Medical Image Analysis

Chris McIntosh

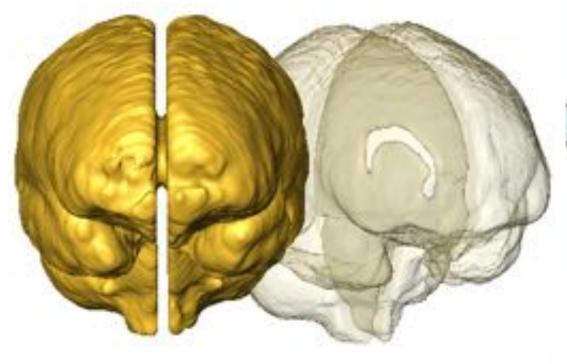




Medical Imaging



- Enable clinicians to examine anatomy in-vivo (without extracting it)
- Some major areas for computer science
 - Data visualization
 - Image Analysis
 - Computer assisted diagnosis (CAD)
 - Disease understanding





Sagittal Plane

Acquisition

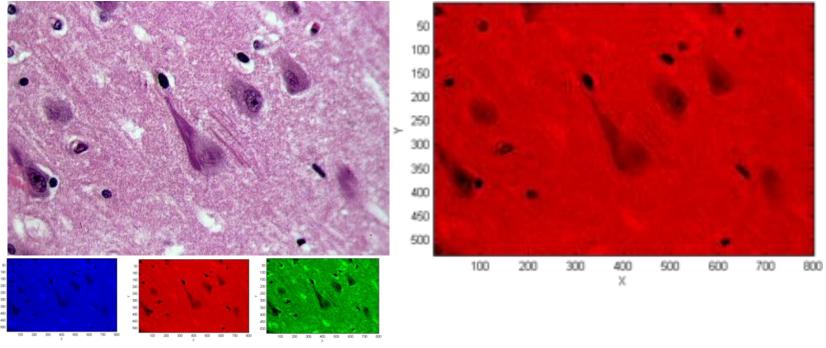


- Many different types of signals
 - Colour (dermatology, pathology)
 - Radiodensity (structural, geometrical)
 - Radioactive isotope uptake over time (functional)
 - Water and fat (soft-tissue structural)
 - Water diffusion over time (soft-tissue functional)
 - High frequency sound wave refraction

Colour Images



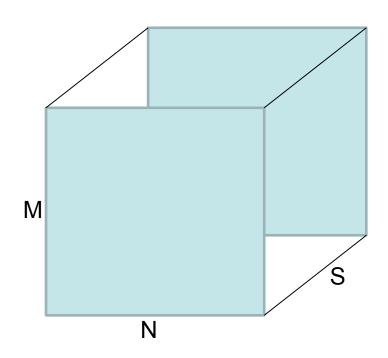
- Acquired by a camera, optionally with aid
 - Microscope, Dermatoscope, Endoscope, etc.
- Composed of 3 data channels yields an MxNx3 array
- Each discrete element is a pixel on the X, and Y axis

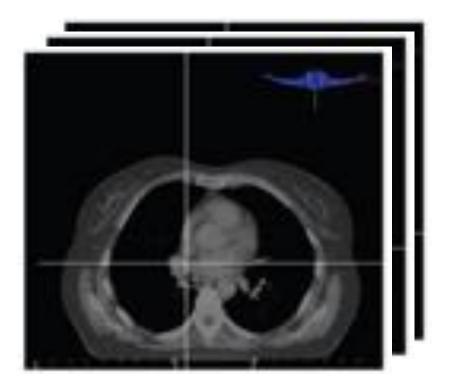


Radiodensity



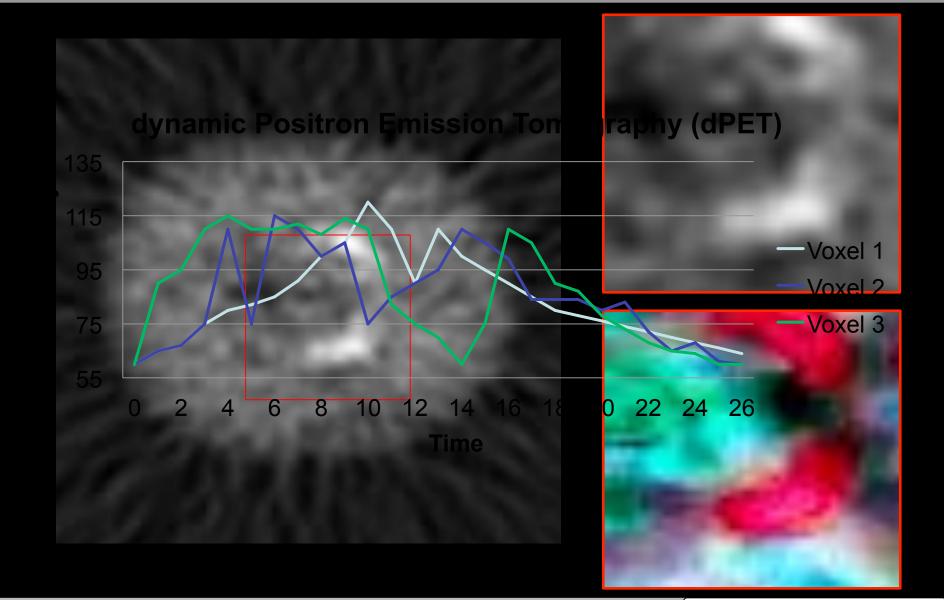
- CT Imaging
- MxNxS where S is the number of slices
- Each element is now a voxel in (X,Y,Z)





