

## The Digital Image

Image Processing.

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## Outline

- What is an image?
- What is a pixel?
- How do we store them?

Image Processing.

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## What is an image?



Image Processing.

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## Image as 2D signal

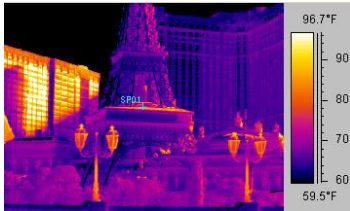
- **Signal:** function depending on some variable with physical meaning
- **Image:** continuous function
  - 2 variables:  $xy$  - coordinates
  - 3 variables:  $xy + \text{time}$  (video)
- Brightness is usually the value of the function
  
- But can be other physical values too: temperature, pressure, depth ...

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## Example 2d images



ultrasound

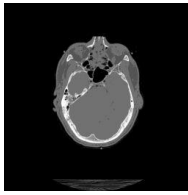


temperature



camera image

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CT

## Image?

```
>> t=rand(256,256);  
>> imshow(t)
```

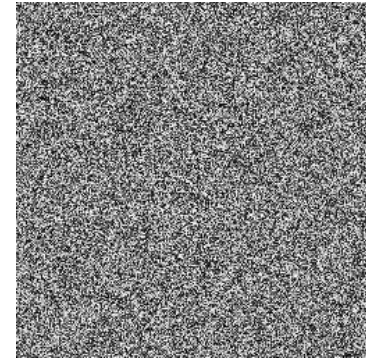


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## Where do images come from?

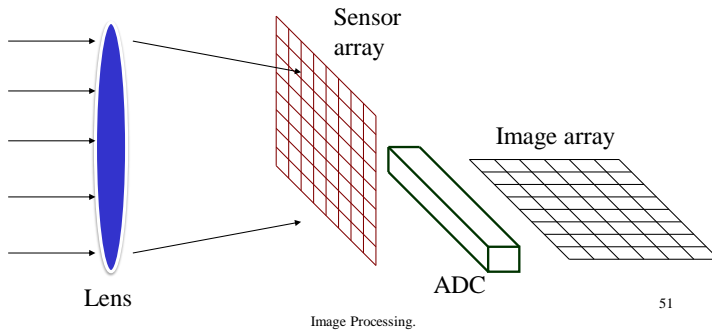
- Digital cameras
- MRI scanners
- Computer graphics packages
- Body scanners
- Laser range finders
  
- Many more...

## Where do images come from?

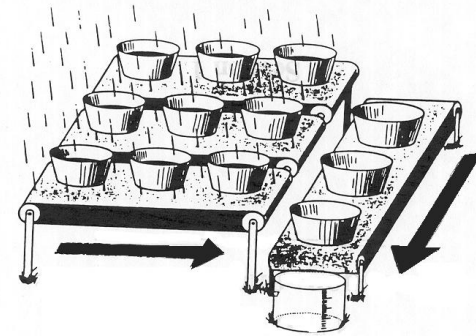
- **Digital cameras**
- MRI scanners
- Computer graphics packages
- Body scanners
- Laser range finders
  
- Many more...

## The digital camera

- A Charge Coupled Device (CCD).



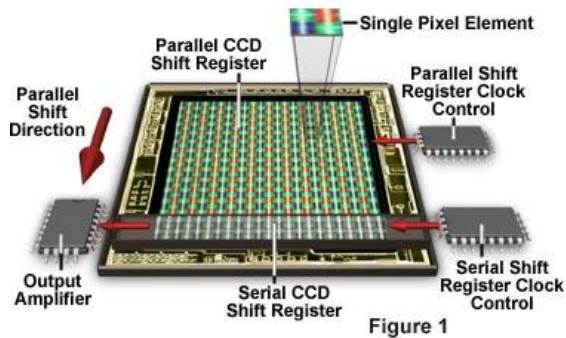
## Capturing photons



From: Lecture Notes – EAAE and/or Science “Nuggets” 2000

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### Full-Frame CCD Architecture



<http://www.astro.virginia.edu/class/oconnell/astr121/im/CCD-fullframearc-FSU.jpg>

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## The sensor array

- Can be  $< 1\text{cm}^2$ .
- An array of *photosites*.
- Each photosite is a bucket of electrical charge.
- They contain charge proportional to the incident light intensity during exposure.

