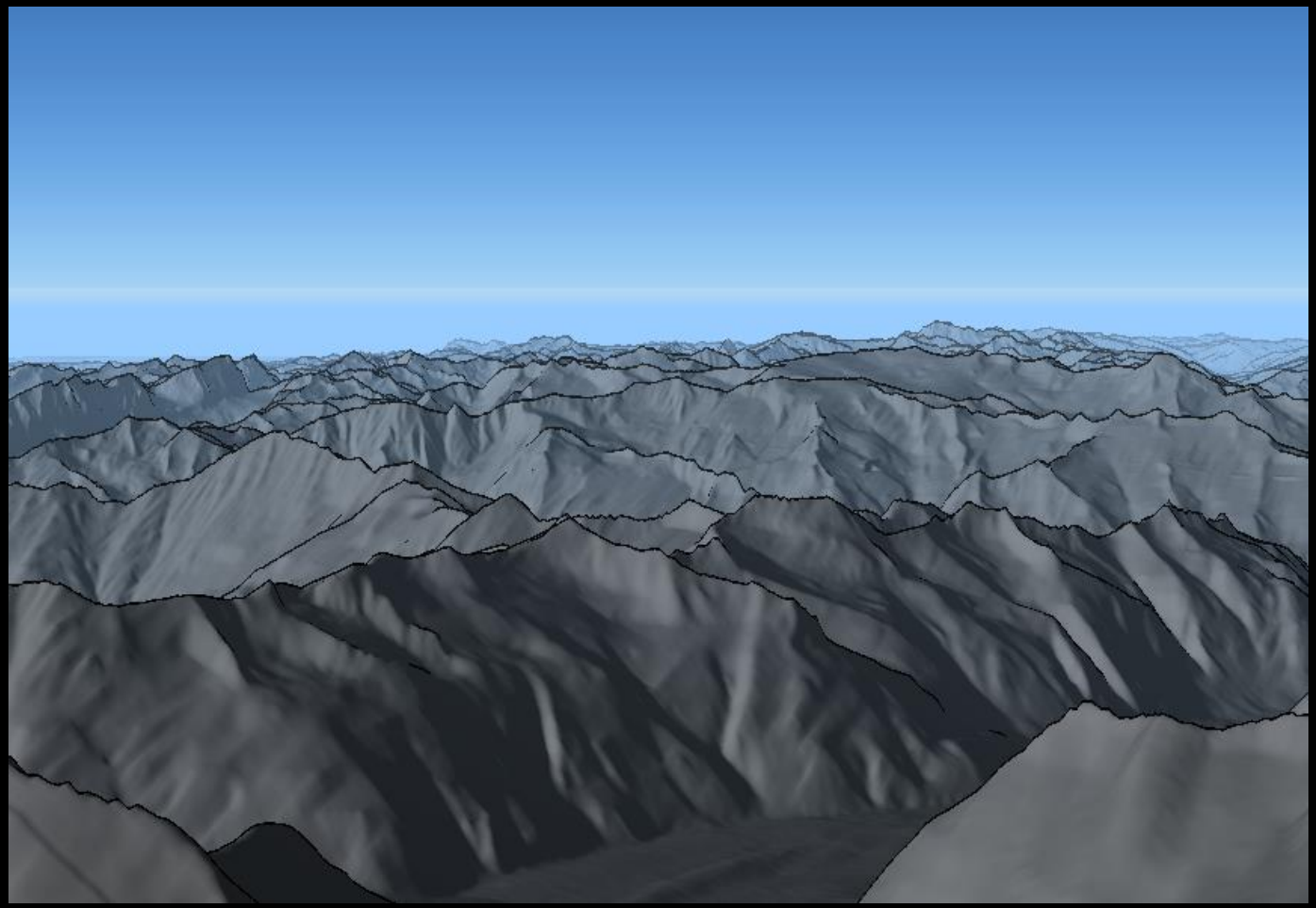
GeoPose3K - lighting



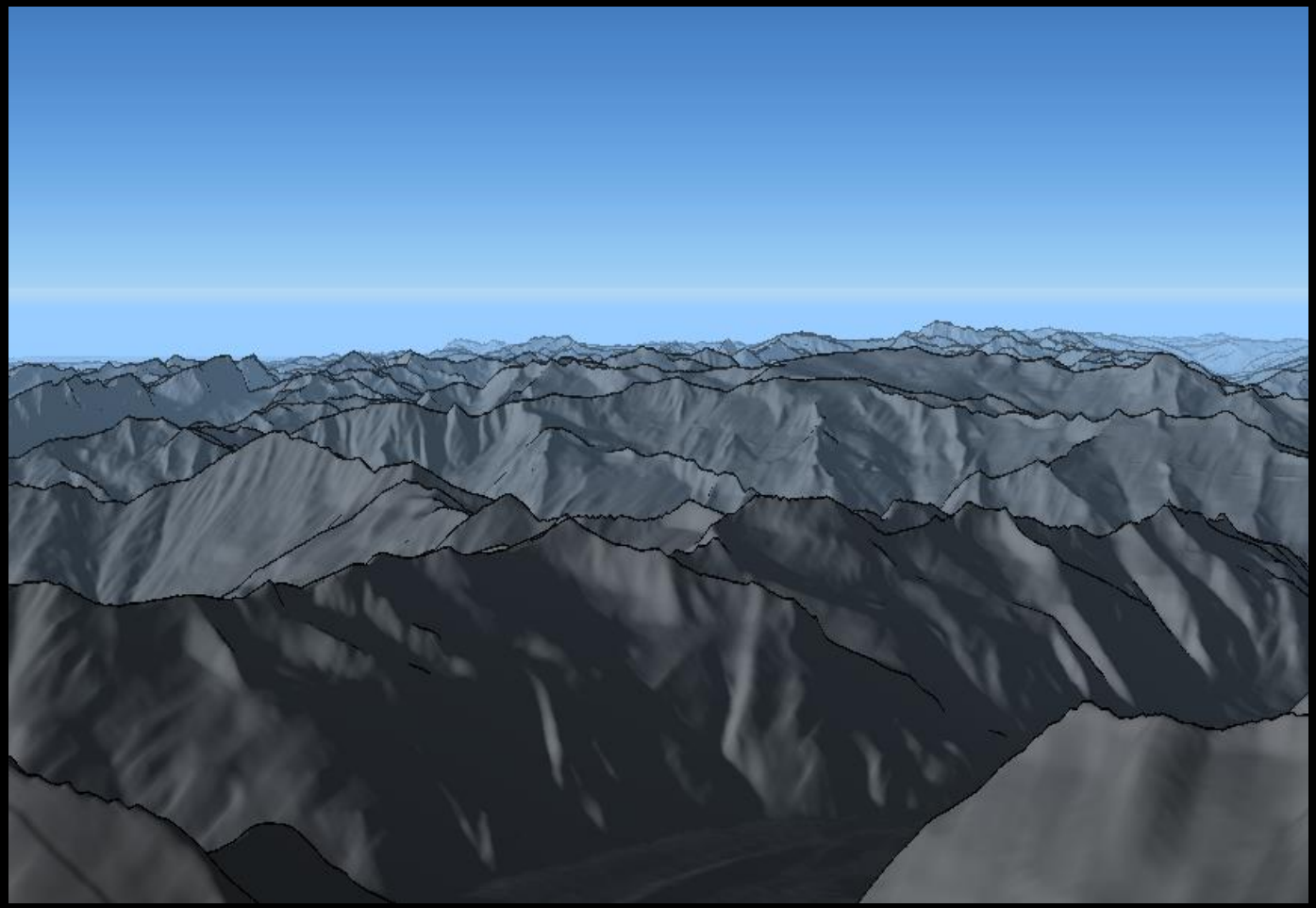
GeoPose3K - lighting



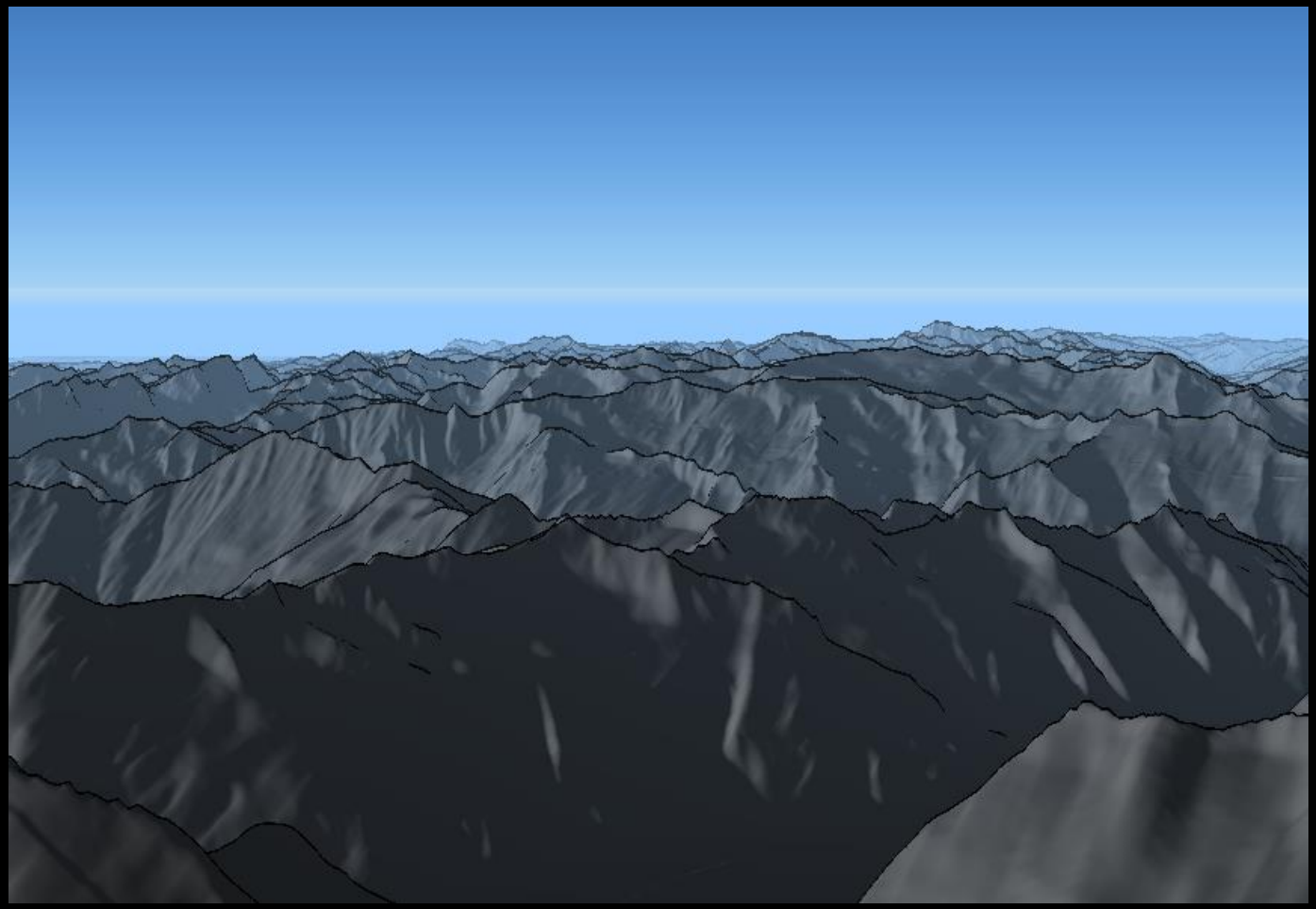
GeoPose3K - lighting



