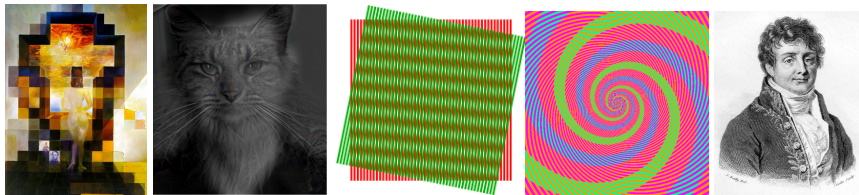


# Sampling and Frequency (1)

Lu Sheng (盛律) Spring 2024



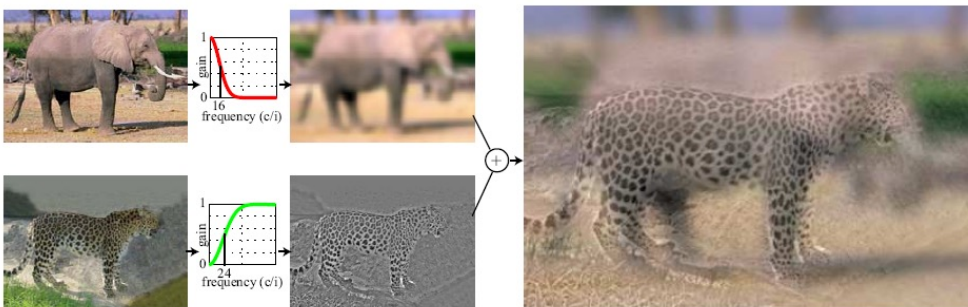
Why does a lower resolution image still make sense to us? What information do we lose?



2



## Hybrid images

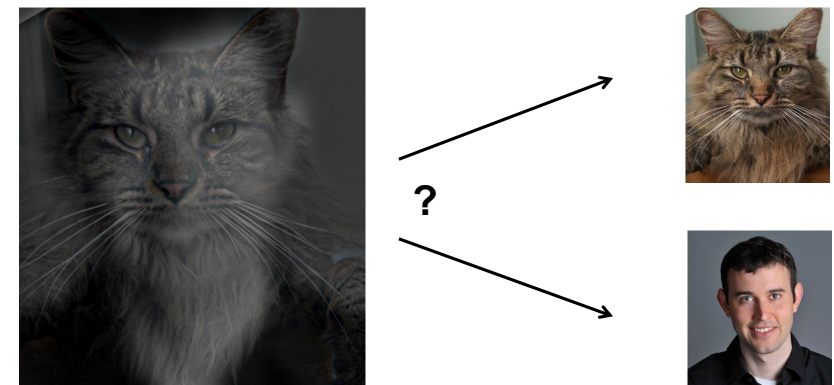


A. Oliva, A. Torralba, P. G. Schyns, Hybrid Images, Siggraph 2006

3



Why do we get different, distance-dependent interpretations of hybrid images?



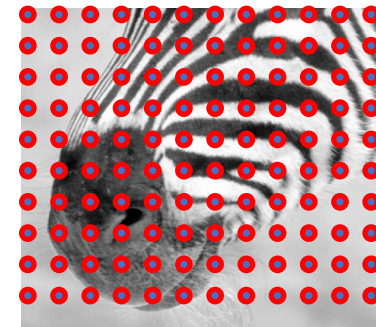
4

# Sampling



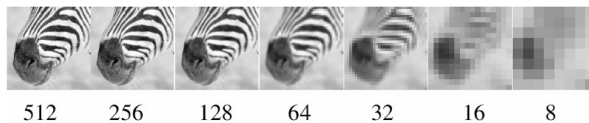
5

## Subsample by factor of 2



Throw away every other row and column to create a 0.5 size image

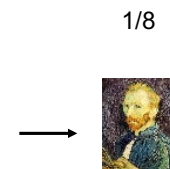
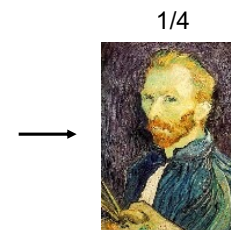
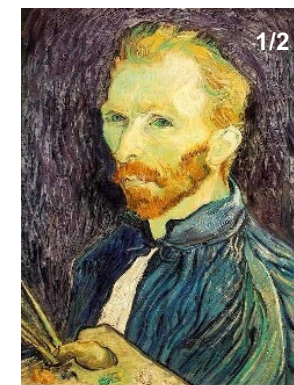
6



- Big image
  - Hair on the nose
- Smaller images
  - Stripes on the nose
- Smallest image
  - Nose

