Quantitative and Functional Imaging

BME 4420/7450

Fall 2022

Biomedical imaging

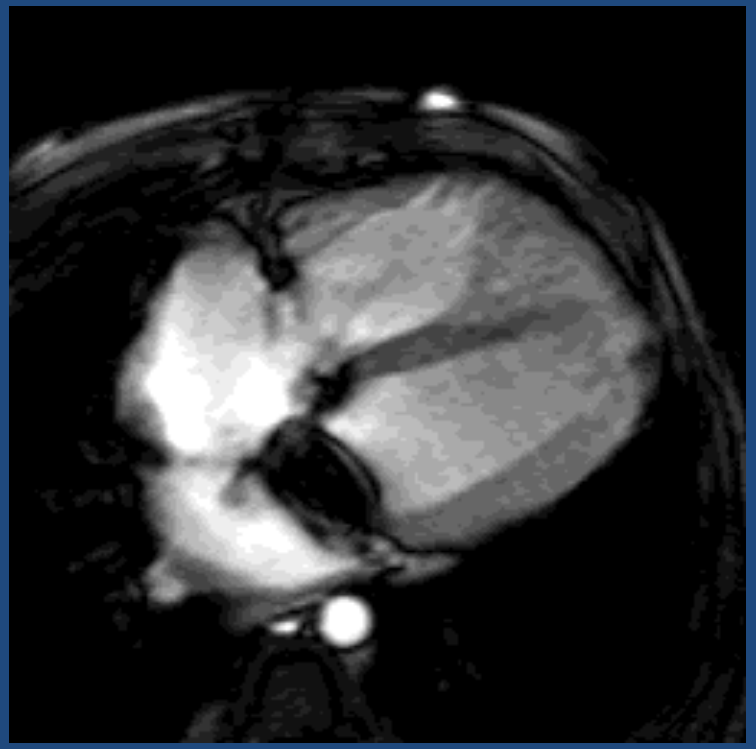
- Qualitative for most of its history
- Much more information available
- Apply knowledge of
  - Basic science
  - Math
  - Engineering

  to gain more information

Image from 1896 (Kevles, 1997)

Information in biomedical images

- Spatial information
  - Geometric properties
  - Spatial resolution (organ/tissue specificity)
- Time dependence
  - Position vs. time (velocity)
  - Image series to capture changes over time
- Physical properties
  - Interactions between tissues and external sources of energy



Quantitative Imaging

- How are biomedical imaging methods used to measure tissue structure and function in the body?
  - How do structure and function affect images?
  - What biophysical properties can be mapped with imaging?
- Imaging modalities
  - Ultrasonography (US)
  - X-ray computed tomography (CT)
  - Magnetic resonance imaging (MRI)
  - Positron emission tomography (PET)

Physical properties revealed by imaging

- Image intensity can reflect
  - Atomic/Molecular composition
  - Chemical properties
  - Mechanical properties
  - Electromagnetic properties
- These physical properties in turn vary with tissue composition and function
- Reflect physiology and pathology