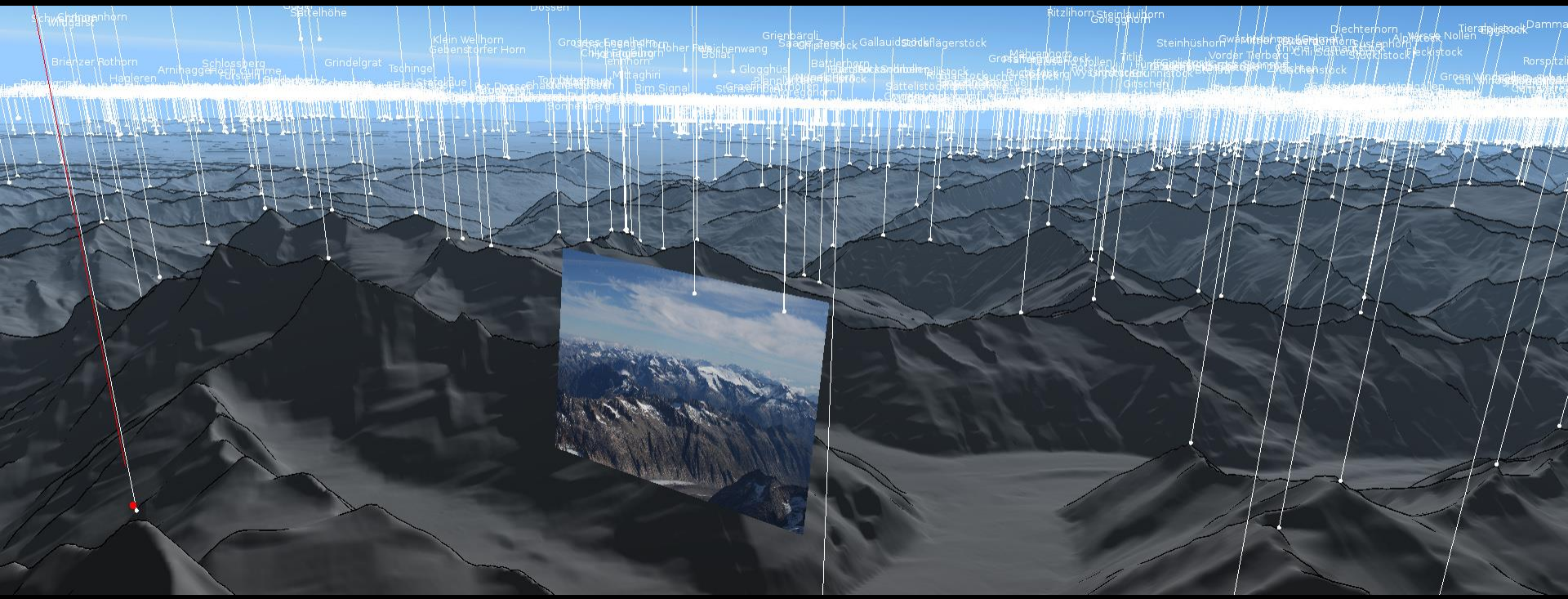
GeoPose3K - lighting



GeoPose3K - lighting



GeoPose3K - Metadata

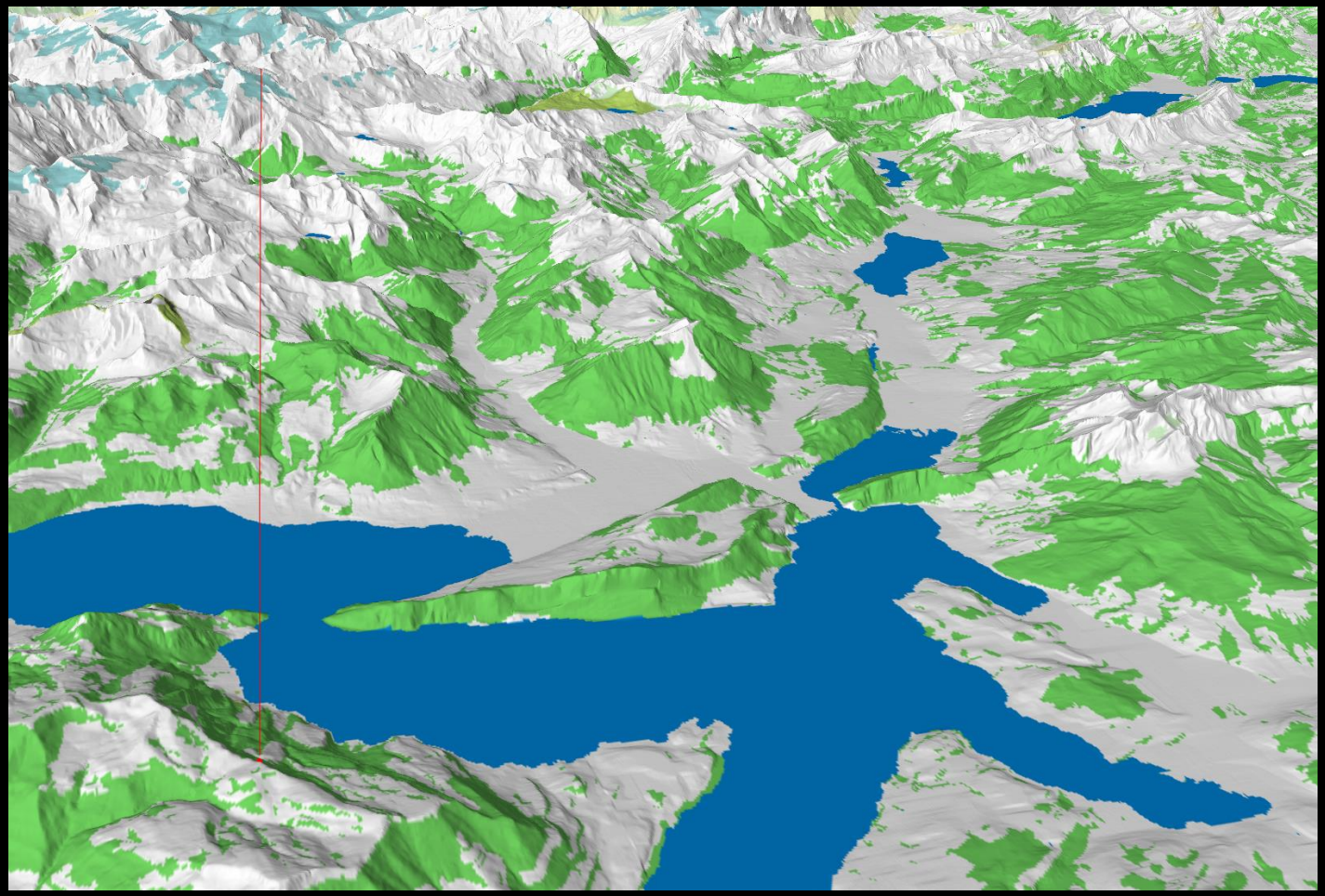


Metadata source: OpenStreetMap

