DATA 3464: Fundamentals of Data Processing

Image Processing

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Topic overview

- Image representation
- File formats and compression
- Preprocessing for image recognition tasks

Resources used:

- Computer Vision: Algorithms and Applications (2nd edition)
- Pillow Documentation
- A blog post on image compression
- JPEG demo

Images as 2D signals

- The light that enters a camera can be modelled as continuous signal:

$$f(x, y), \quad -\infty < x, y < \infty$$

- Digital images are sampled:

$$f[n, m], \; n = n\Delta_x, m = n\Delta_y$$

  where typically $\Delta_x = \Delta_y$

- The area $\Delta_x \times \Delta_y$ is called a **pic**ture **el**ement, or **pixel**

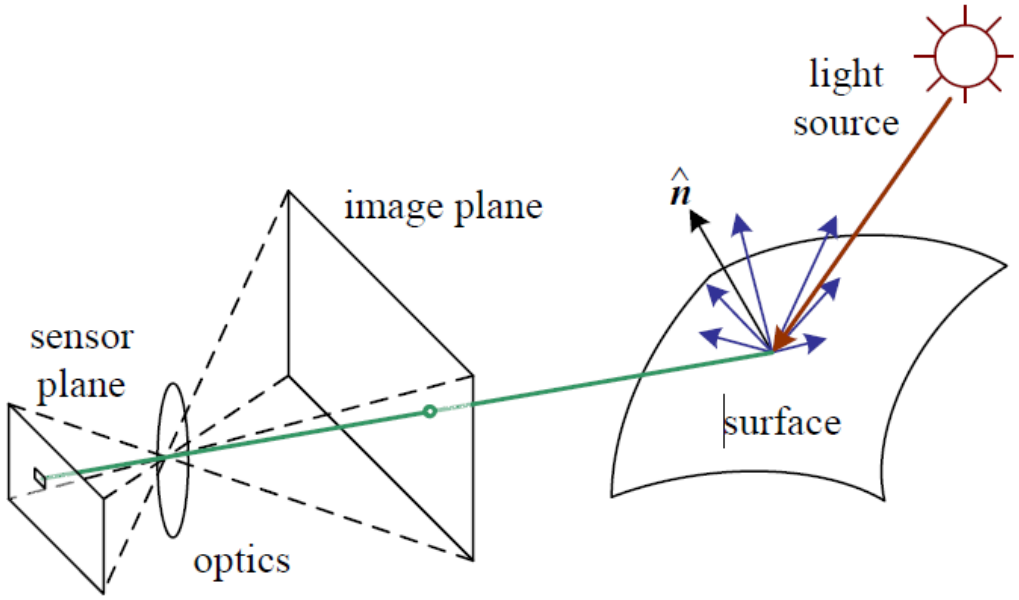
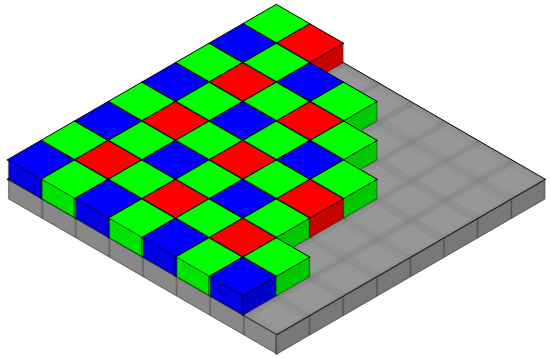


Image is Figure 2.14 in Computer Vision: Algorithms and Applications by Richard Szeliski

Image channels

- A photosensor responds to **light intensity** with an electrical signal
- Physical filters restrict the colour that reaches each sensor
- On most digital cameras, 1 sensor $\neq$ 1 pixel; it is instead **interpolated** to create a typical **3-channel image**
- (Inexplicably, the Python imaging library Pillow uses the term "band")



Bayer sensor pattern diagram by en:User:Cburnett - Own work, CC BY-SA 3.0, Link

Images as (3D) 2D arrays

- Size (`np.shape`) usually defined as `[rows, cols, (channels)]`
- Typical 8-bit image: integers from 0 to 255
  - For processing, common to convert to float and **normalize**
- RGB examples of individual pixels:
  - `[255, 0, 0]`
  - `[128, 128, 128]`
  - `[255, 255, 255]`

Portable Network Graphics

- PNG is an image format released in 1996 as a GIF replacement
- Typically 8 bits per channel, but can be 1, 2, 4, 8, or 16
- 3x RGB channels, plus an optional alpha (transparency) channel
- Space saved in two ways:
  - Indexed colour, where numbers map to a finite set of colours
  - Lossless compression, e.g. `[0 0 0 0 0 0 0]` $\longrightarrow$ `7 0`

> *What kinds of images would benefit from this compression scheme?*

Joint Photographic Experts Group

- JPEG is an image standard released in 1992 for photographic images
- **Lossy** compression based on human vision:
    i. Channels converted to YCbCr colourspace
    ii. The colour components (Cb/Cr) are downsampled 2-3x
    iii. Blocks of 8x8 pixels are transformed to frequency domain
    iv. Amplitudes are quantized with larger buckets at higher frequencies
    v. Finally, lossless compression is applied
- The "quality" of a JPEG relates the degree of quantization

