THE TREACHERY OF IMAGES

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Agenda

- Introduction
- Understanding Images
- Extracting Information
- Measurement Error
- References
- Acknowledgements

What is a Digital Image?

Simply stated, a digital image is a function. It is a function with spatial coordinates and a scalar quantity centered on those coordinates. We call these pixels.

The scalar quantity is determined by the source of the image and the imaging system. The imaging system can be represented as a discrete mapping from the source to the recorded image.

Images are data, with a mathematical structure that allows manipulation and decomposition just like any other two, three or higher-dimensional data.

Mt. Hood reflected on Mirror Lake, OR

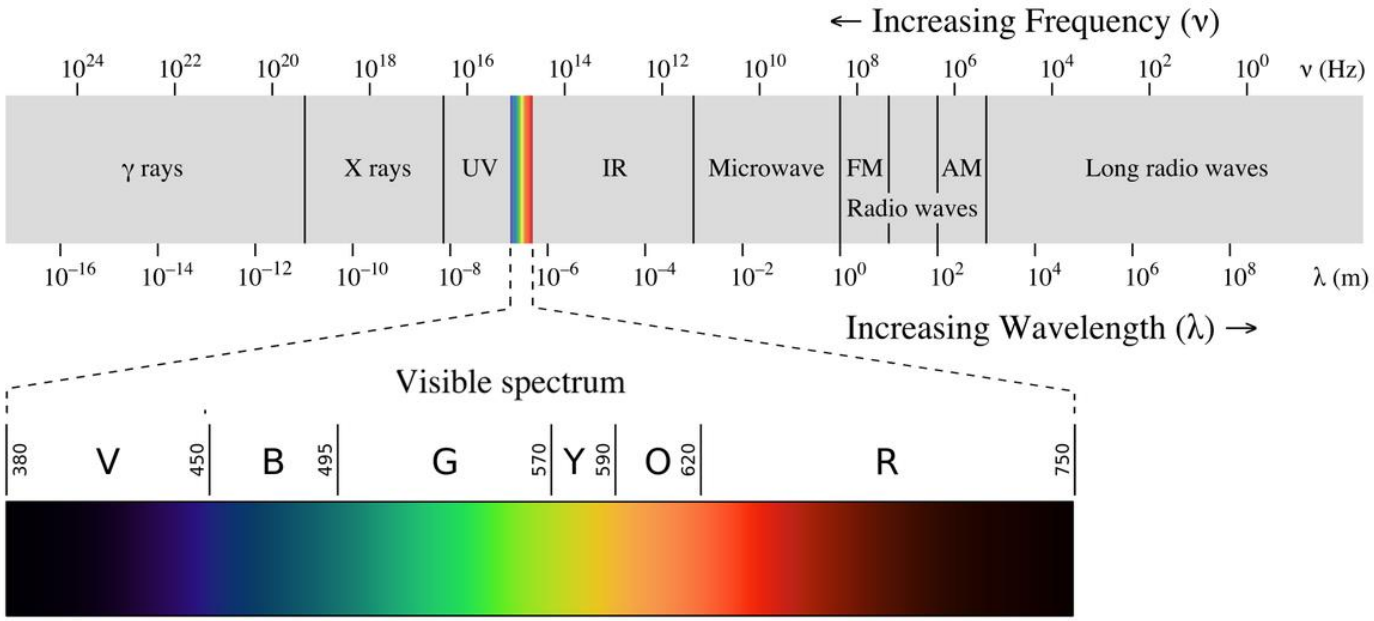
Image Processing – History

- Digital image processing requires a lot of computational power and storage so the development of the field of image processing has been dependent on the development of the digital computer, storage, display, and transmission.
- The1960s is when computers existed that could do basic image processing. At that time, the space program helped to push advances in image processing.
- In 2017, it is estimated that 1.2 trillion images were taken – mostly by cell phones.

Ranger 7 took this image, the first picture of the Moon by a U.S. spacecraft, on 31 July 1964 at 13:09 UT (9:09 AM EDT) about 17 minutes before impacting the lunar surface. Photo courtesy of NASA/JPL.

Types of Images

When thinking of images most people think of pictures taken from cellphones or cameras. These images are from the visible spectrum, which is a very small component of the electromagnetic spectrum.