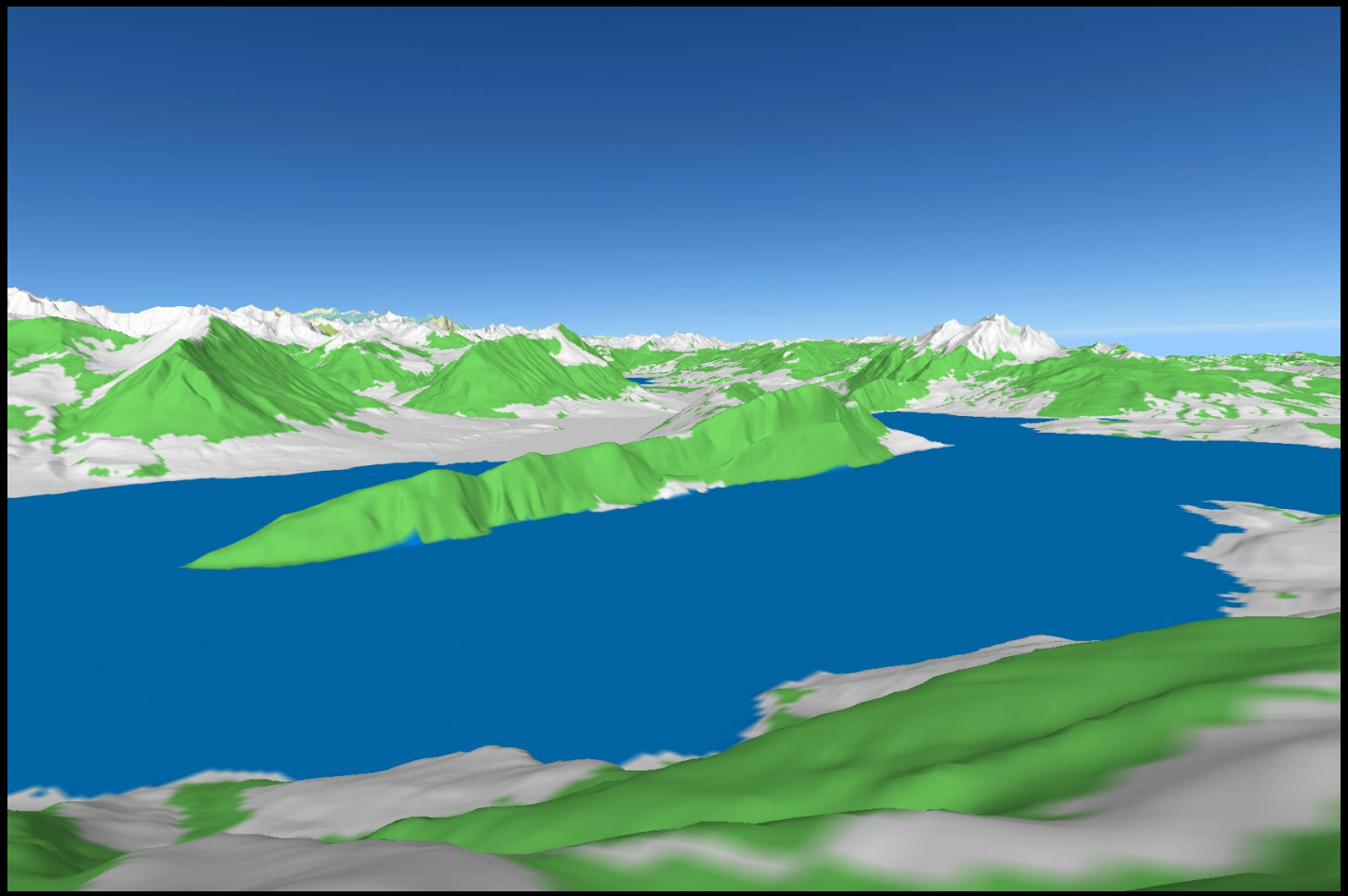
GeoPose3K - Metadata

Synthetic Semantic Segmentation

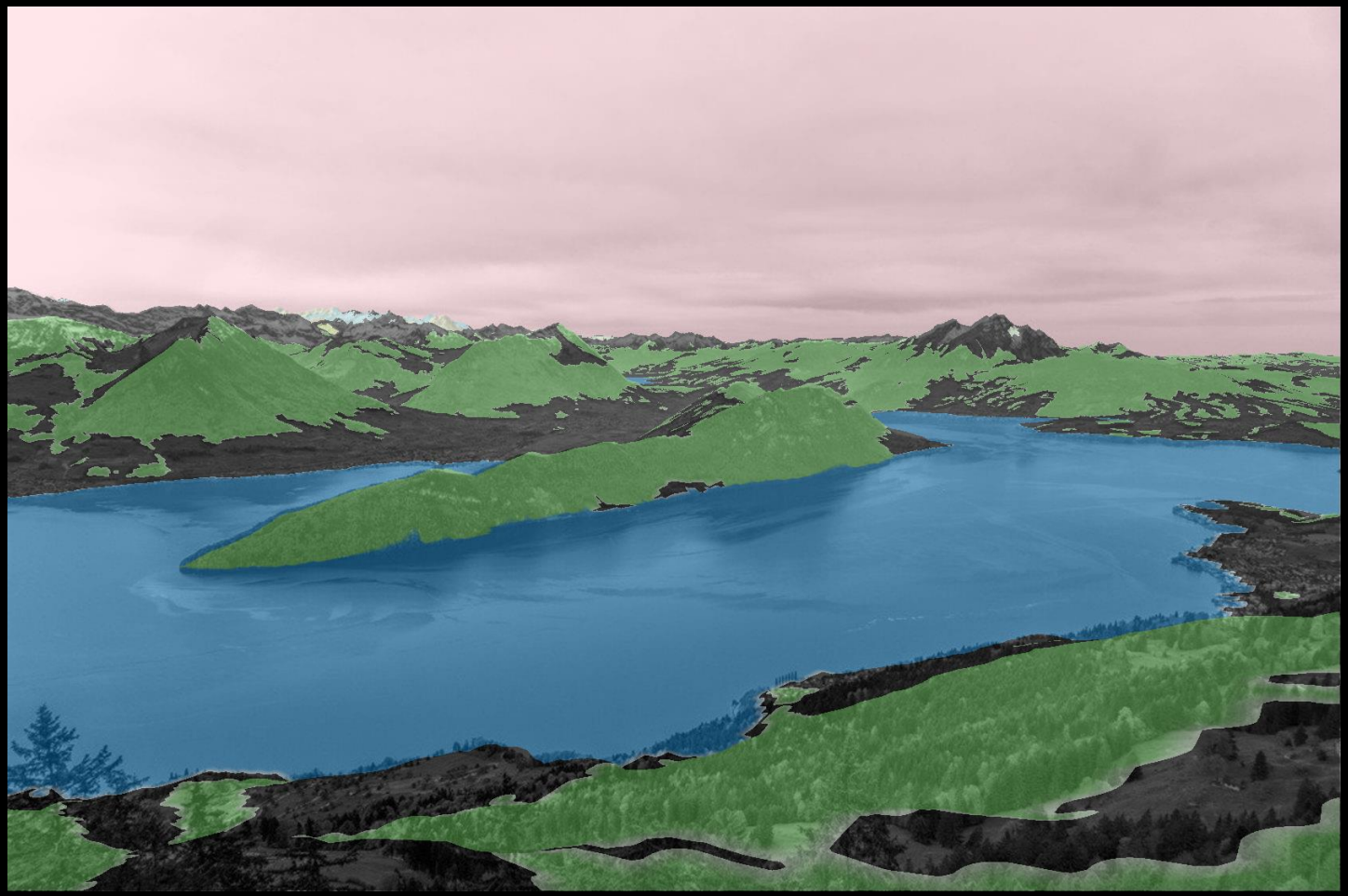
Synthetic Semantic Segmentation



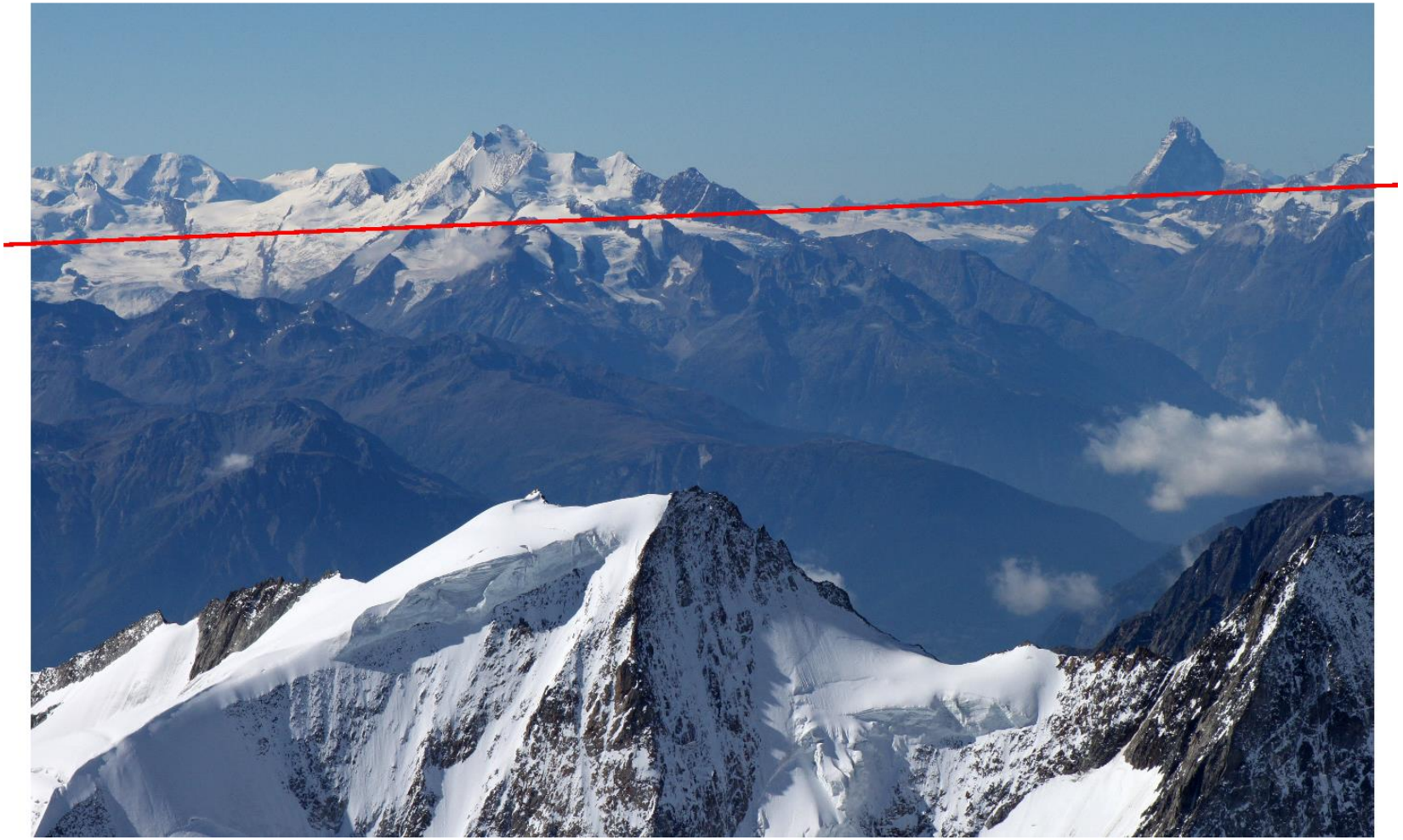