Non-invasive measures of the internal state of the body

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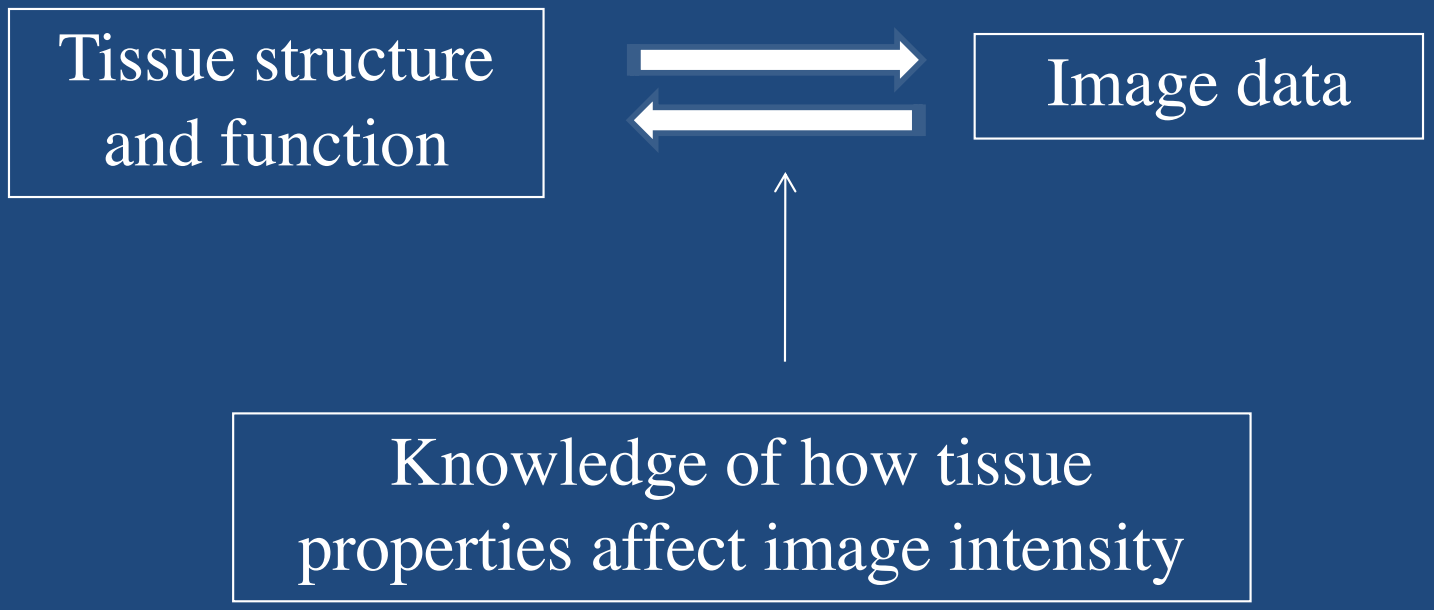


Image contrast is sensitive to physiology

Physiology

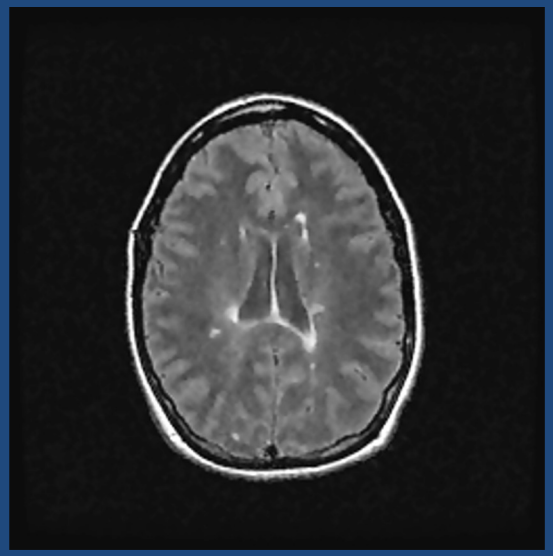
Physical tissue properties

Image data

Inflammation

Decreased macromolecular concentration

Brighter MRI image pixels



Physiology

Knowledge of how physiology affects physical properties

Physical tissue properties

Knowledge of how tissue properties affect contrast

Contrast variations

Images acquired under different conditions

Image data

Improved understanding of disease

Dependence of physiological variable on disease state, treatment, development, etc.

Physiology

Knowledge of how physiology affects physical properties

Physical tissue properties

Knowledge of how tissue properties affect contrast

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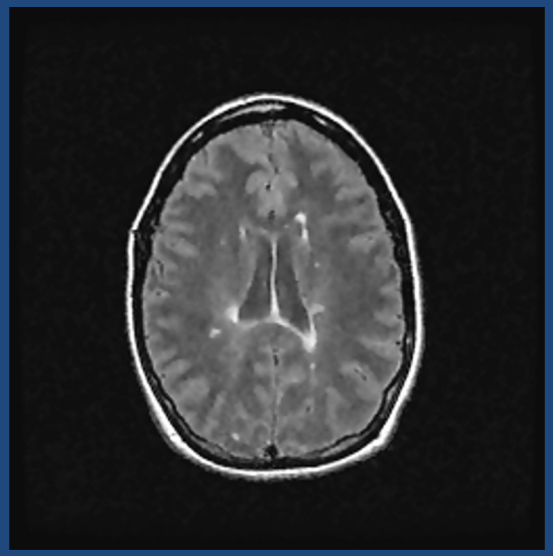
Images acquired under different conditions