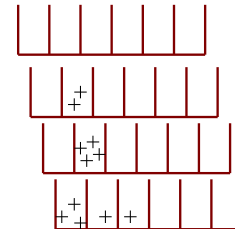


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# Analog to Digital Conversion

- The ADC measures the charge and digitizes the result.
- Conversion happens line by line.
- The charges in each photosite move down through the sensor array.

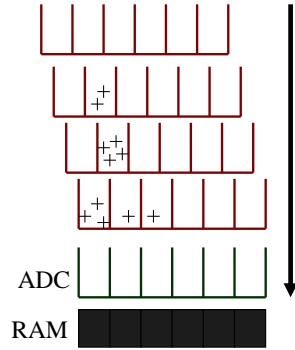


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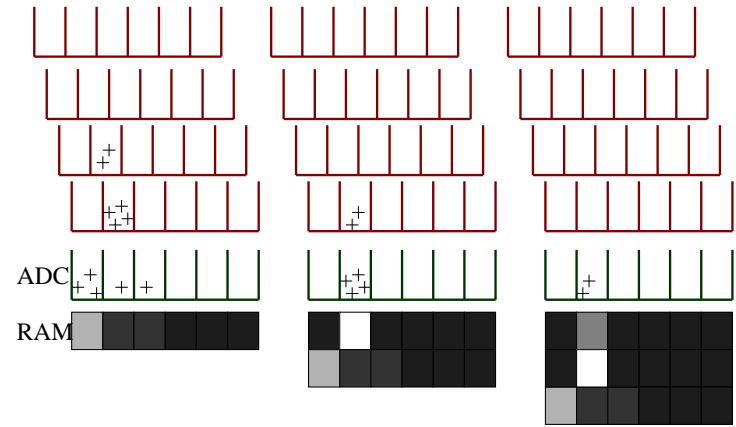


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# Blooming

- The buckets have finite capacity
- Photosite saturation causes blooming

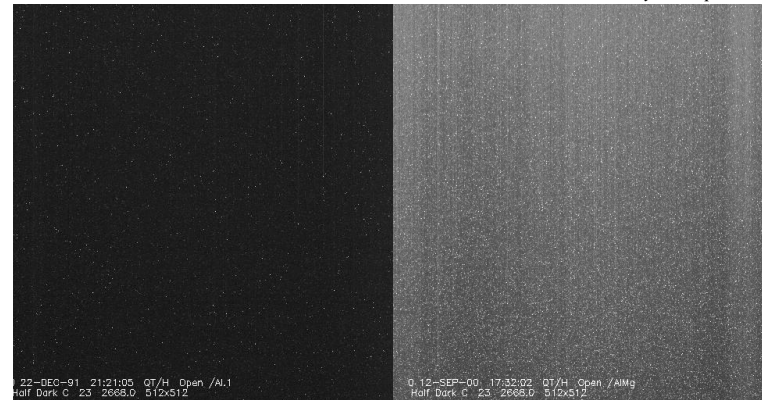


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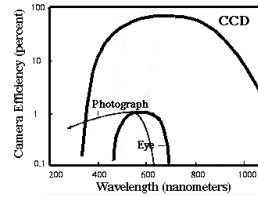
# Dark Current