Synthetic Semantic Segmentation



Synthetic Semantic Segmentation



Leveling Horizon



original

Leveling Horizon

corrected

Depth-assisted Dehazing

original

Depth-assisted Dehazing

dehazed

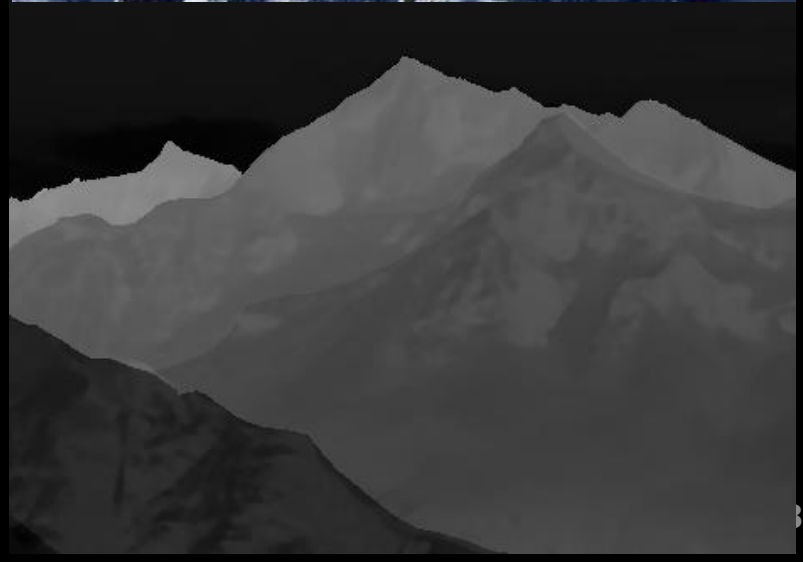
Depth-assisted Dehazing

original

Depth-assisted Dehazing

dehazed

Depth-assisted Dehazing



Simulating Depth-of-Field

original