Electromagnetic Spectrum

The Treachery of Images

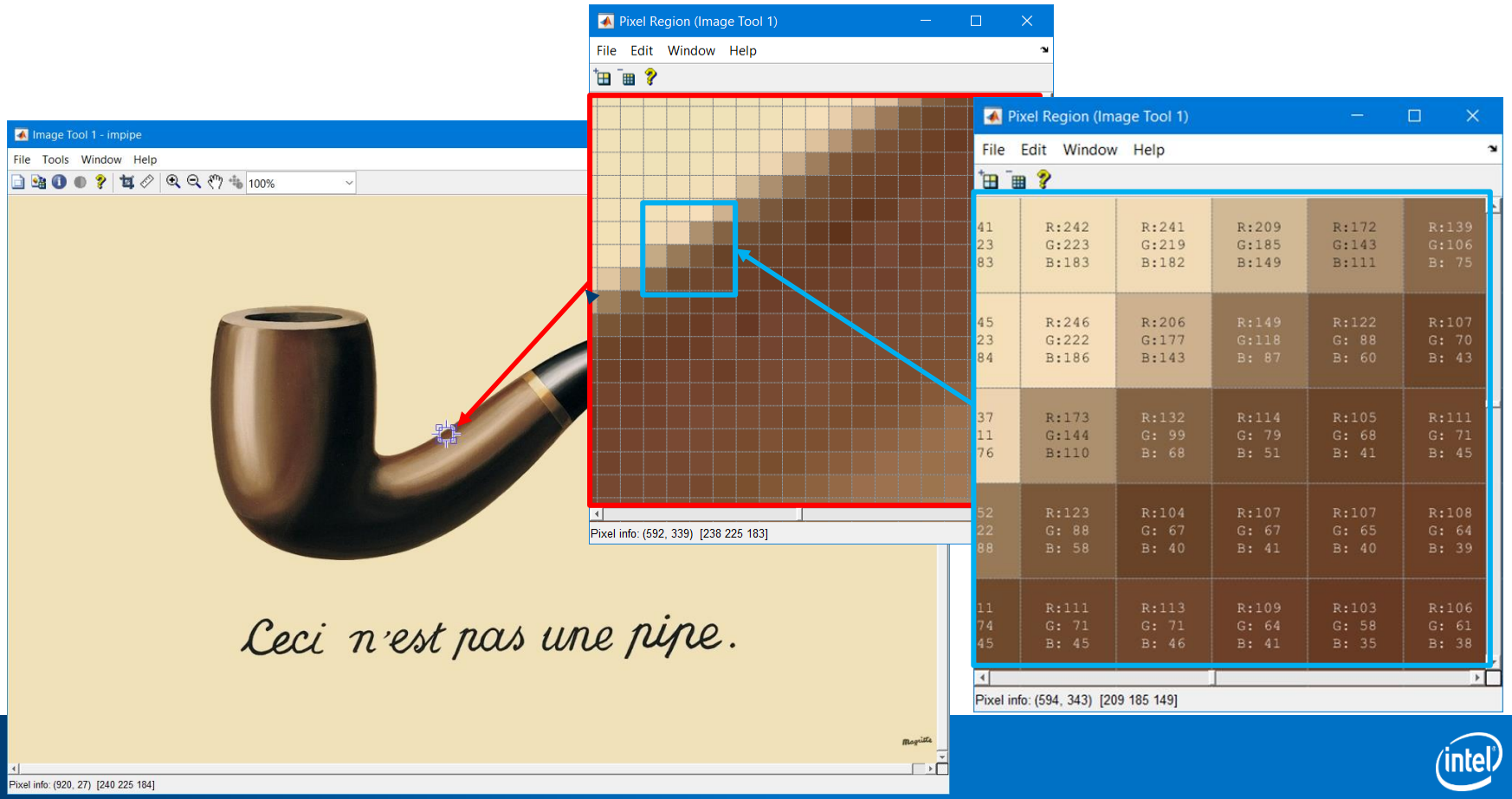
Rene Magritte, The Treachery of Images, 1929

The Treachery of Images

Rene Magritte, The Treachery of Images, 1929

The Treachery of Images

An image is a function and behind each pixel is a number or set of numbers. RGB is very common for colored pictures; HSV is a different scale that is more intuitive; and grayscale and black (=0) and white (=1) can be only a single number.

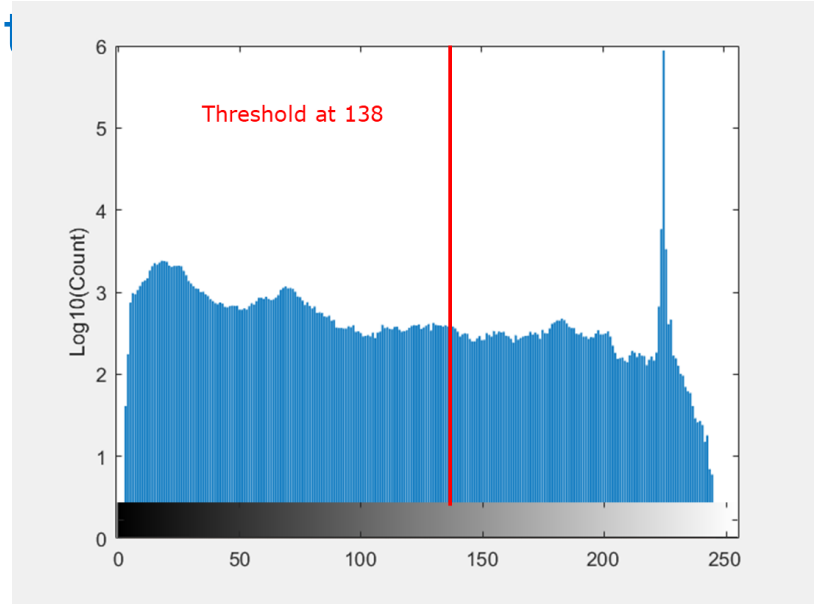


The Treachery of Images – Extract Information

Image converted to grayscale

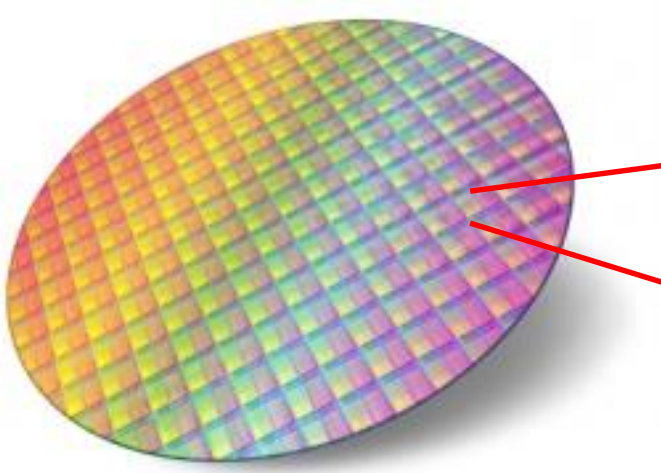
Image converted to black & white

The image was converted to grayscale and then black and white. A 1-D threshold method was used to determine the B&W