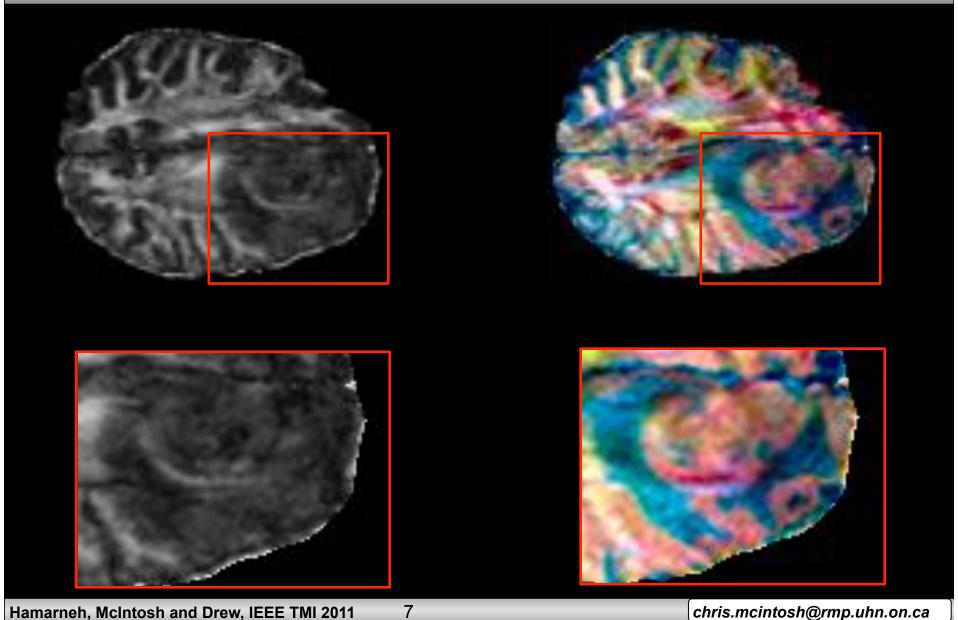
Positron Emission Tomography





Diffusion Tensor MRI





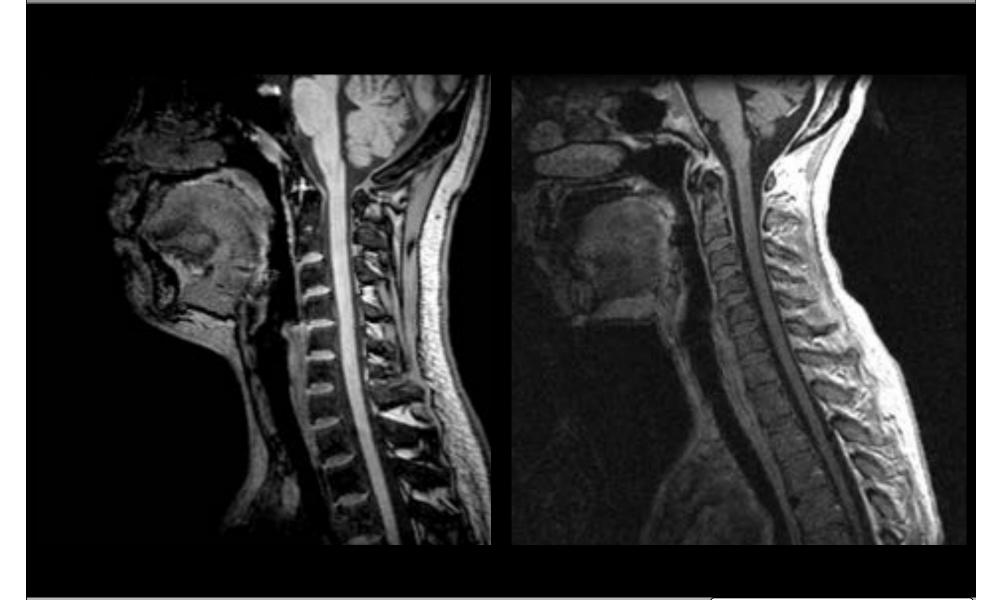
Common Tasks





Disease Understanding

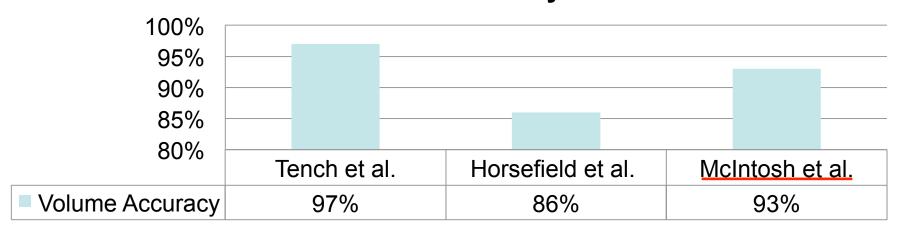




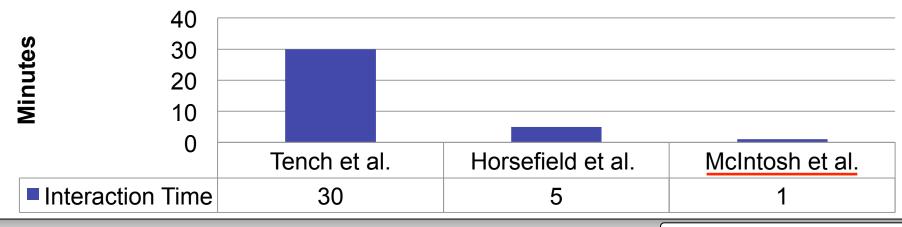
Disease Understanding



Volume Accuracy



Interaction Time



Summary



- Understanding the end-user
 - Not trying to replace medical experts
 - Augmenting ability
- It's about standardization and time
 - Make the region of interest more obvious (visualization)
 - Point me to the interesting data (Detection and CAD)
 - Extract the interesting data faster (segmentation, and shape analysis for disease understanding)