Simulating Depth-of-Field

Simulating Depth-of-Field

S=9km

Simulating Depth-of-Field

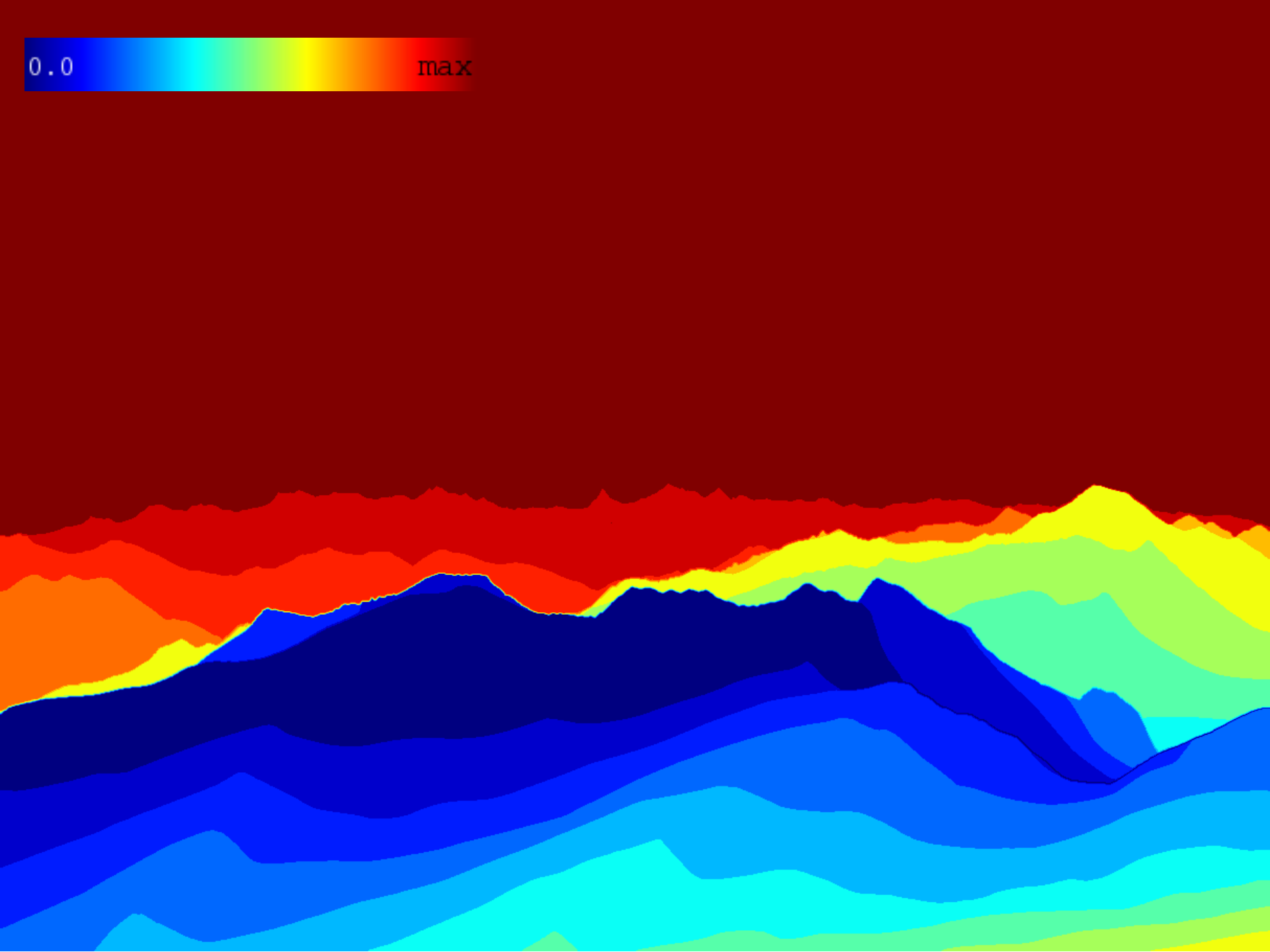
S=20km

Simulating Depth-of-Field

S=30km

Simulating Depth-of-Field

