CPSC 425: Computer Vision

Lecture 8: Sampling

( unless otherwise stated slides are taken or adopted from Bob Woodham, Jim Little and Fred Tung )
Menu for Today (September 21, 2018)

Topics:

- Sampling (continued)
- Aliasing
- Color Filter Arrays
- Bayer patterns

Readings:

- Today’s Lecture: Forsyth & Ponce (2nd ed.) 4.5
- Next Lecture: Forsyth & Ponce (2nd ed.) 4.6, 4.7

Reminders:

- Assignment 1: Image Filtering and Hybrid Images due September 24th
Today’s “fun” Example: Optical Illusions

Aerial view of the white stripes at the lake shore drive in Chicago.
Today’s “fun” Example: Anchoring and Ordering

Champagne, Sparkling, Rose, Sweet Wines

Champagne
CH18 NV GREMILLET "Brut Selection" - Champagne $65
CH31 NV ERNEST RAPENEAU "Selection Brut" - Champagne $65
CH12 NV CHAMPAGNE ERNEST RAPENEAU - BRUT - Chardonnay/Pinot Noir/Pinot Meunier $75
CH05 NV DRAPPER "Cote d'OIR" - Champagne $78
CH100 2007 ERNEST RAPENEAU VINTAGE - Chardonnay/ Pinot Noir - Champagne $80
CH02 NV ERNEST RAPENEAU "Pavillon Cru Brut" - Champagne $84
CH28 NV DRAPPER Brut Rose - Champagne $85
CH29 2012 DRAPPER "Ailesime Exception" - Champagne $90
CH11 2008 DRAPPER "Grecia Grande Sandre" - Champagne $130
CH39 NV ERNEST RAPENEAU "Grand Cru Reserve" - Magnum - Champagne $130

Sparkling Wines
CH06 NV IL CORTIGIANO - Prosecco Extra Dry - Veneto $50
CH17 NV VALLERMOOVS "Clark" - Semi Seco - Casa $50
CH24 NV VEUEW MOISSY "Blanc de Blancs" - Loire Valley $50
CH25 NV VALDO - Prosecco Extra Dry - Treviso, Veneto $50
CH54 NV VALDO "Orvieto" Rose - Veneto $50
CH03 2012 CHATEAU MONTGIERET Surnum Soc Rose - Cabernet Franc - Loire Valley $52
CH04 NV CAYA MAURY RESERVA BRUT - Macabeo/Xarello/Parellada - Cava $52
CH14 NV TRIVENTO "But Nature" - Mendoza $52
CH21 2015 CAMASELLA - Gloria - Veneto $52
CH93 2018 BRUT D'ARGENT ICE - Chardonnay - France $52
CH01 NV VALDO "ORO PURO" Prosecco Superiore - Veneto $56
CH40 NV MAISON DARRAGON - AOC Vouvray Brut - Loire Valley $58
CH09 NV LOU MIRANDA ESTATE "LEONE" - Sparkling Shiraz - Barossa Valley $62

Rose Wines
PO03 2014 CASAL MENDES Rose - Baga - Portugal $50
RI09 2014 LA VIE EN ROSE - Cisault - Languedoc $50
RH08 2015 LES EMBRIS "La Croix des Sultans" - Sable de Camargue $50
RH06 2015 LES MATIERS VINIERSONS DE ST TROPEZ - Cotes de Provence $52
RH15 2015 MAISON - COTES DE PROVENCE - Grenache/Cinsault/Syrah - Provence $54
RH04M 2015 LES MATIERS VINIERSONS DE LA PRESERFLOW DE SAINT TROPEZ - Grenache/Mourvè $60

Sweet Wines
AR22 2015 TRIVENTO "Birds & Bees" White - Mendoza $50
BR14 2015 TRIVENTO "Birds & Bees" Red - Mendoza $50
AU05 2015 DEAKIN ESTATE - Moscato - Murray Darling $50
AU12 2016 Chalk Hill - Moscato - McLearen Vale $50
AU08 NV WESTEND ESTATE "Richland" - Moscato - New South Wales $50
AU07 NV WESTEND ESTATE "Richland" - Pink Moscato - New South Wales $50
In the continuous case, images are functions of two spatial variables, $x$ and $y$.

The discrete case is obtained from the continuous case via sampling (i.e. tessellation, quantization).