- A patient should receive the same diagnosis and treatment on a Monday morning in Toronto, or Friday night in Whitehorse

What is Vision?

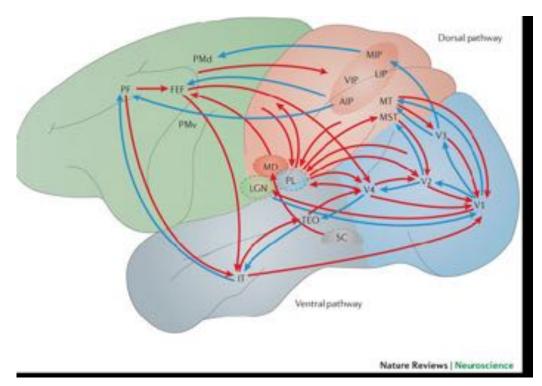


 If the goal is observe or highlight something a person can see in an image, we must first understand how a person can see

A Nobel Prize



- Hubel & Wiesel won the Nobel Prize in Physiology or Medicine in 1981
- Inserted microelectrodes into cats, and monkeys, and studied the response of different areas of the brain under different stimuli



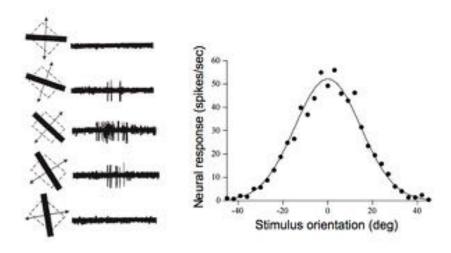
Gilbert and Li, Nature Reviews, 2013

The First Layer



- Primary visual cortex (V1)
- Different neurons respond to differently oriented bright vs dark bars
- We call this edge response