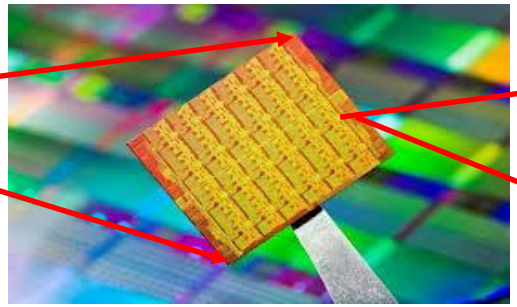


Graph of # of pixels vs. grayscale values. Threshold = 0.5373 (normalized to be between 0 and 1)

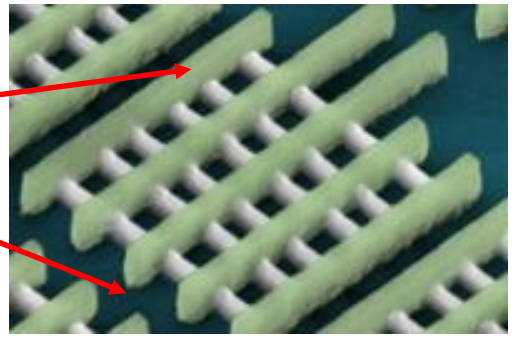
Semiconductor Industry: What We Do…



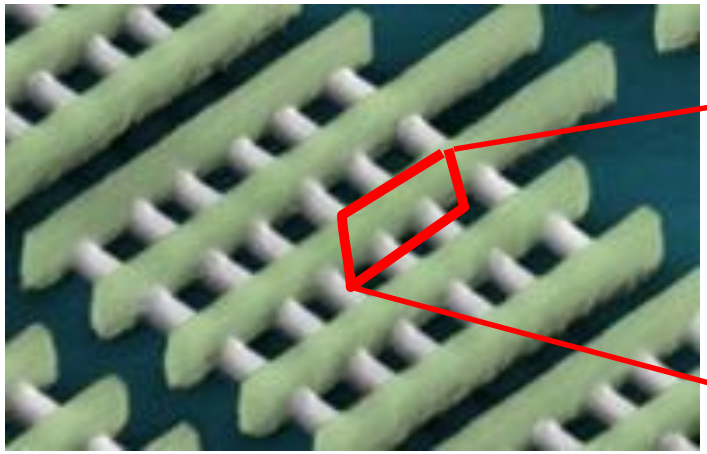
300mm Wafer

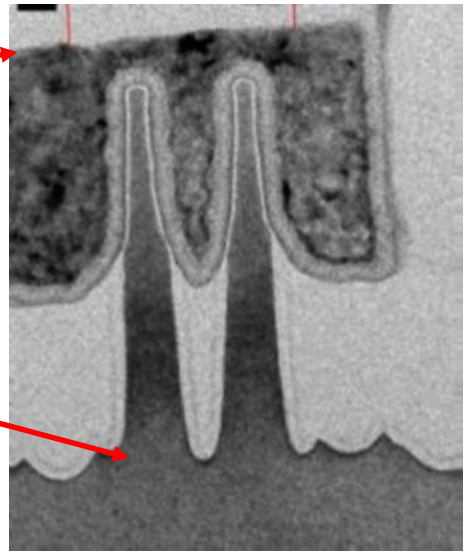


CPU



3D Tri-Gate Transistor





Source: Intel Corp.

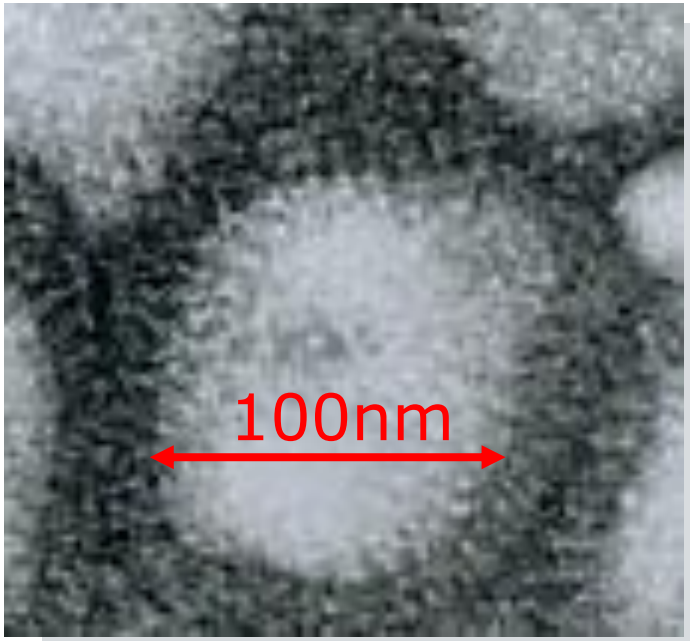
How Big is a Nanometer?

The original transistor built by Bell Labs in 1947 was large enough that it was pieced together by hand.

By contrast, it is estimated that about 100 million 22nm transistors could fit onto the head of a pin.

A transistor can switch on and off well over 100 billion times in one second. It would take you around 2000 years to flick a light switch on and off that many times.

Intel's factories produce over 5 billion transistors every second.