If a signal is bandlimited then it is possible to design a sampling strategy such that the sampled signal captures the underlying continuous signal exactly.
The challenge to intuition is the fact that music (in the 1D case) and images (in the 2D case) can be represented as linear combinations of individual sine waves of differing frequencies and phases (remember discussion on FFTs)

A fundamental result (Sampling Theorem) is:

For bandlimited signals, if you sample regularly at or above twice the maximum frequency (called the Nyquist rate), then you can reconstruct the original signal exactly
Question: For a bandlimited signal, what if you oversample (i.e., sample at greater than the Nyquist rate)
Sampling Theory (informal)

**Question:** For a bandlimited signal, what if you **oversample** (i.e., sample at greater than the Nyquist rate)

**Answer:** Nothing bad happens! Samples are redundant and there are wasted bits
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**Answer:** Nothing bad happens! Samples are redundant and there are wasted bits

**Question:** For a bandlimited signal, what if you **undersample** (i.e., sample at less than the Nyquist rate)

**Answer:** Two bad things happen! Things are missing (i.e., things that should be there aren’t) There are artifacts (i.e., things that shouldn’t be there are)
Sampling Theory (informal)

Forsyth & Ponce (2nd ed.) Figure 4.7
Reducing Aliasing Artifacts

1. **Oversampling** — sample more than you think you need and average (i.e., area sampling)
Aliasing

aliasing artifacts

anti-aliasing by oversampling

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)
Reducing Aliasing Artifacts

1. **Oversampling** — sample more than you think you need and average (i.e., area sampling)

2. **Smoothing** before sampling. Why?
Aliasing in Photographs

This is also known as “moire”
Imagine a spoked wheel moving to the right (rotating clockwise). Mark wheel with dot so we can see what’s happening.

If camera shutter is only open for a fraction of a frame time (frame time = 1/30 sec. for video, 1/24 sec. for film):

Without dot, wheel appears to be rotating slowly backwards! (counterclockwise)
Temporal Aliasing

Wagon wheel effect

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)
Temporal Aliasing
Sometimes **undersampling** is unavoidable, and there is a trade-off between “things missing” and “artifacts.”

— **Medical imaging**: usually try to maximize information content, tolerate some artifacts

— **Computer graphics**: usually try to minimize artifacts, tolerate some information missing
— Images also can be considered a function of time. Then, we write $i(x, y, t)$ where $x$ and $y$ are spatial variable and $t$ is a **temporal variable**

— To make the dependence of brightness on wavelength explicit, we can instead write $i(x, y, t, \lambda)$ where $x$, $y$ and $t$ are as above and where $\lambda$ is a **spectral variable**

— More commonly, we think of “color” already as discrete and write

\[
\begin{align*}
  i_R(x, y) \\
  i_G(x, y) \\
  i_B(x, y)
\end{align*}
\]

for specific colour channels, R, G and B
**Color** is an Artifact of Human Perception

“Color” is **not** an objective physical property of light (electromagnetic radiation). Instead, light is characterized by its wavelength.

What we call “color” is how we subjectively perceive a very small range of these wavelengths.

**Slide Credit:** Ioannis (Yannis) Gkioulekas (CMU)
Color Filter Arrays (CFA)
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Color Filters

Two **design choices**:
- What spectral sensitivity functions $f(\lambda)$ to use for each color filter?
- How to spatially arrange ("mosaic") different color filters?
Color Filters

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— What spectral sensitivity functions $f(\lambda)$ to use for each color filter?
— How to spatially arrange (“mosaic”) different color filters?

Generally do not match human sensitivity

Canon 50D

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)
Color Filters

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- How to spatially arrange ("mosaic") different color filters?

Why more green pixels?

**Canon 50D**

Generally do not match human sensitivity

$\text{Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)}$
Different Color Filter Arrays (CFAs)

Finding the “best” CFA mosaic is an active research area.

How would you go about designing your own CFA? What criteria would you consider?
Many **Different Spectral Sensitivity** Functions

Each camera has its more or less unique, and most of the time secret, SSF

Same scene captured using 3 different cameras with identical settings

**Slide Credit:** Ioannis (Yannis) Gkioulkas (CMU)
RAW Bayer Image

After all of this, what does an image look like?

- Kind of disappointing
- We call this the RAW image

lots of noise
mosaicking artifacts

Slide Credit: Ioannis (Yannis) Gkioulakes (CMU)
CFA Demosicing

Produce full RGB image from mosaiced sensor output

Any ideas on how to do this?
CFA Demosicing

Produce full RGB image from mosaiced sensor output

Interpolate from neighbors:
- Bilinear interpolation (needs 4 neighbors)
- Bicubic interpolation (needs more neighbors, may overblur)
- Edge-aware interpolation
Demosaicing by Bilinear Interpolation

Bilinear interpolation: Simply average your 4 neighbors.

\[ G_? = \frac{G_1 + G_2 + G_3 + G_4}{4} \]

Neighborhood changes for different channels:

Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)
The sequence of image processing operations applied by the camera’s image signal processor (ISP) to convert a RAW image into a “conventional” image.

- RAW image (mosaiced, linear, 12-bit)
- Analog front-end
- CFA demosaicing
- White balance
- Tone reproduction
- Compression
- Final RGB image (non-linear, 8-bit)
- Color transforms
- Denoising

*Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)*
In the continuous case, images are functions of two spatial variables, $x$ and $y$.

The discrete case is obtained from the continuous case via sampling (i.e. tessellation, quantization).

If a signal is \textbf{bandlimited} then it is possible to design a sampling strategy such that the sampled signal captures the underlying continuous signal exactly.

Adequate sampling may not always be practical. In such cases there is a trade-off between “things missing” and “artifacts”.

— Different applications make the trade-off differently