Image data



Imaging provides a non-invasive probe of the internal state of the body

- Images carry information on the state of tissues
- Quantitative image analysis characterizes that state
  - Similar to a blood test (chemistry and cells)
  - Provides different information (if we know how to derive it)
- Benefits for
  - Human studies
    - Only feasible measurement method in many cases
  - Animal studies
    - Longitudinal (survival) studies

Relation of imaging to other measurements

- Spatial localization can improve sensitivity, specificity
- But imaging methods have limited
  - Time resolution
  - Sources of contrast
- Imaging can provide information complimentary to other biomedical data

Aspects of quantitative image analysis

- Measure image properties
  - Area (or volume), signal differences
- Fit signal changes to mathematical models
  - Determine values of parameters in the model
  - Test models
- Improve image quality
  - Signal-to-noise ratio, contrast-to-noise, resolution
  - Suppress artifacts
  - Improves diagnosis

Applications of quantitative imaging

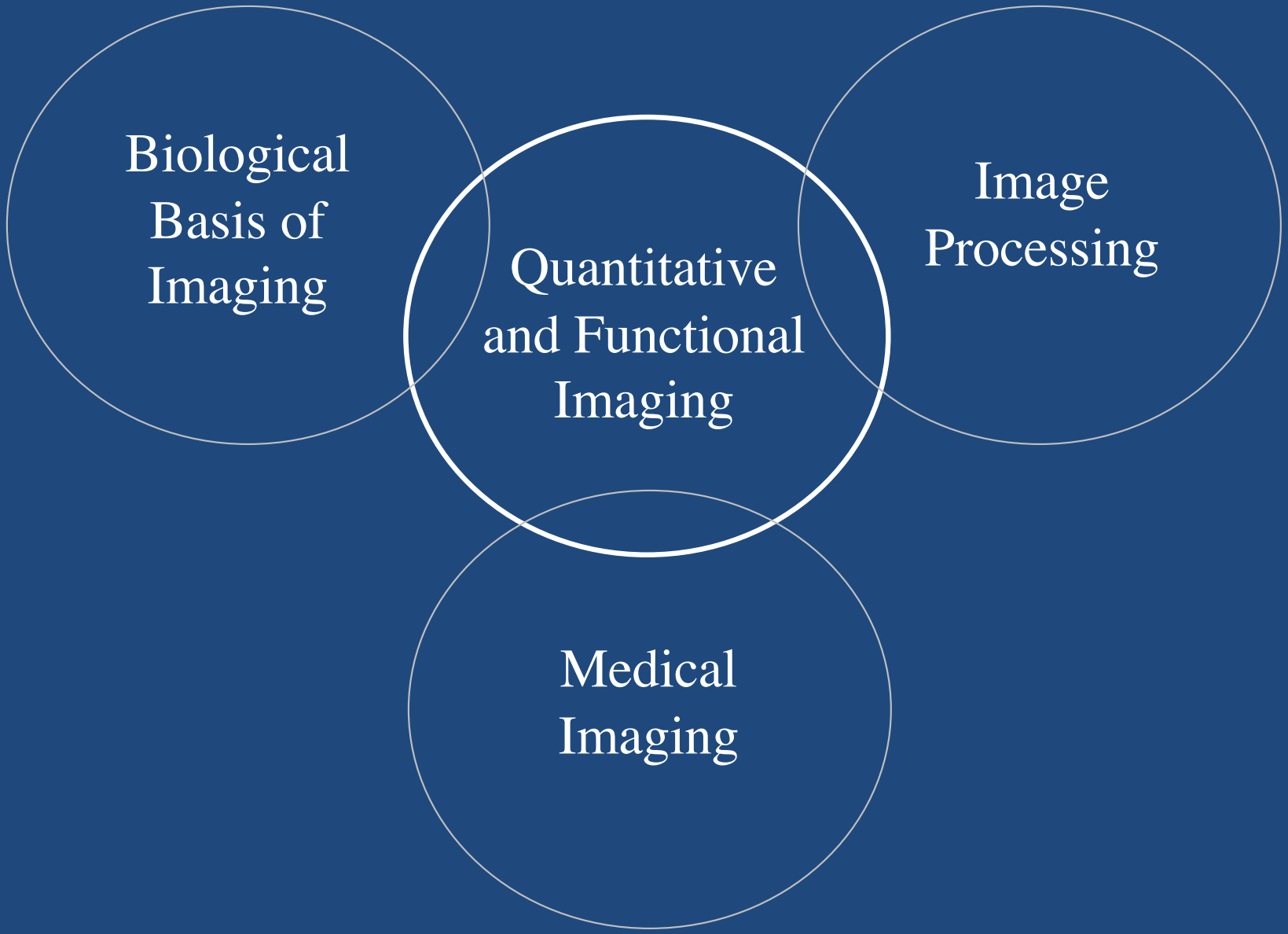
- Patient-based
  - Diagnosis
  - Treatment planning
  - “Precision” medicine
- Disease-based
  - Causes/consequences of pathology
- Basic science
  - Normal physiology
  - Cognitive science
- Pharmaceutical R&D
  - Drug development
  - Clinical trials