Influenza virus

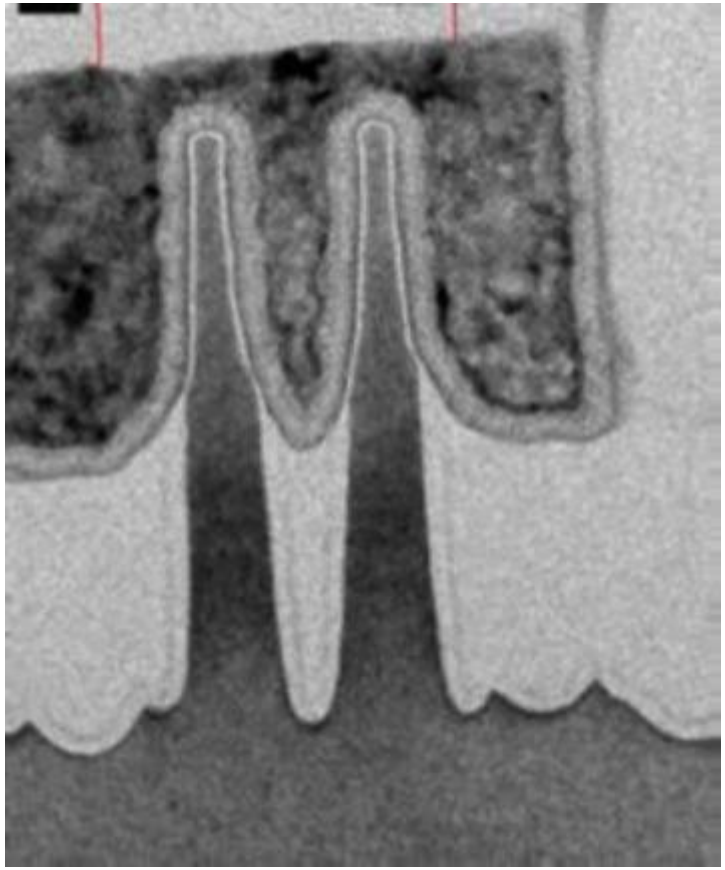
Source: CDC

Semiconductor Images

This is a Transmission Electron Microscope (TEM) cross section from Intel's 10nm process.

Information from images like this are used to develop and monitor technologies.

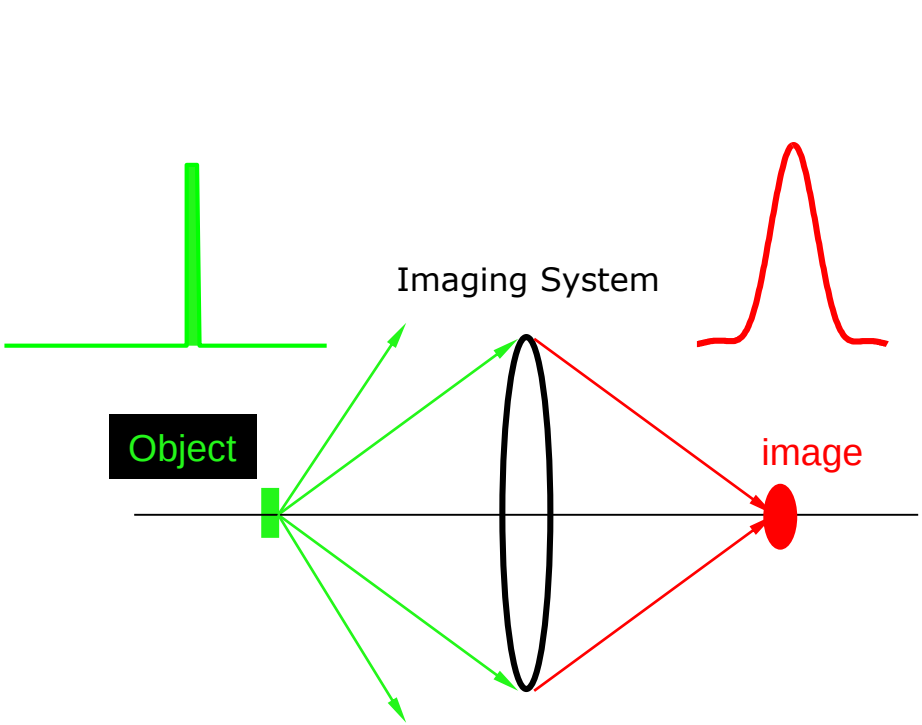
Segmentation of the image simplifies and creates partitions of the image, which then allows the extraction of information from the image.