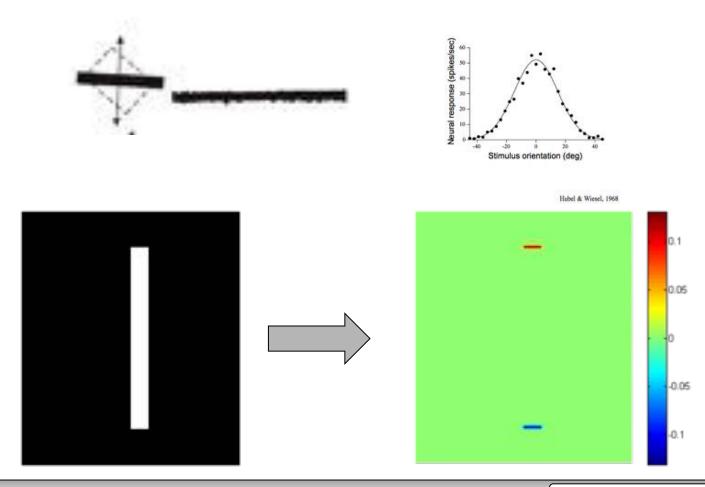
V1 physiology: orientation selectivity



Hubel & Wiesel, 1968



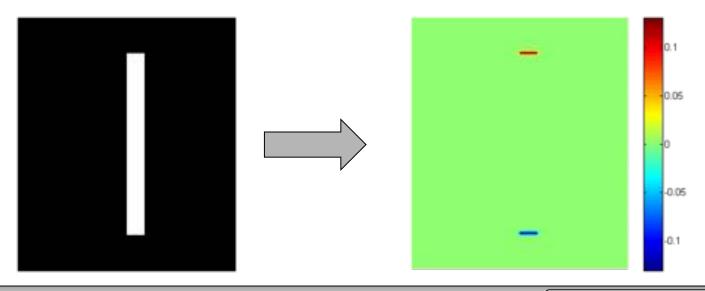
Examine response for a single neuron



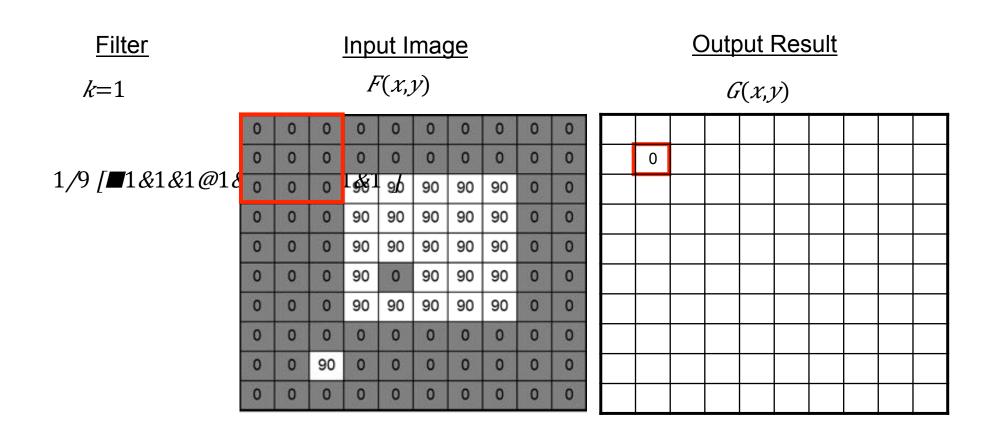
Filtering



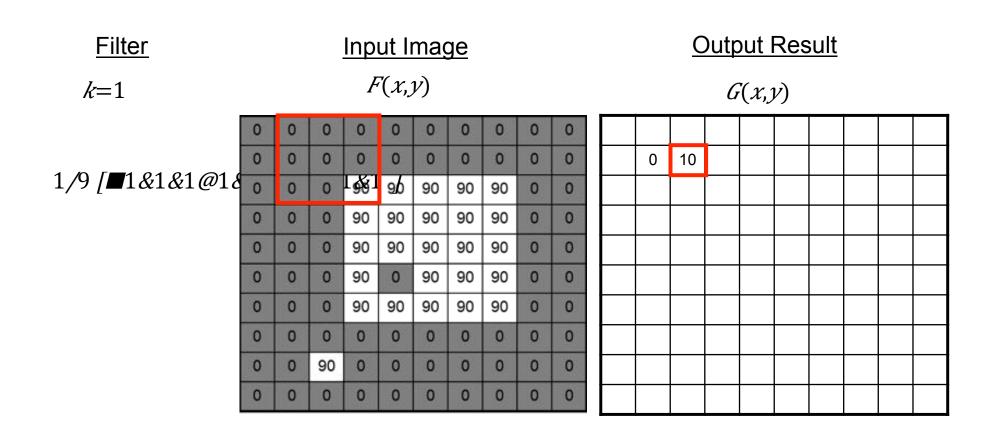
- We need examine every pixel of an MxN image and compare it to the pattern's discovered by Hubel and Weise
- We call the pattern a filter, and it will be a [2*k+1,2*k+1] array.