7

## Image subsampling

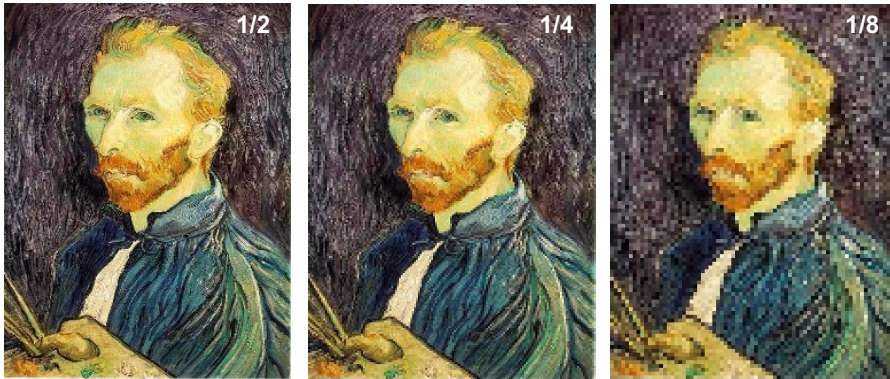


Throw away every other row and column to create a **0.5** size image

8



## Image subsampling



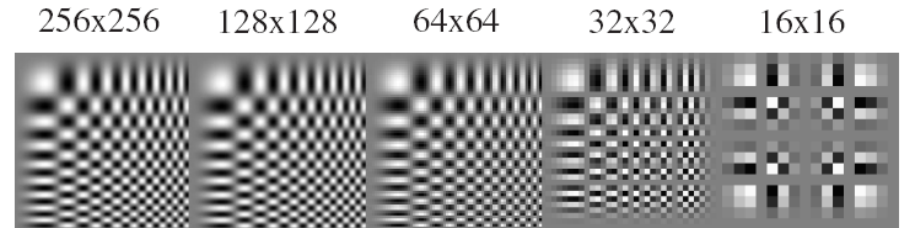
2x subsample

4x subsample

9



## Sampling and aliasing

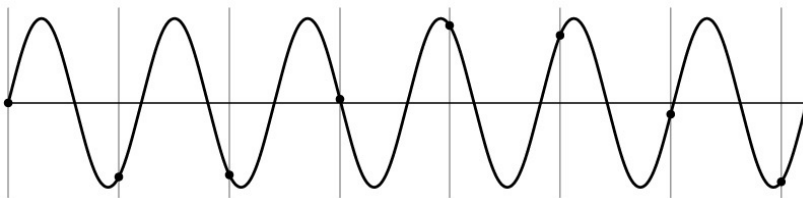


Tremendously change of spatial distribution → aliasing (混叠) artifacts

10



## Aliasing problem

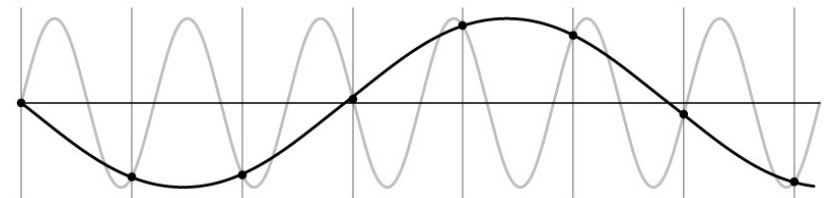


• 1D example: sinewave

11



## Aliasing problem



• 1D example: sinewave

12





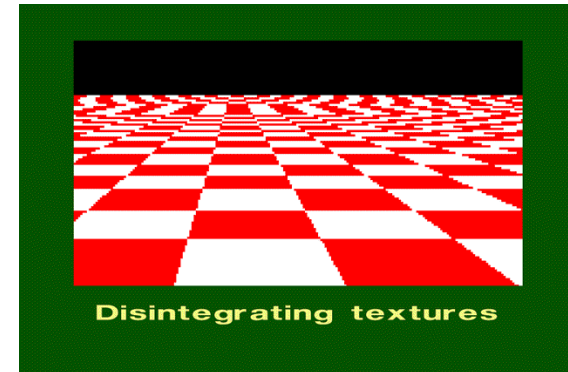
## Aliasing problem

- Subsample may be dangerous
- Some typical errors may appear:
  - Car wheels rolling the wrong way in movies
  - Checkerboards disintegrate in ray tracing
  - Striped shirts look funny on color television

13



## Aliasing in Graphics



14



## Aliasing and Moiré patterns



Gong 96, 1932, Claude Tousignant, Musée des Beaux-Arts de Montréal

15



## Aliasing in videos

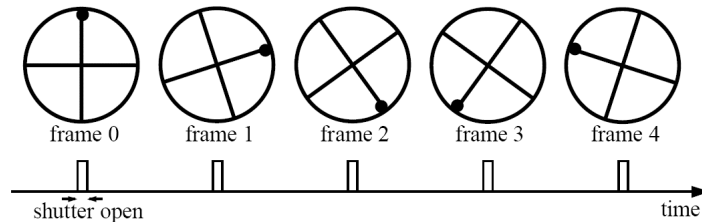


16



## Aliasing in videos

- Imagine a spoked wheel moving to the right (rotating clockwise)
- If camera shutter is only open for a fraction of a frame time