S=70km

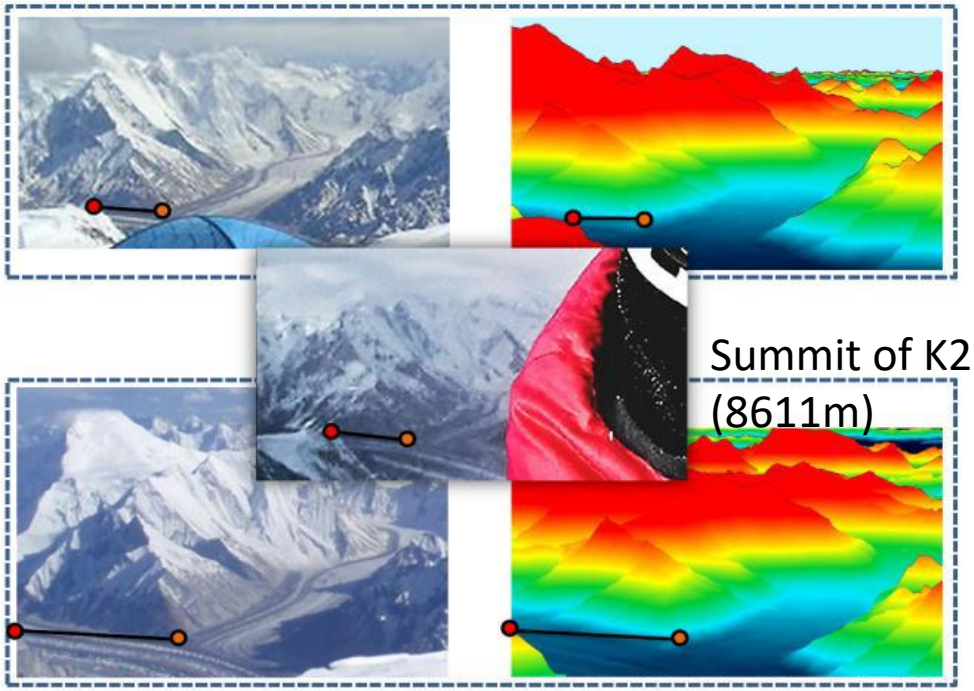

0.0
max

Synthetic Depth-of-Field

camera = Lenses 35 mm (FullFrame)
Coc = 0.0288
focal length = 1200.0000
F-number = 22.0000
distance = 2552.0400