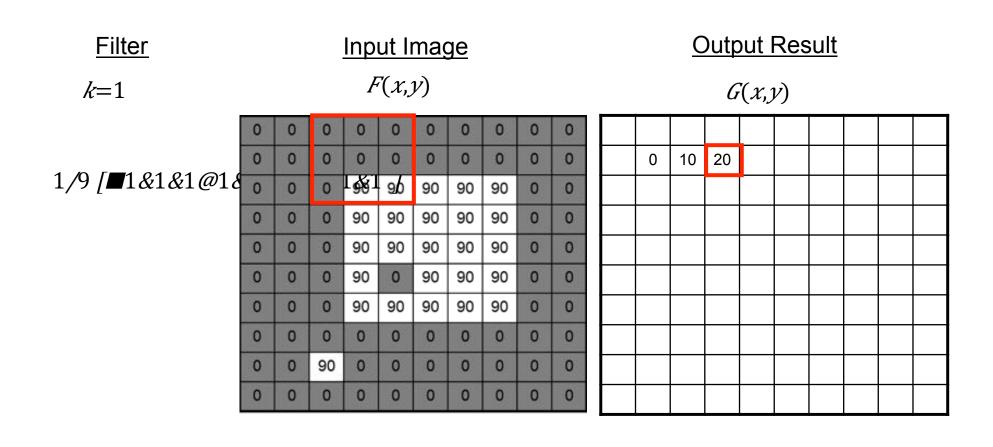












Boundary Conditions



0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	
0	0	0	90	90	90	90	90	0	0	
0	0	0	90	90	90	90	90	0	0	
0	0	0	90	90	90	90	90	0	0	
0	0	0	90	0	90	90	90	0	0	
0	0	0	90	90	90	90	90	0	0	
0	0	0	0	0	0	0	0	0	0	
0	0	90	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	



<u>Filter</u>	Input Image								Output Result									
<i>k</i> =1	F(x,y)									G(x,y)								
	0	0	0	0	0	0	0	0	0	0								\neg
	0	0	0	0	0	0	0	0	0	0	0 10	20	30	30	30	20	(10)	\neg
1/9 [■ 1&1&1@1&	0	0	0	ايوا	90	90	90	90	0	0	0 20	40	60	60	60	40	20	
	0	0	0	90	90	90	90	90	0	0	0 30	60	90	90	90	60	30	
	0	0	0	90	90	90	90	90	0	0	0 30	50	80	80	90	60	30	
	0	0	0	90	0	90	90	90	0	0	10 E 30	50	80	80	90	60	30	
	0	0	0	90	90	90	90	90	0	0	0 20	30	50	50	60	40	20	
	0	0	0	0	0	0	0	0	0	0	10 28	30	30	30	30	20	10	
	0	0	90	0	0	0	0	0	0	0	10 10	10	D	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0								\Box

Source: S. Seitz, S. Fidler

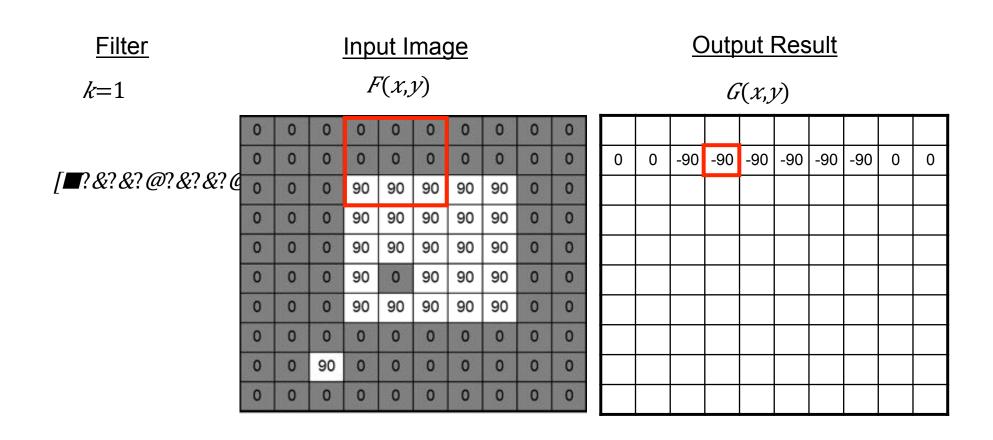
Algorithms



- Three main variants
 - 2D Filtering
 - Convolution
 - Same as filtering with a filter flipped in Y and then
 X to gain a few important mathematical properties
 - Normalized cross-correlation or templatematching
 - Same as filtering, but the response at each pixel normalized by the magnitude of the filter times the pixel-window