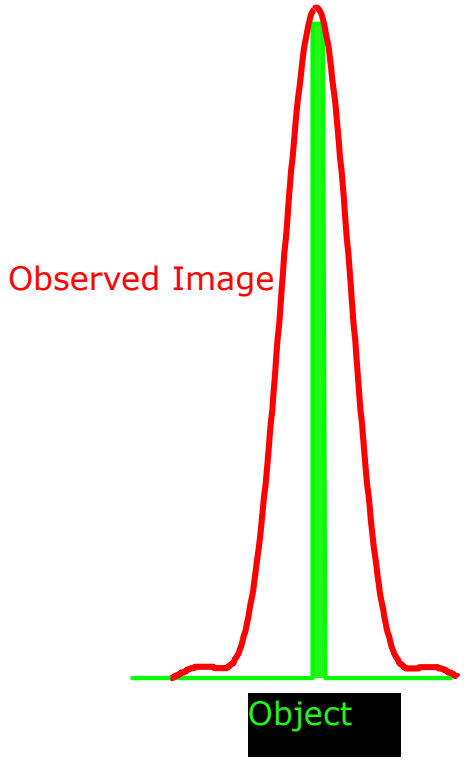


Intel 10nm technology node Fin
Courtesy of C. Auth, Intel Corporation

Imaging Systems Are Limited By Physical Optics

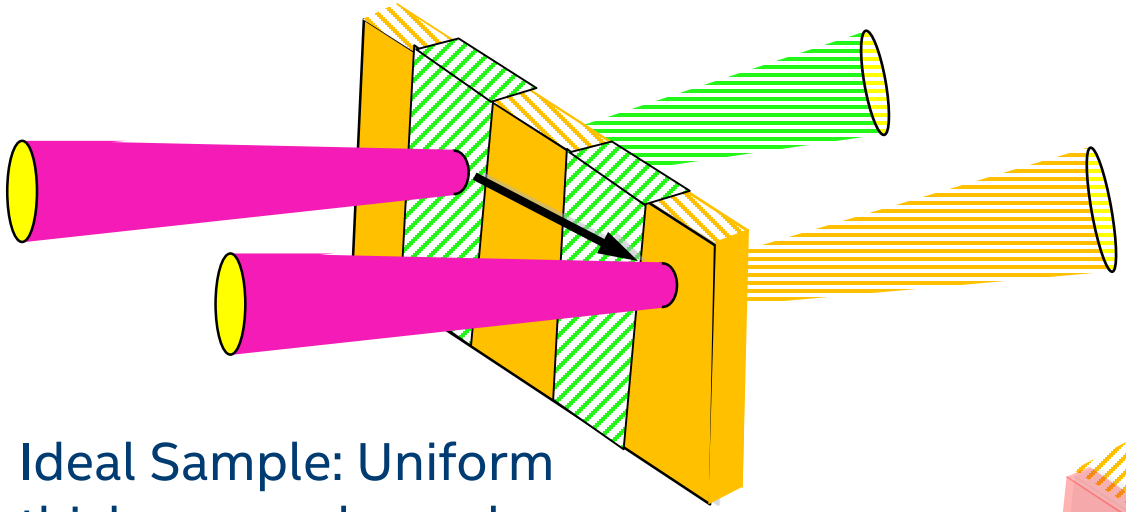
- Diffraction and Aberrations Blur The Observed Image
- Think of the system response as an averaging of details
- Red (observed) image is the convolution of the system's Transfer Function of a Delta-function object.





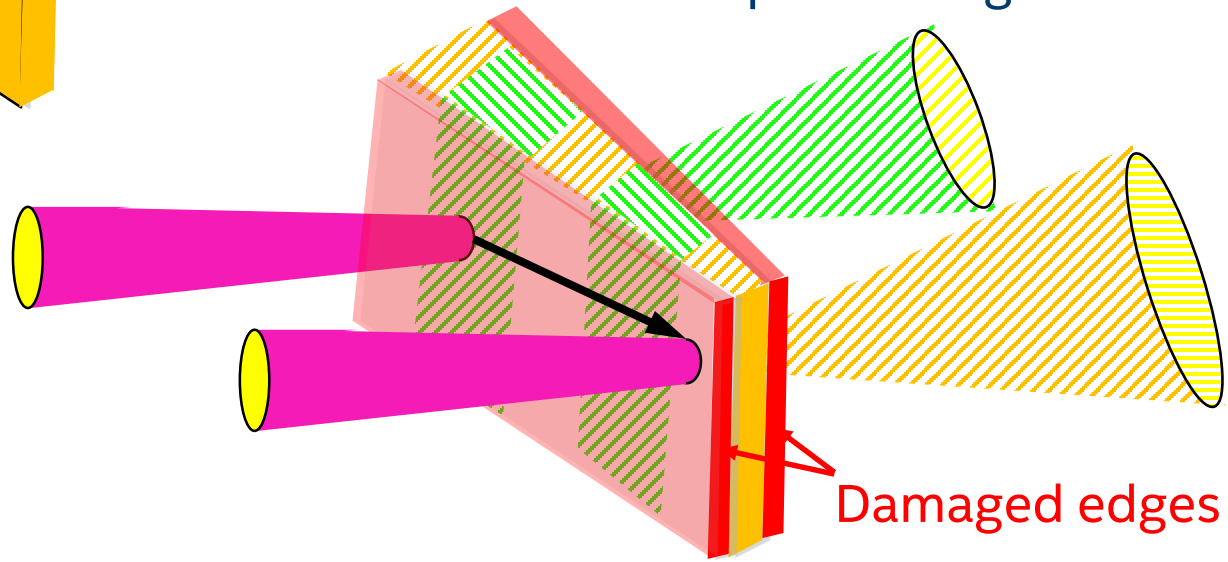
Sample Preparation Effects

- Sample artifacts such as thickness variation and damage also degrade the ideal image even for scanned systems



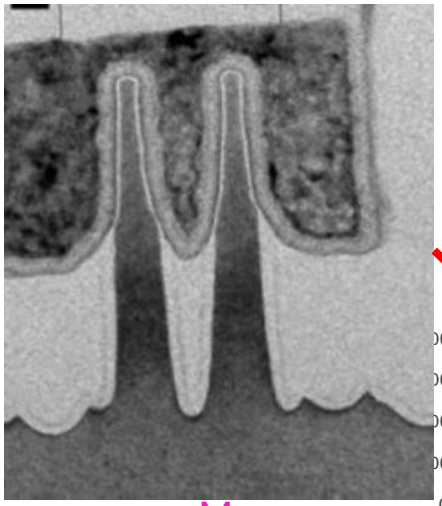
Ideal Sample: Uniform thickness and no edge damage