D. Ballon, NIBIB Picture Gallery

What is an image?

- Graphical representation of the 2(+) dimensional distribution of data
- Many different possible formats for storing this information
- Often, an image file includes image data and information about the data (*metadata*)
- First in-class exercise:
  - What metadata do you think would be useful?
  - This will vary with the application, so be specific.

How is this course related to others?

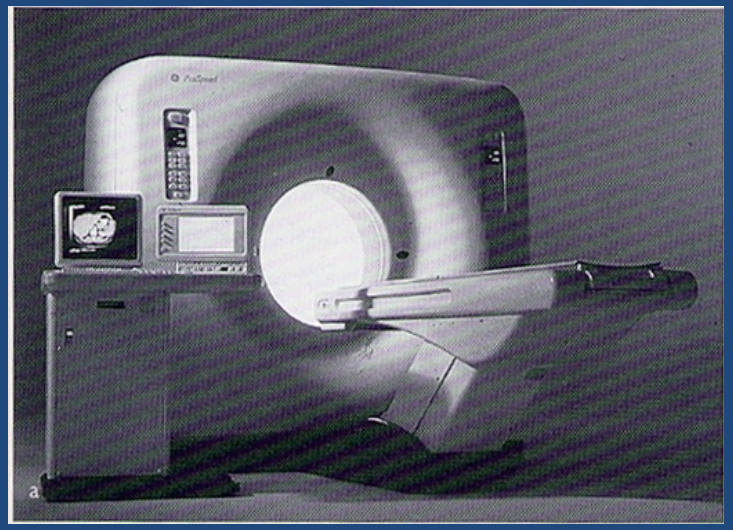


QFI Main Topics

- Image properties
- Image modeling
- Anatomy and tissue structure
- Motion and flow
- Metabolism
- Molecular imaging
- Biomarkers

Imaging methods

- Computed tomography
- Ultrasonography
- Positron emission tomography
- Magnetic resonance



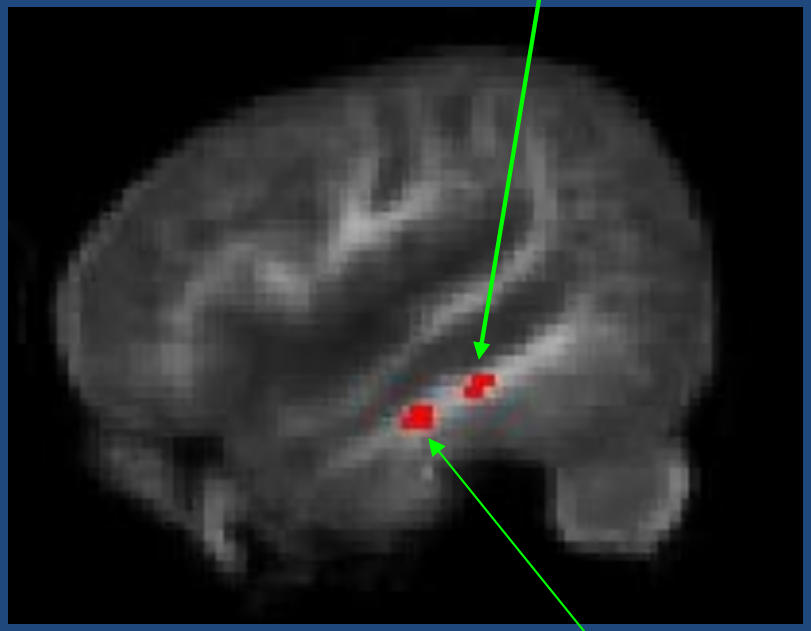
Wolbarst (1999)