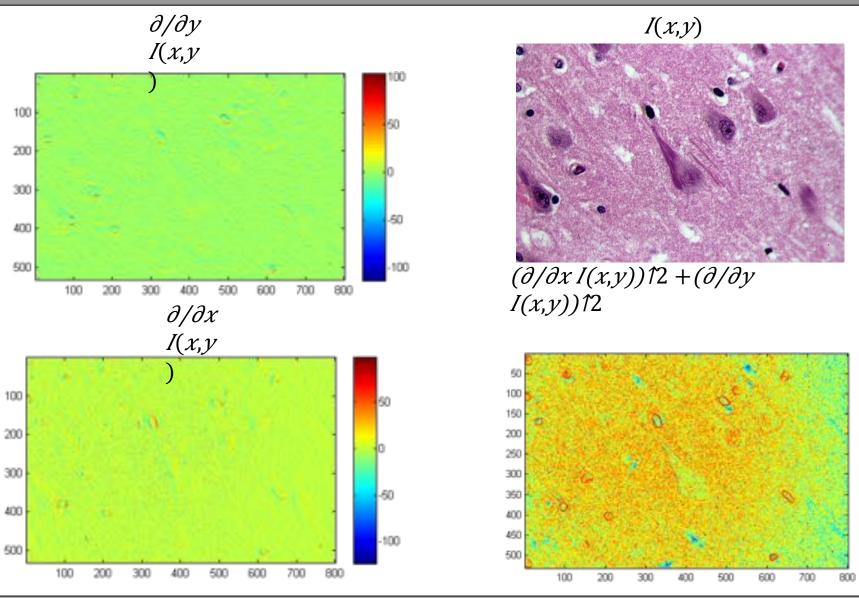
Edge Response





Edge Response

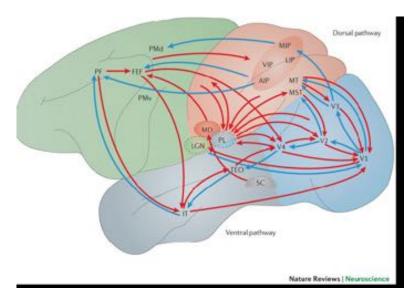




Higher levels of vision



- As we progress through the visual cortex we begin grouping responses from lower levels to create more complex representations
- This grouping gives rise to contours and shapes (Gilbert and Li, Nature Reviews, 2013)
- V4 has shown strong response to texture (Kastner et al., J Neurophysiology, 2000)



Gilbert and Li, Nature Reviews, 2013



Let's watch a short <u>video</u> and perform a basic vision task





Do both blocks have a gradient?



Photo by Dodek, CC BY-SA 3.0



Do both blocks have a gradient?



Photo by Dodek, CC BY-SA 3.0



• The same dog or different?



Psychological



- Vision is a psychological and perceptual phenomena, not a physical measurement
- Computer vision can emulate human vision
- It can also build measured responses to assist human vision
- Measurements lead to quantitative markers that can help decision making
- We call these features (some are perceptual, some are physical, some are both)

Features

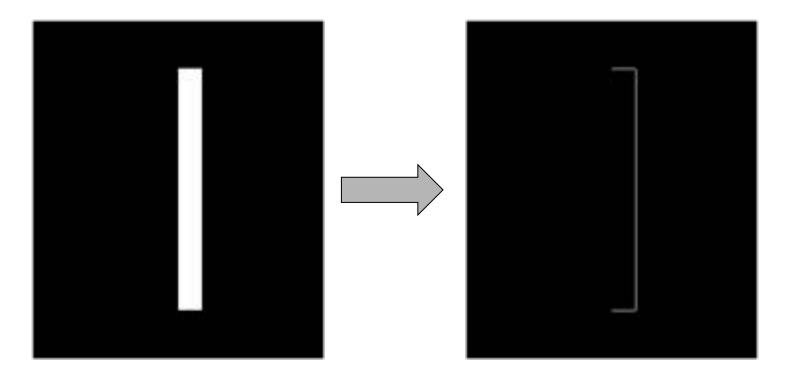


- In computer vision we call the lower level responses/ structures used to define an object features
- Features can be anything
- Represent a voxel or group of voxels by a number
 - Try and describe the local structure
 - Bright vs dark
 - Wavy vs smooth
 - Round vs square
- The features will enable us to build our applications (e.g. image segmentation)

Edge Detection



- Our edge filter is local (per pixel)
- Edges are connections of strong responses that group into a logical contour



Edges Are Both



 Humans implicitly ignore edges that are not relevant to their perception of an image



Martin et al., A Database of Human Segmented Natural Images..., Computer Vision and Pattern Recognition, 2001

Texture



Repeating intensity patterns in the data







 Texture analysis, called radiomics, in CT has been shown to correlate with genomic features and cancer outcomes (Aerts et al., Nature Methods, 2014)