Where we left off on March 24

A Cautionary Tale of Image Classification

- As convolutional neural networks (CNNs) gained popularity as image recognition powerhouses, people started using them for all sorts of things
- One example: predicting whether someone is a criminal based on a photo
- Thoroughly debunked in a paper that mentions, among other issues:
  - Criminal samples are all 8-bit greyscale PNG photographs of printed images, taken with the same camera
  - Non-criminals are RGB JPEGs from 5 different sources, converted to greyscale to be "compatible with mugshots from the criminal category"

> *What's the problem here?*

Preparing images for machine learning

- As with audio, images should be **consistent**
- Let's check out some public datasets
- Two approaches:
  - keep raw data and process on the fly (e.g. ImageNet)
  - apply some preprocessing and store (e.g. CIFAR-10)
- Common to do a bit of both, e.g. resize and save with consistent format, then apply various transforms during both training and inference

> *As usual, there is a tradeoff between time and space*

Image Transformations

- **Geometric transforms** resize, rotate, skew, shift, etc
- **Point operators** independently change each pixel, e.g. histogram equalization
- **Linear filters** compute new pixel values from a weighted sum of values in a small neighbourhood
- **Nonlinear filters** compute new pixel values from a small neighbourhood in a nonlinear fashion

Resizing

- For computer vision purposes, most images need to be resized
- Most often, a **square aspect ratio** is used
  - Can be rotated 90 degrees without modifying code
  - Simplifies parameter specification
  - Maybe some CUDA advantage if divisible by 8 (e.g. 224×224)
- Resizing needs interpolation (or resampling), and distorts aspect ratio
- Alternatively (or additionally), image **crops** can be used

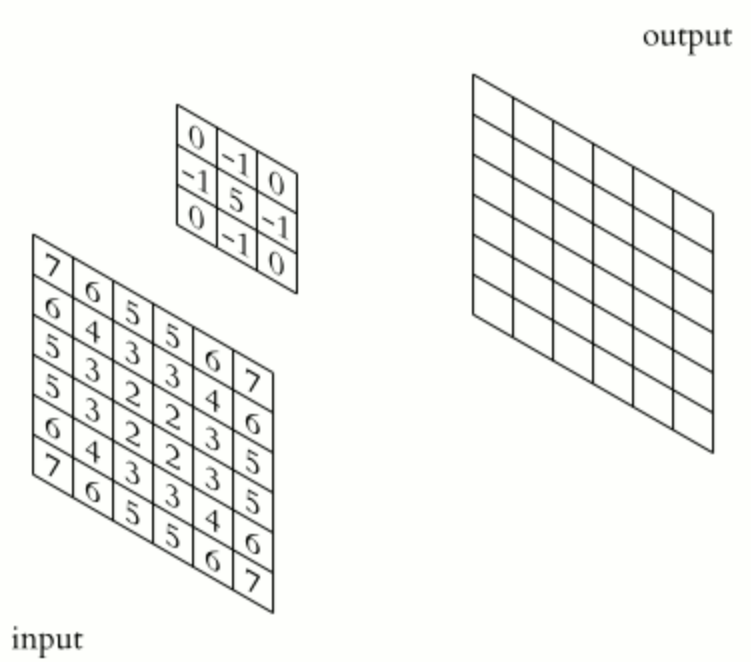
Where we left off on March 26

Linear Filters: Convolution

- A filter or convolution **kernel** is a small (usually) square matrix that gets **convolved** with the image:

$$(f * g)[n, m] = \sum_{i=0}^{n} \sum_{j=0}^{m} f[i, j] g[n - i, m - j]$$

- Fun fact: this is the same as multiplication in frequency



By Michael Plotke - Own work, CC BY-SA 3.0, From Wikipedia

Beyond linear filters

- Linear filters are simple weighted summations, and form the core of **convolutional neural networks**, widely used in computer vision
- Sometimes, nonlinear effects are useful, such as:
  - Median image filtering to reduce certain types of noise
  - Morphological operators for binary image masks

> *There is a huge world of image processing, including techniques for segmentation, feature detection, registration... too much to cover in this course!*

Tools

In addition to Pillow and the usual numpy, matplotlib, scipy libraries:

- ImageMagick is a command-line tool that can be combined with bash scripting to process a bunch of images, e.g.:

```
mkdir resized
for img in *.jpg; do
   magick $img -resize 512x512! resized/$img
done
```

- OpenCV has functionality overlap with Pillow, but also computer vision algorithms
- Torchvision provides load-time transformations for use with deep learning models
- ITK is the OG classical image processing toolbox focused on medical imaging

What about videos?

- There are an absurd number of video formats
- Most common: MPEG4 container, H.264 video, AAC audio
- Containers can hold video, audio, subtitles, chapter information, etc
- Often video-only data is treated as a series of images (e.g. Kinetics)
- New considerations:
  - Temporal (re)sampling
  - Dataset splitting!!

Coming up next

- Image processing lab
- Assignment 3 due soon
  - Ask me for help!
- Data augmentation and generation