*Yohkoh satellite, 9 years apart*



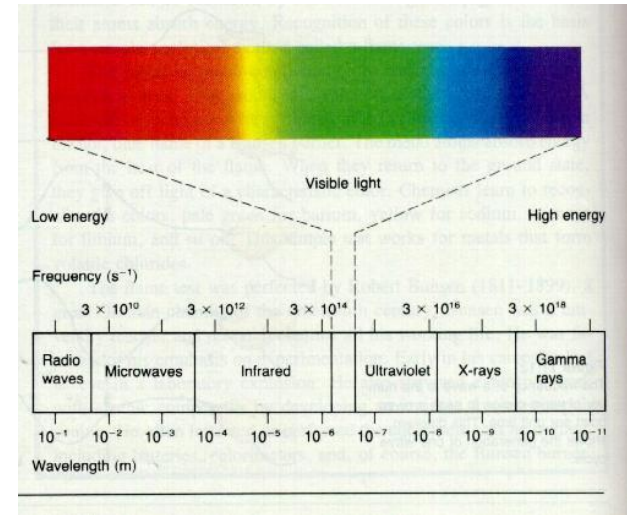
## Dark Current

- CCDs produce thermally-generated charge.
- They give non-zero output even in darkness.
- Partly, this is the *dark current*.
- Fluctuates randomly.



From: Lecture Notes - EAAE

- How can we reduce dark current?

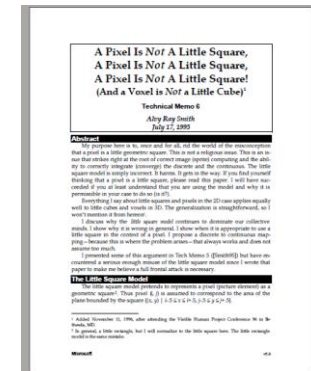


## What is a pix-el?

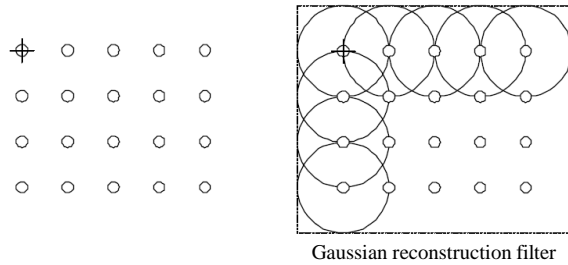


## Not a little square!

- *A Pixel Is Not A Little Square, A Pixel Is Not A Little Square, A Pixel Is Not A Little Square! (And a Voxel is Not a Little Cube),*  
 – Alvy Ray Smith,  
 MS Tech Memo 6, Jul 17, 1995



## Not a little square!

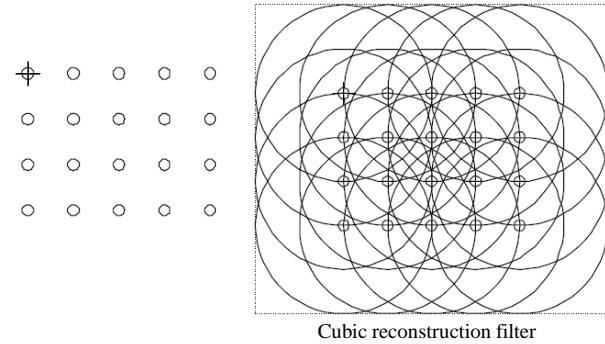


Illustrations: Smith, MS Tech Memo 6, Jul 17, 1995

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## Not a little square!



Illustrations: Smith, MS Tech Memo 6, Jul 17, 1995

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## Not a little square!