Image modeling

- Links image data to tissue properties
- Model fitting
  - Linear
  - Non-linear
- Correlation with non-imaging data aids interpretation

PR RT	EC RT	Wrat-M
-.615**	-.598**	.482**

* p< .05; ** p < .01

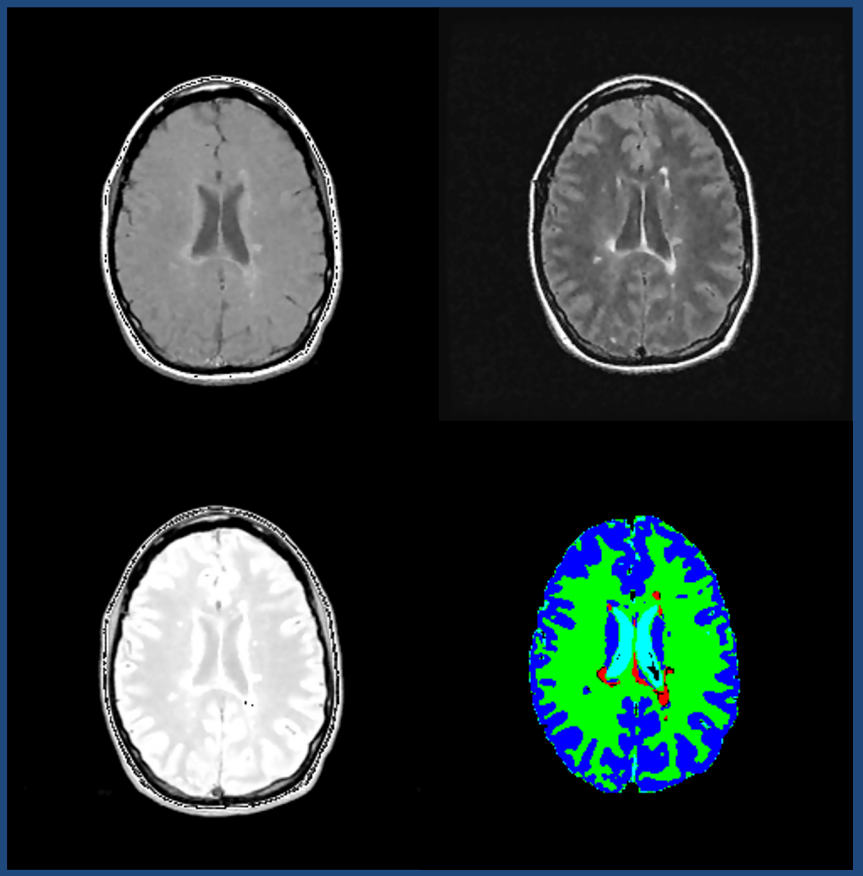


PJPrePC	Wrat-M
.382*	.449**

* p< .05; ** p < .01

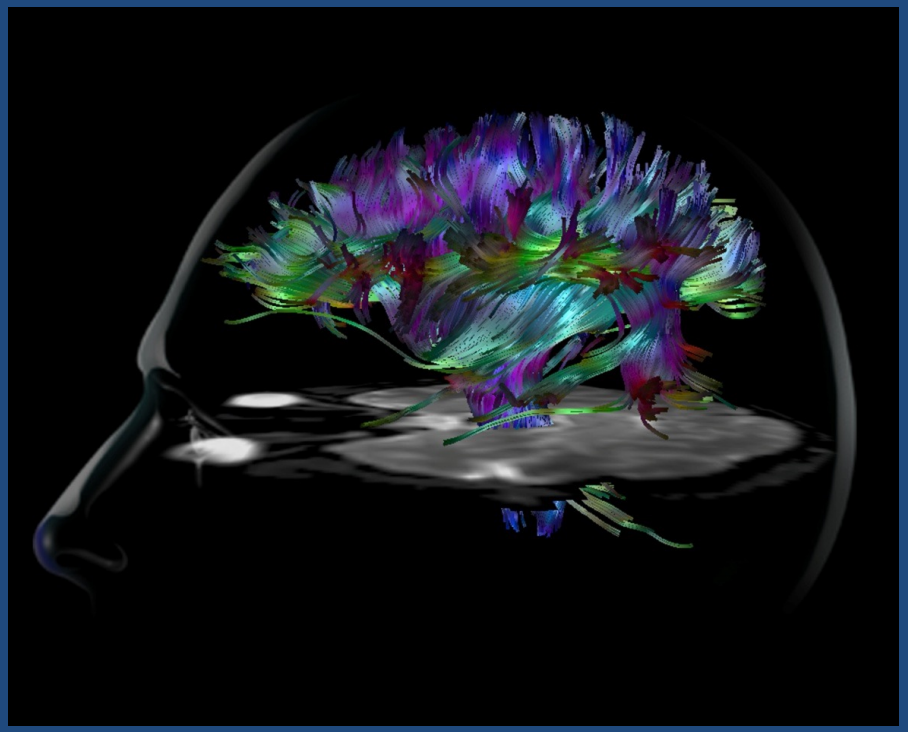
Tissue structure

- Volumetrics
  - Cardiac ejection fraction