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

17



## Nyquist-Shannon Sampling Theorem

- When sampling a signal at discrete intervals, the sampling frequency must be **larger** than  $2 \times f_{\max}$
- $f_{\max}$  : maximum frequency of the input signal
- This will allow to reconstruct the original perfectly from the sampled version

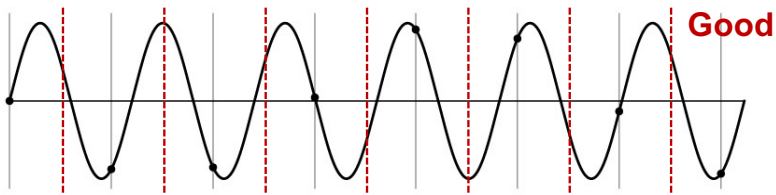


18



## Nyquist-Shannon Sampling Theorem

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- $f_{\max}$  : maximum frequency of the input signal
- This will allow to reconstruct the original perfectly from the sampled version

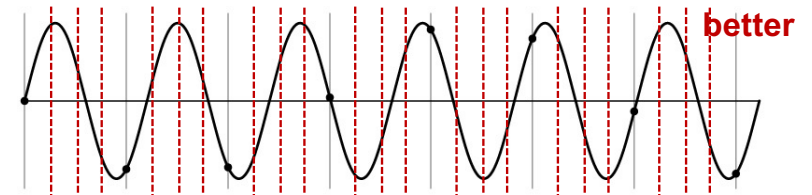


19



## Nyquist-Shannon Sampling Theorem

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- This will allow to reconstruct the original perfectly from the sampled version



20



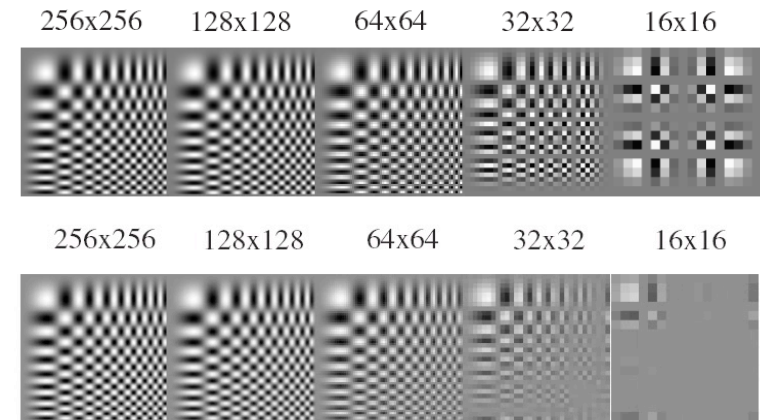
## How to fix aliasing?

- Solutions?
- Better sensors: sampling more often
- Get rid of all frequencies that are greater than half the new sampling frequency
  - Will lose information
  - But it's better than aliasing
  - Apply a smoothing (*low pass*) filter

21



## Anti-aliasing



22



## Algorithm for downsampling by factor of k

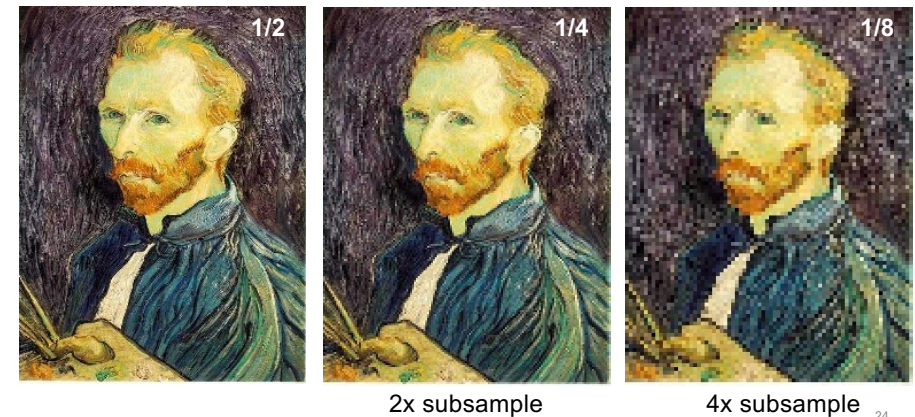
1. Start with `im(h, w)`
2. Apply low-pass filter  
`im_blur = imfilter(im, f_low_pass)`
3. Sample every other pixel  
`im_small = im_blur(1:k:end, 1:k:end)`

Note that the bandwidth of `f_low_pass` should be larger than **twice** the size of the sampling factor