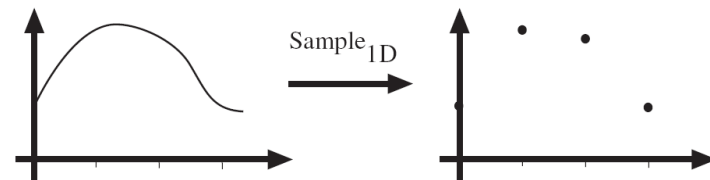


Graphics: Dick Lyon, 2006

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## Sampling 1D

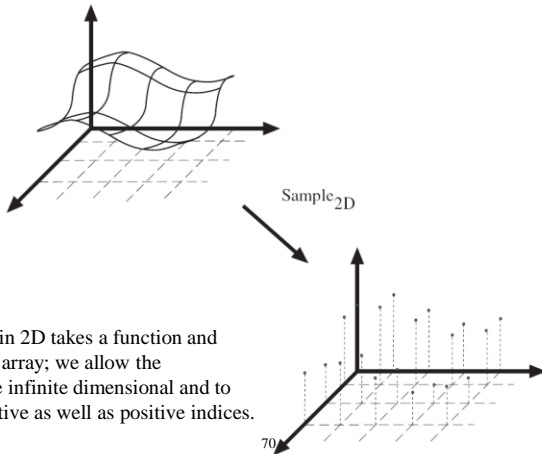


Sampling in 1D takes a function, and returns a vector whose elements are values of that function at the sample points.

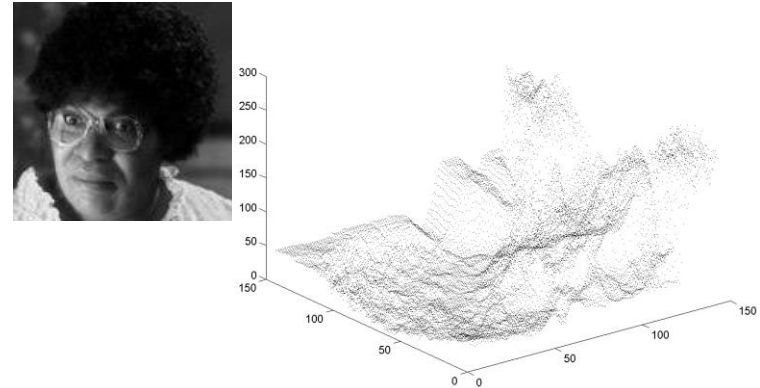
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## Sampling 2D



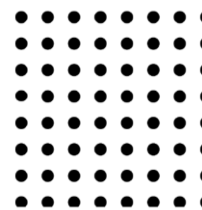
## Greyscale digital image



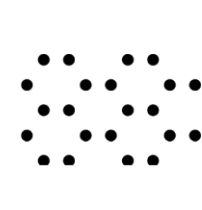
## Nyquist Frequency

- Half the sampling frequency of a discrete signal processing system

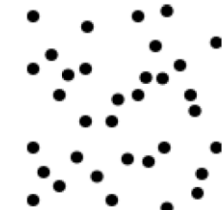
## Sampling grids



Cartesian sampling

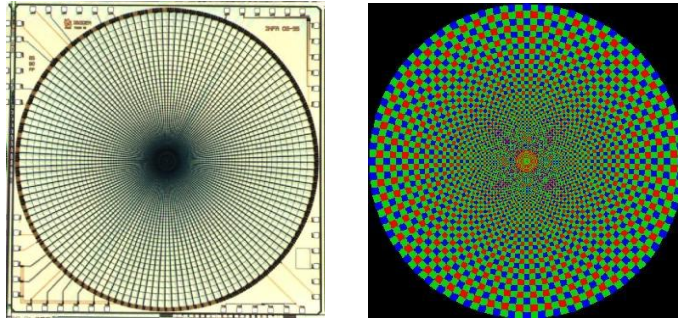


Hexagonal sampling



Non-uniform sampling

## Retina-like sensors



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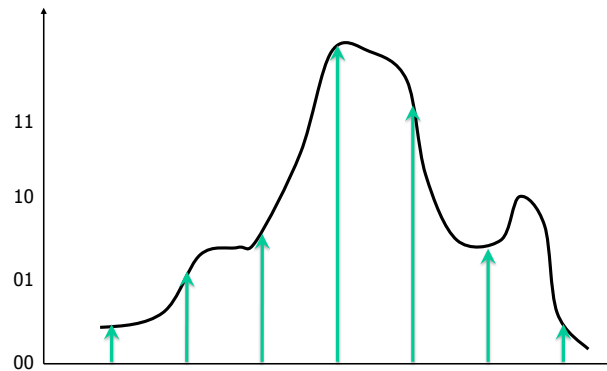
## Quantization