- Tissue classification
  - Multiple sclerosis lesion load



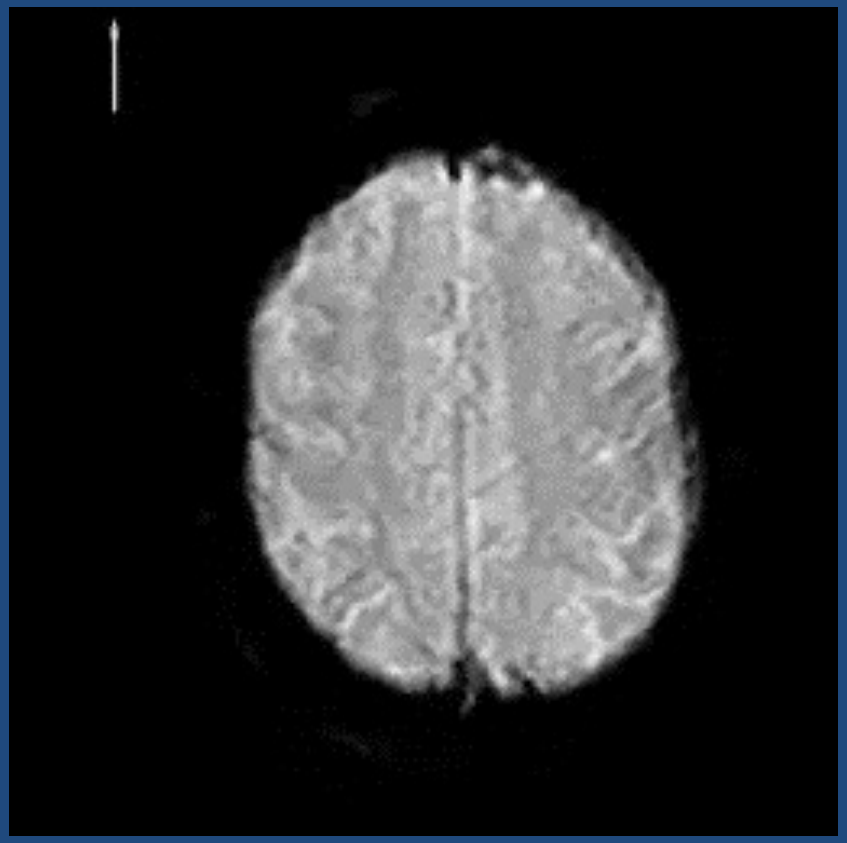
Tissue microstructure

- Detect changes on cellular level
  - Cell populations
  - Myelination
  - Cell orientation
- Neuronal fiber tracking
  - Brain connectivity



Tissue perfusion

- Perfusion is capillary level blood flow
- Exchange
  - Blood <=> tissue
- Reflects metabolism
- Stroke detection