Real Sample:
Thickness variation
and amorphized edges



From Filtered Images to Segmented Map

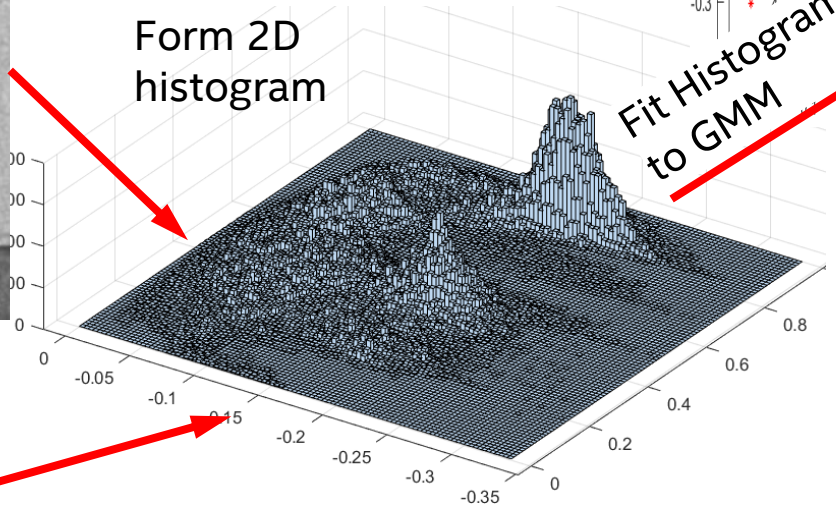
Averaged 5x5 image



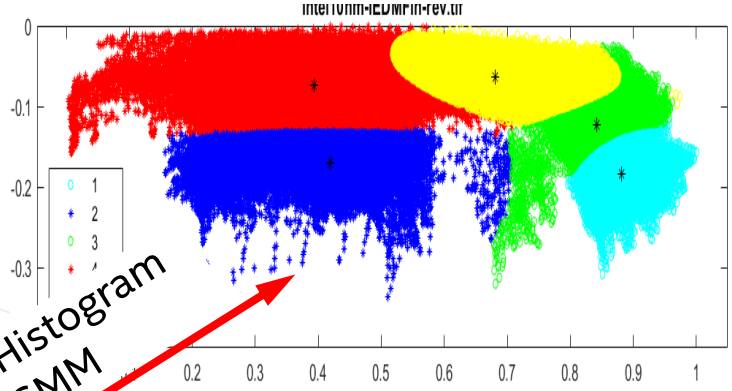
N

M

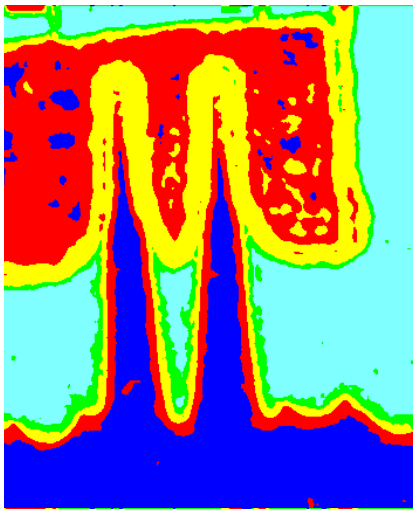
Form 2D histogram



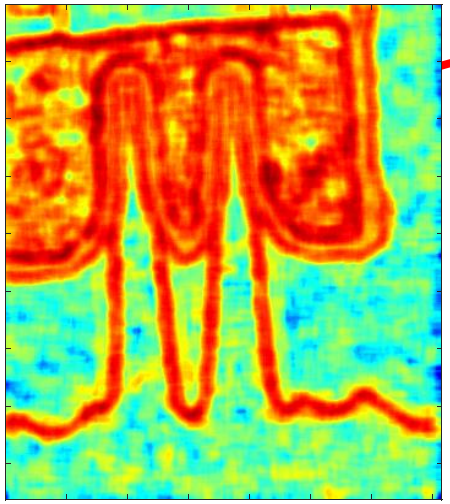
Fit Histogram to GMM



Assign each pixel to a Gaussian cluster and redraw image



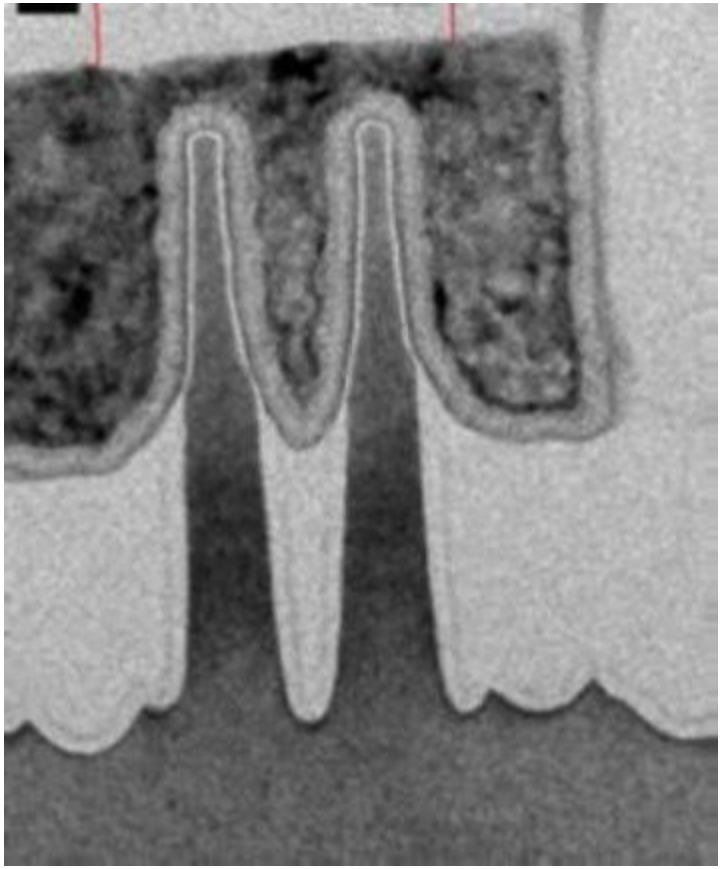
Log_{10}(Entropy(15x15))