- Real valued function will get digital values – integer values
- Quantization is lossy!!
  - After quantization, the original signal cannot be reconstructed anymore
- This is in contrast to sampling, as a sampled but not quantized signal **can** be reconstructed.
- Simple quantization uses equally spaced levels with  $k$  intervals

$$k = 2^b$$

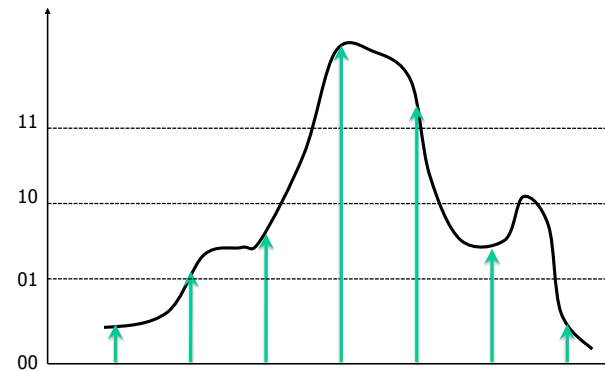
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## Quantization



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## Quantization



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## Usual quantization intervals

- Grayvalue image  
8 bit =  $2^8 = 256$  grayvalues
- Color image RGB (3 channels)  
8 bit/channel =  $2^{24} = 16.7$ Mio colors
- 12bit or 16bit from some sensors
- Nonlinear, for example log-scale

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Photo: Paulo Barcellos Jr.

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## Properties

- Image resolution
- Geometric resolution: How many pixel per area
- Radiometric resolution: How many bits per pixel

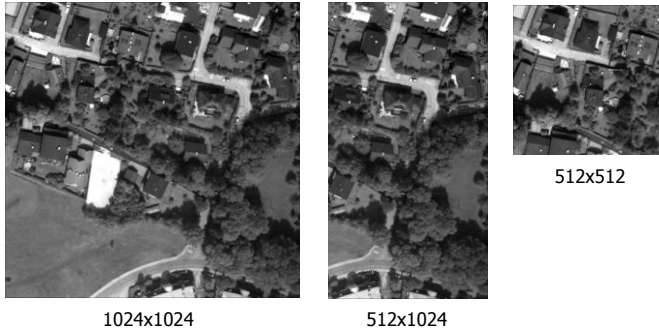
## Winding Down

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## Image resolution



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## Geometric resolution

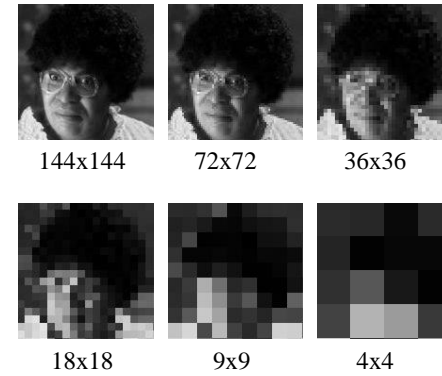


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## Radiometric resolution

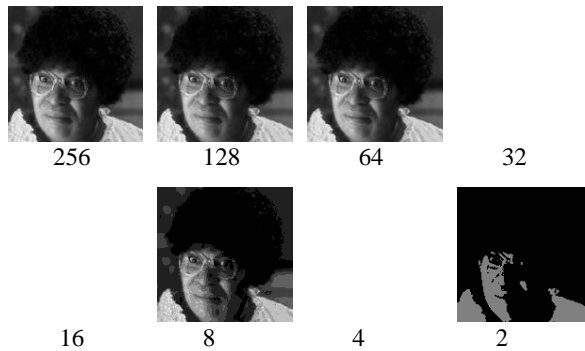


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## Lossless vs. Lossy

- Name some formats?

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## Aliasing and SNR

- What is the disadvantage of low sampling resolution?
- What is the disadvantage of high sampling resolution?

## Finish

Next week:  
Image segmentation