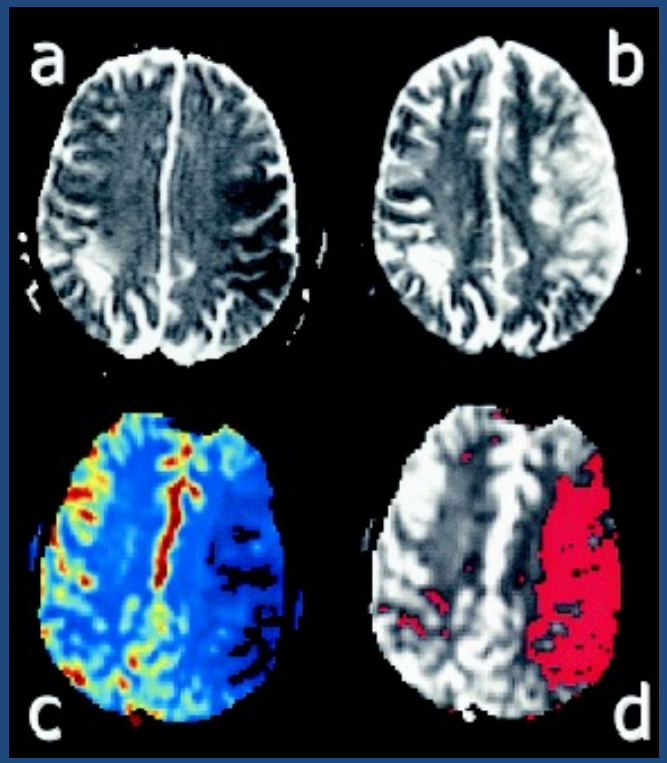


Microscopic flow

- Tissue perfusion
  - Hypoperfusion in stroke
- Predict tissue fate
  - Death
  - At-risk
  - Uninjured

ADC map (at 2 hours)

T_2-w at 7 days



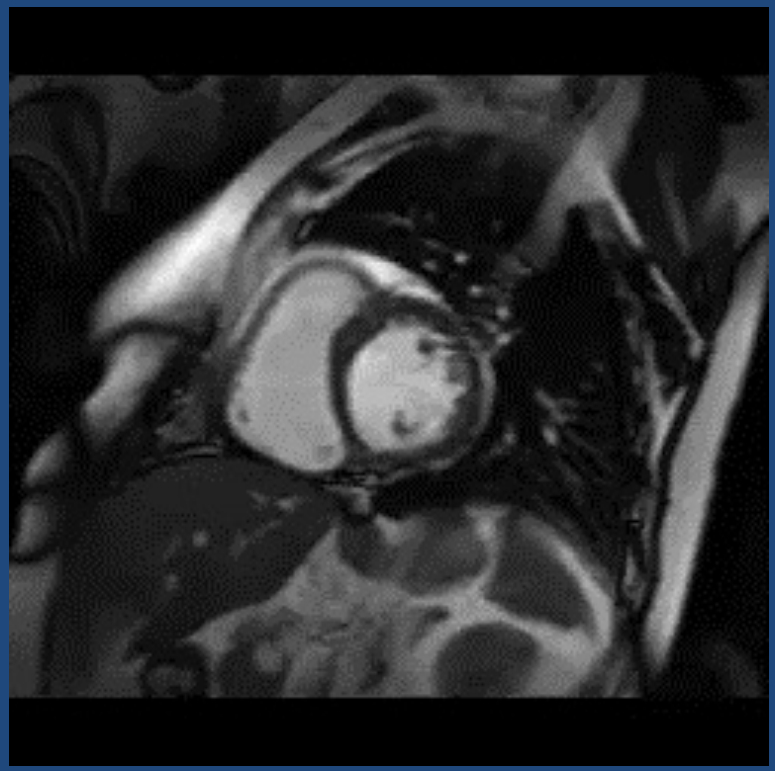
Perfusion map (at 2 hours)