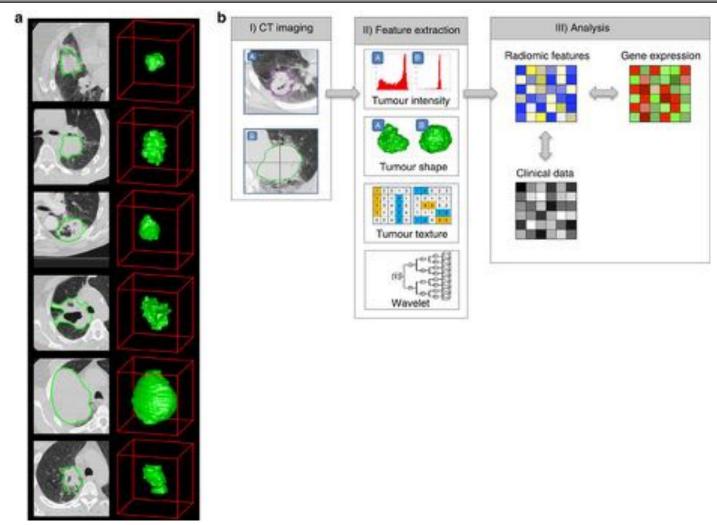
Shape





Radiomics





Aerts et al., Nature Methods, 2014

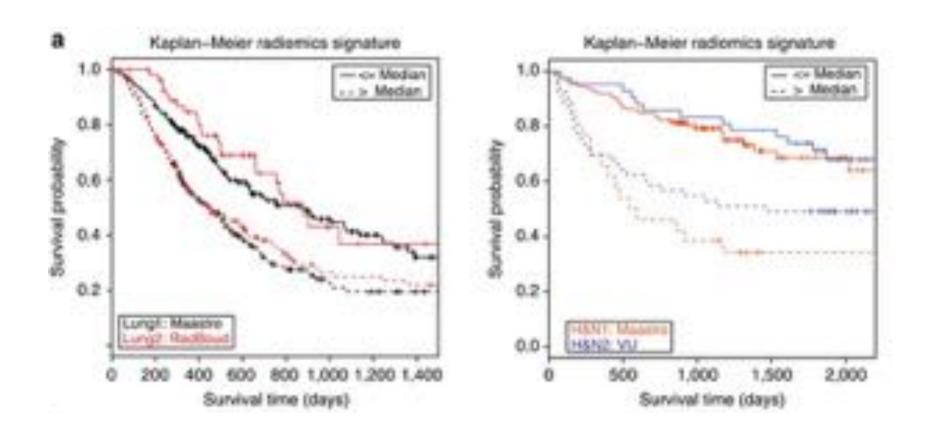
Building a Model



- Once features are extract the next step is to build a model to make predictions based on the features
 - F(features)=Outcome
- Model can be coded based on prior knowledge or learned via machine learning

Radiomics



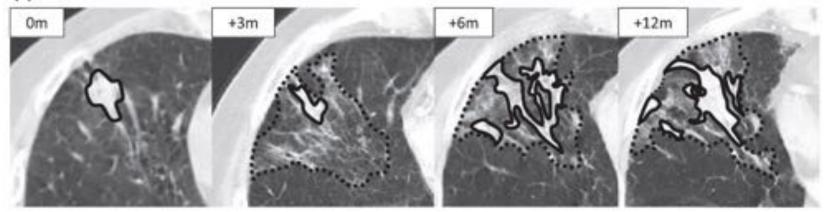


Aerts et al., Nature Methods, 2014

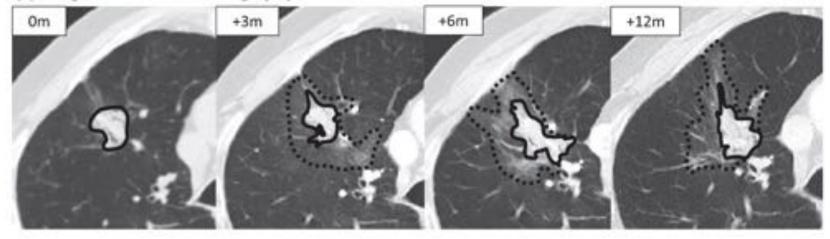
Lung Cancer Recurrence



(a) Recurrence



(b) Benign radiation-induced lung injury

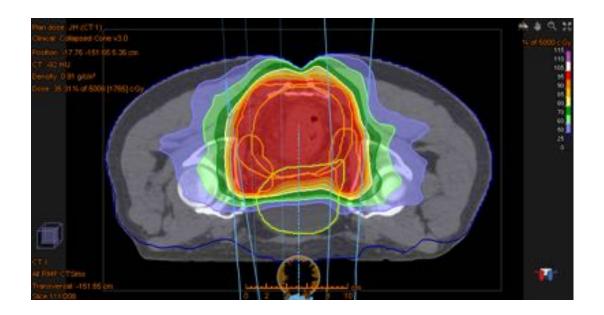


Mattonen et al., Medical Physics, 2014

Patients and Treatment



 Relating patient's anatomical geometry, texture, shape and appearance to radiotherapy treatment