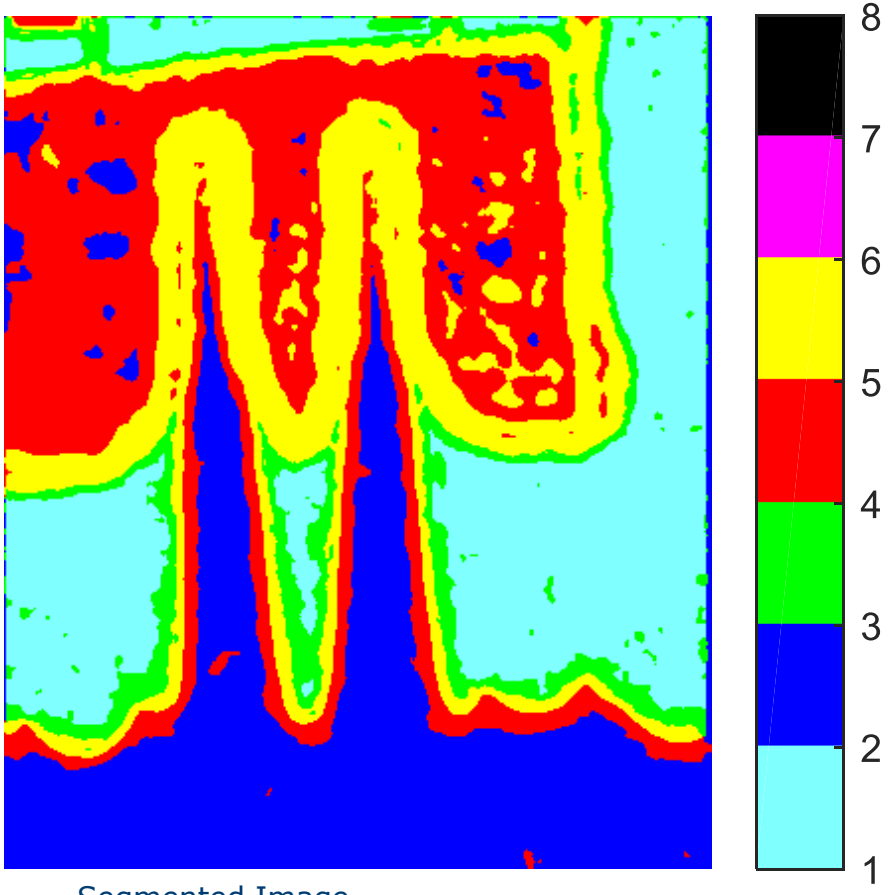
N

M

Segmentation and Clustering



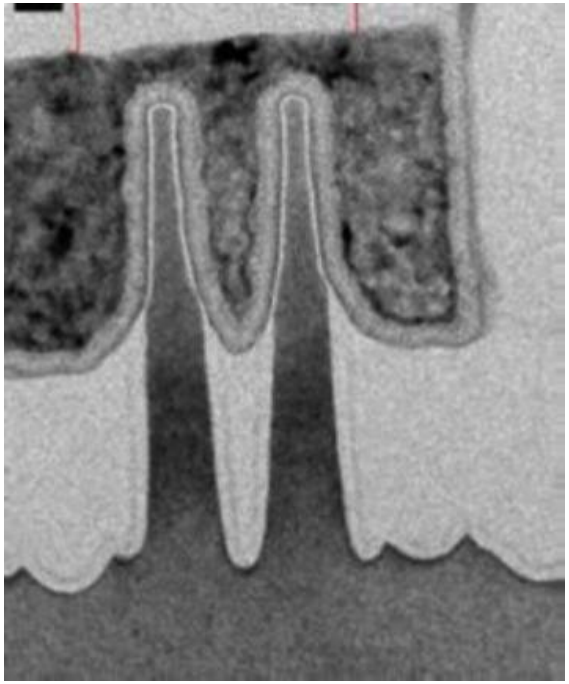
Original Image



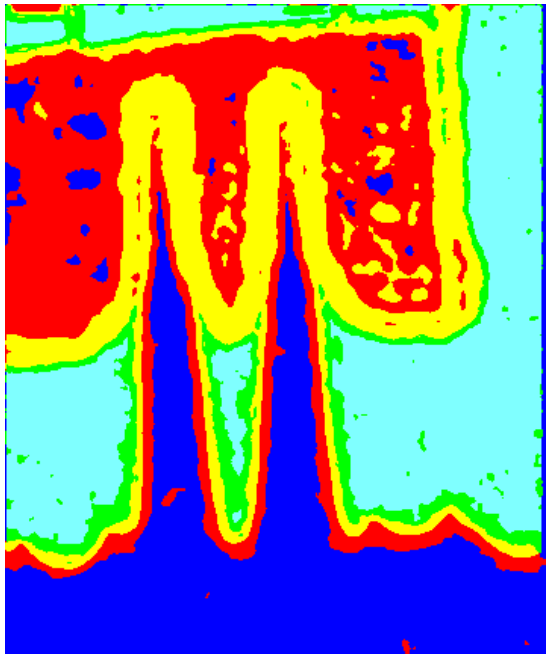
Segmented Image

The segmentation of this image was done by fitting a Gaussian Mixture Model and partitioning the data into k clusters determined by the Gaussian mixture components.