23



## Subsampling without filtering



24



## Subsampling with Gaussian pre-filtering

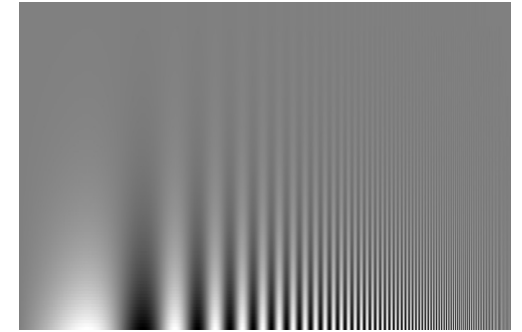


25



北京航空航天大学  
COLLEGE OF SOFTWARE  
BEIHANG UNIVERSITY 软件学院

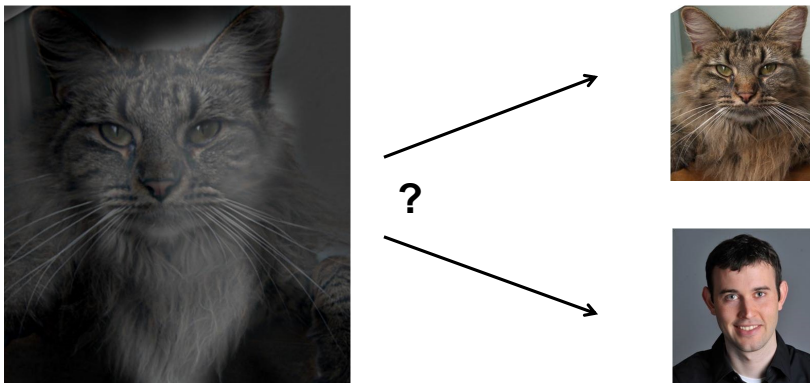
## Frequency



26



## Why do we get different, distance-dependent interpretations of hybrid images?

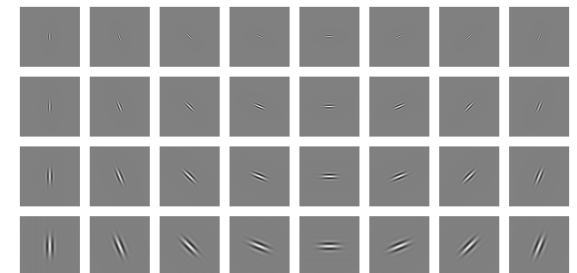


27



## Clues from human perception

Early processing in human filters for orientations and scales of frequency



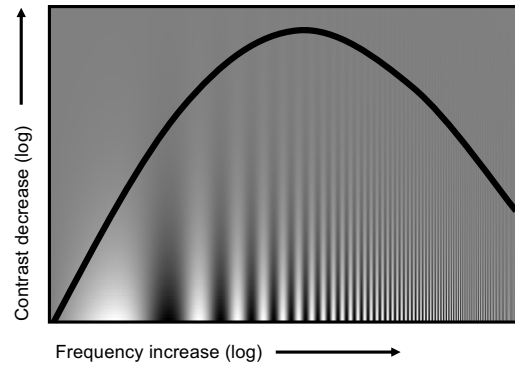
**Early visual processing:** Multi-scale edge and blob filters

28





## Campbell-Robson contrast sensitivity curve

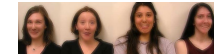


Perceptual cues in the mid-high frequencies dominate perception

29



When we see an image from far away, we are effectively subsampling it!



30



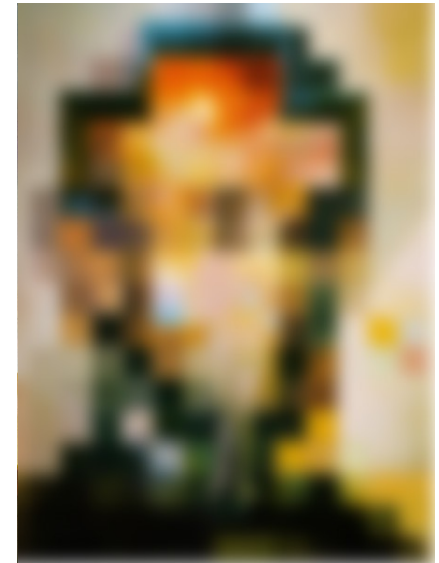
**Salvador Dali**  
"Gala Contemplating the Mediterranean Sea,  
which at 30 meters becomes the portrait  
of Abraham Lincoln", 1976



31



**Salvador Dali**  
"Gala Contemplating the Mediterranean Sea,  
which at 30 meters becomes the portrait  
of Abraham Lincoln", 1976



32





## Questions?

- Sampling
- Aliasing and Anti-aliasing
- Human response of frequency and hybrid images