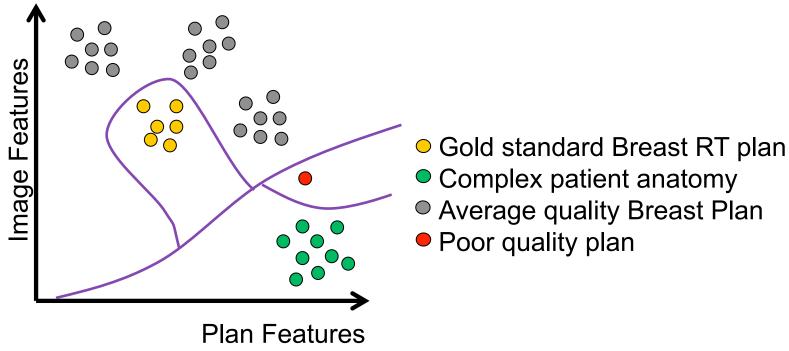


Distribution of Features



- Different radiotherapy plans and qualities have different image and plan features
- Machine Learning learns to distinguish between the different groups
- Learns to:
 - Automatically catch low quality plans
 - Rank plans in order of least-to-most complexity for review

Distribution of Features



Planning Error Detection

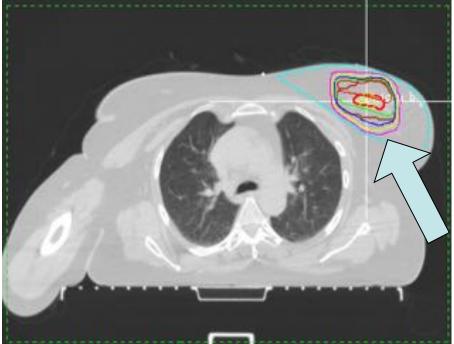


- Preliminary breast study, detects 80% of clinically rejected plans
- Detected plan error with poor high dose conformity (700 cGy isodose)

Rejected



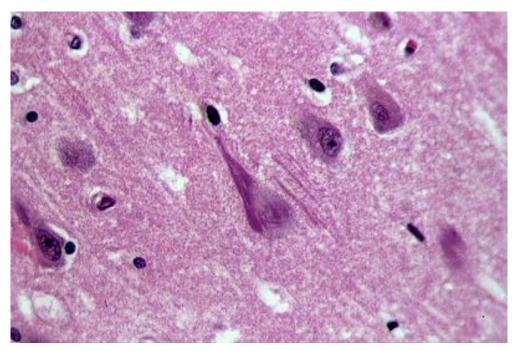
Accepted



Project Example



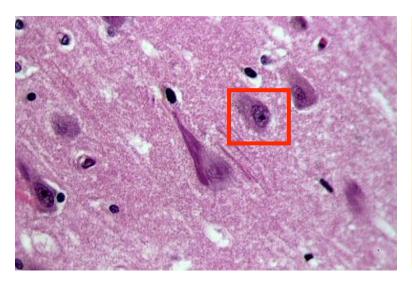
- Four main tasks:
 - Compute features
 - Train a model
 - Predict centres
 - Score

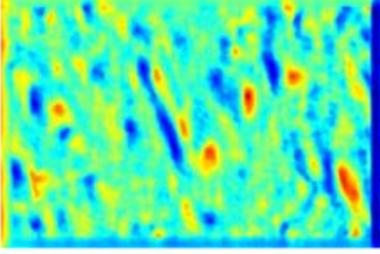


Template Matching



- Might be difficult to construct a good feature for nuclei
- We can use training data to build templates, and find those templates in the image
 - 1. Extract the template as a square around a nuclei centre
 - Use normalized cross-correlation (match_template in python) to find similar patterns
 - 3. Find the (x,y) locations of all of the top responses

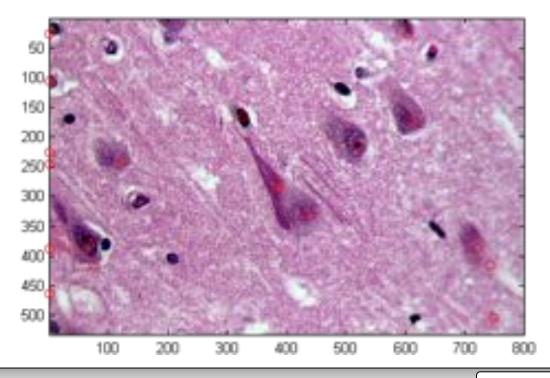




Scoring



- True positive: Any nuclei centre with a prediction sufficiently close by (e.g. 12 pixels)
- False negative: Any nuclei centre without a sufficiently close prediction
- False positive: Any prediction not sufficiently close to a nuclei centre



Summary



- Medical image analysis can aid in standardization and efficiency of measurements for outcomes, treatments, and disease understanding
- Many image features are built on filtering or convolution, emulating a similar process to the human visual system
- Human perception of colors, gradients, and edges is both psychological and physical
- The best systems will pair the strengths of medical experts (domain knowledge, compassion, understanding, interaction, high-level analysis) with the best of computers (repeatable, high throughput, quantitative)