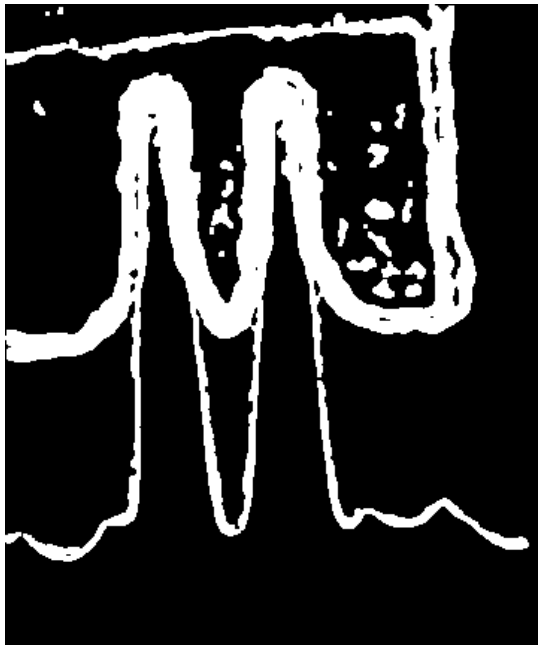
What we did…



Original



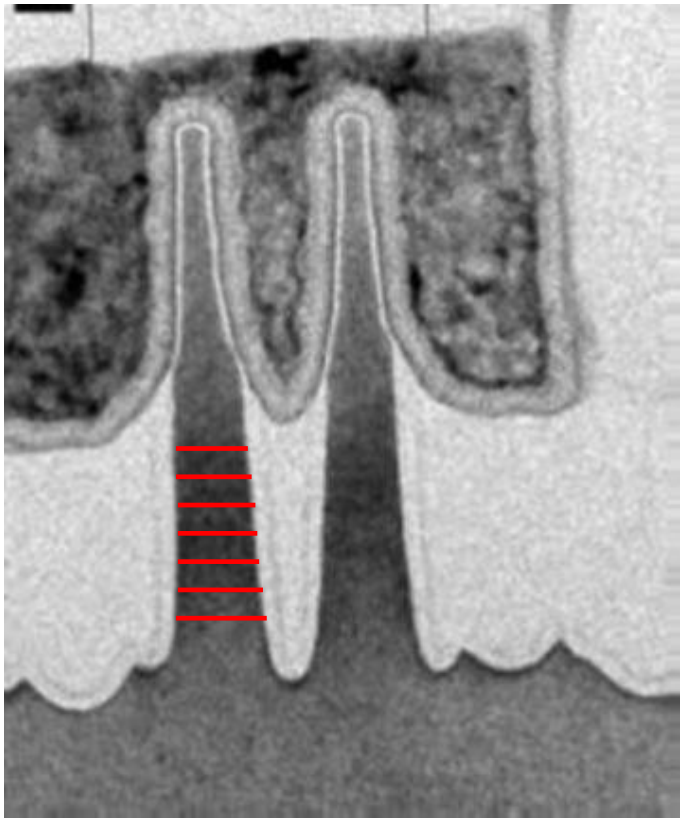
Segmented

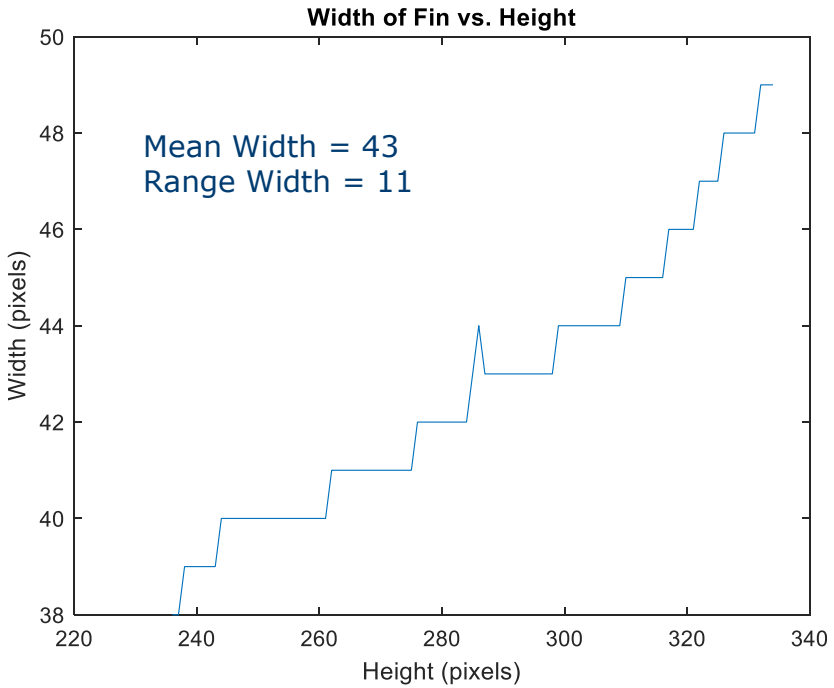


Binary image of segment 5

The original TEM image was segmented and the fifth segment was made into a binary image. Height and width of the fin (in pixels) can now be extracted from the binary image. If you know the size of a pixel, the values can then be converted to nanometers.

Measurements…





Extract the fin width and height. Repeat for many images to determine the largest sources of variation of the fins.

Summary

- Images are functions that can be manipulated, segmented, and classified.
- Images are noisy and imperfect. This makes the data extracted from images noisy and imperfect.
- When measuring very small objects this noise can be significant.
- It is important to understand the noise and not be overly confident in the values that are computed from images, e.g. be aware of the number of significant digits that are reported.
- Process control using image-based metrology must have the same statistical rigor as any other metrology data.

Acknowledgements

Chris Auth

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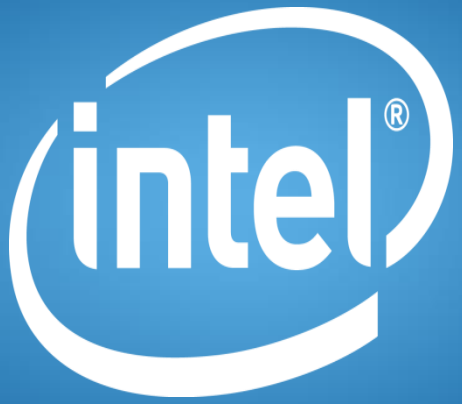
BACKUP

Rene Magritte, La Clairvoyance, 1936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