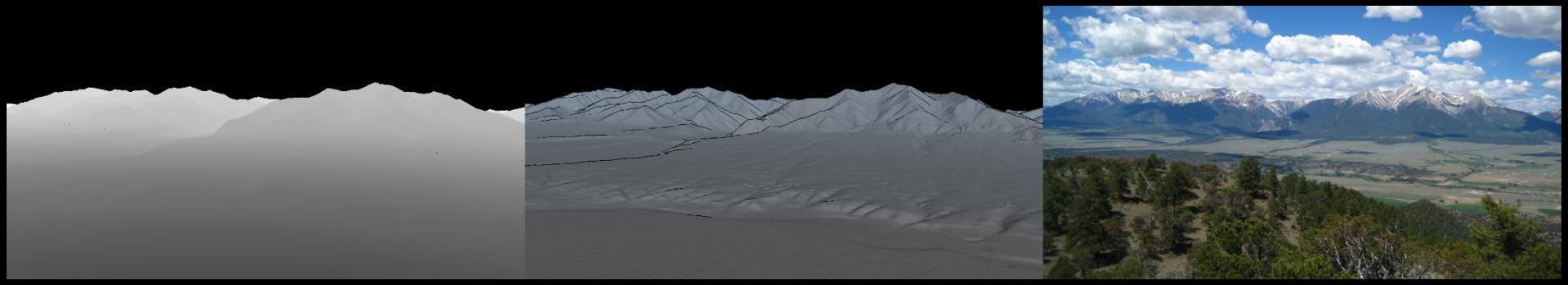
Image Forensics

- Bogus K2 summiting



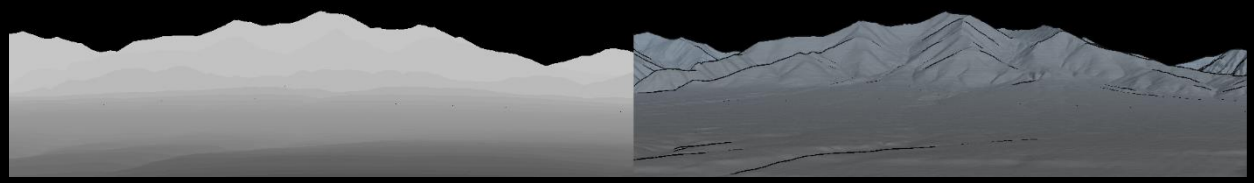
[Chippendale et al., 2013]

Texture Synthesis



example data

Texture Synthesis

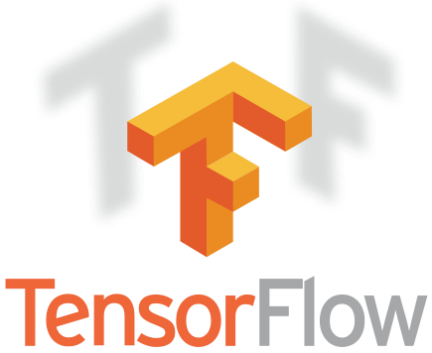


result

- Ph.D. degree programme
- Topics: http://www.fit.vutbr.cz/study/phd/thesis-t.php.en

- Deadline: 26.5.

- Linux, C++, Qt, OpenGL
- Machine Learning
  - DNN, CNN: python, tensorflow (google), keras, pytorch (facebook)



CONCLUSIONS AND OUTLOOK

Computational Photography

- Images that go beyond the capabilities of traditional imaging systems
- New cameras don’t just capture photons; they compute pictures

- Big potential for
  - Research
  - Art
  - Commerce

Computational Photography

- Multiple image captures
- Modifying cameras
- Additional modalities

Outlook

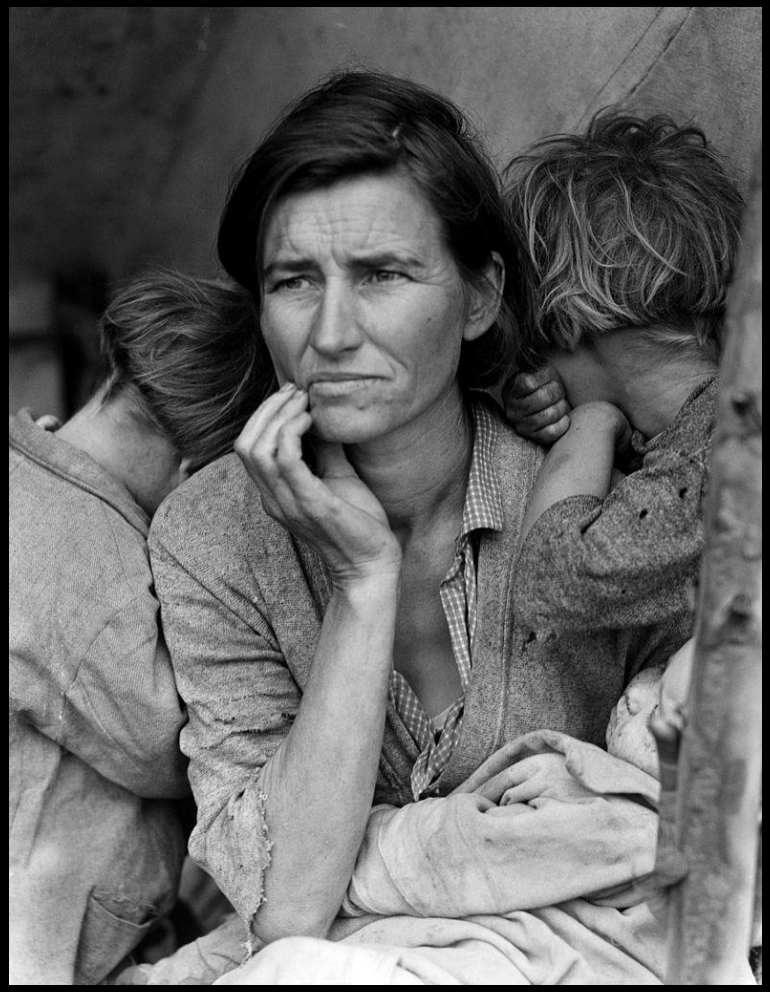
- ultimate post-capture control (exposure, zoom, refocus, synthetic aperture, camera pose change..)
- perceptual quality (not necessarily only visual senses)
- understand the world (computer vision) → natural ways of image enhancement and editing

Outlook

[Kholgade et al., 2014]

Photography has power to change people’s lives.

Cameras don't take photos, people do.



[Lange 1936]

Thank You

cadikm@centrum.cz
http://cadik.posvete.cz

TU WIEN

Universitat de Girona

MAX-PLANCK-GESELLSCHAFT

MARIE CURIE ACTIONS

SoMoPro