Thresholded perfusion

Fiehler et al, Stroke, 2002

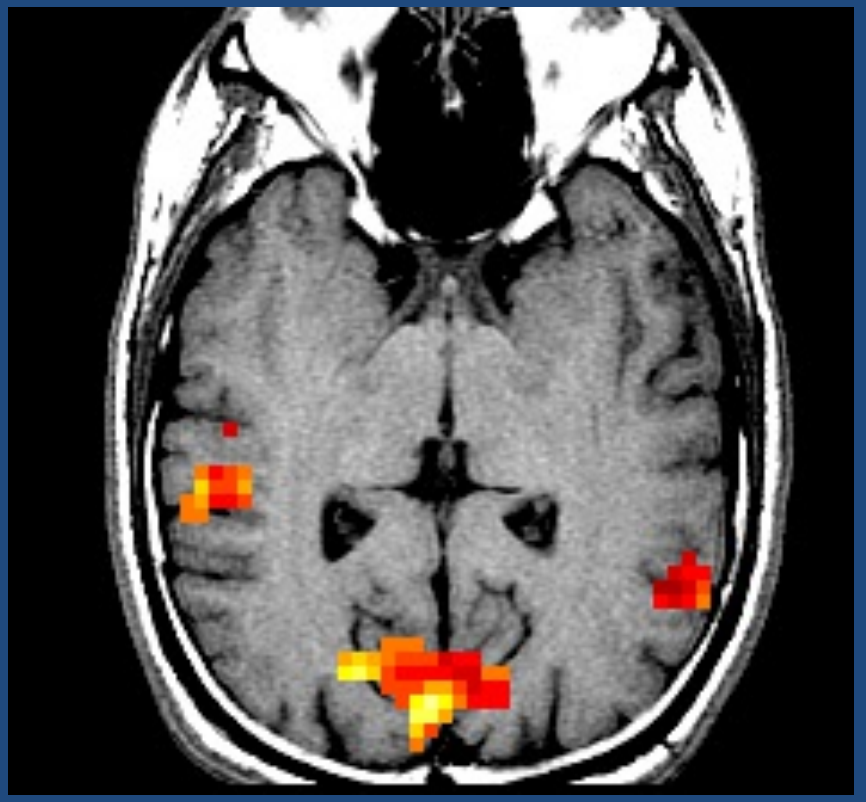
Cardiac function

- Evaluate
  - Blood volume
  - Blood motion
  - Cardiac wall contraction
- Identify site and extent of injuries



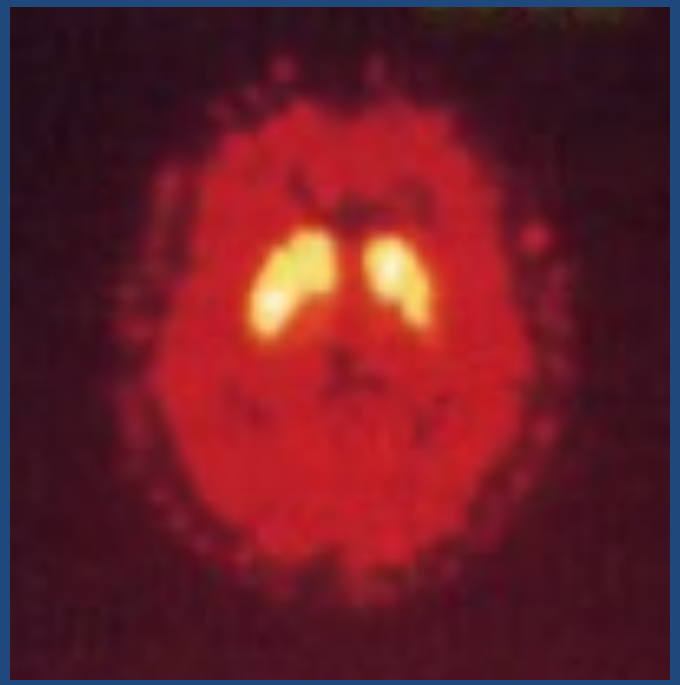
Metabolic imaging

- Mapping blood oxygenation
  - Functional MRI
- Mapping glucose usage
  - Radionuclide PET imaging



Molecular imaging

- Receptor mapping
  - Neurotransmitter receptors
- Targeted contrast agents
  - Cancer screening
  - Cancer therapy



Goals of the course

- Understand how biomedical imaging is being used in medicine and biomedical research
- Have practical skills in image analysis
- Have sufficient knowledge to
  - Work in an imaging lab
  - Use imaging in your research
  - Develop your own new ideas

QFI course assignments

- Analysis projects (65%)
- Problem sets/in-class exercises (10%)
- Final exam (25%)

Suggested Reading

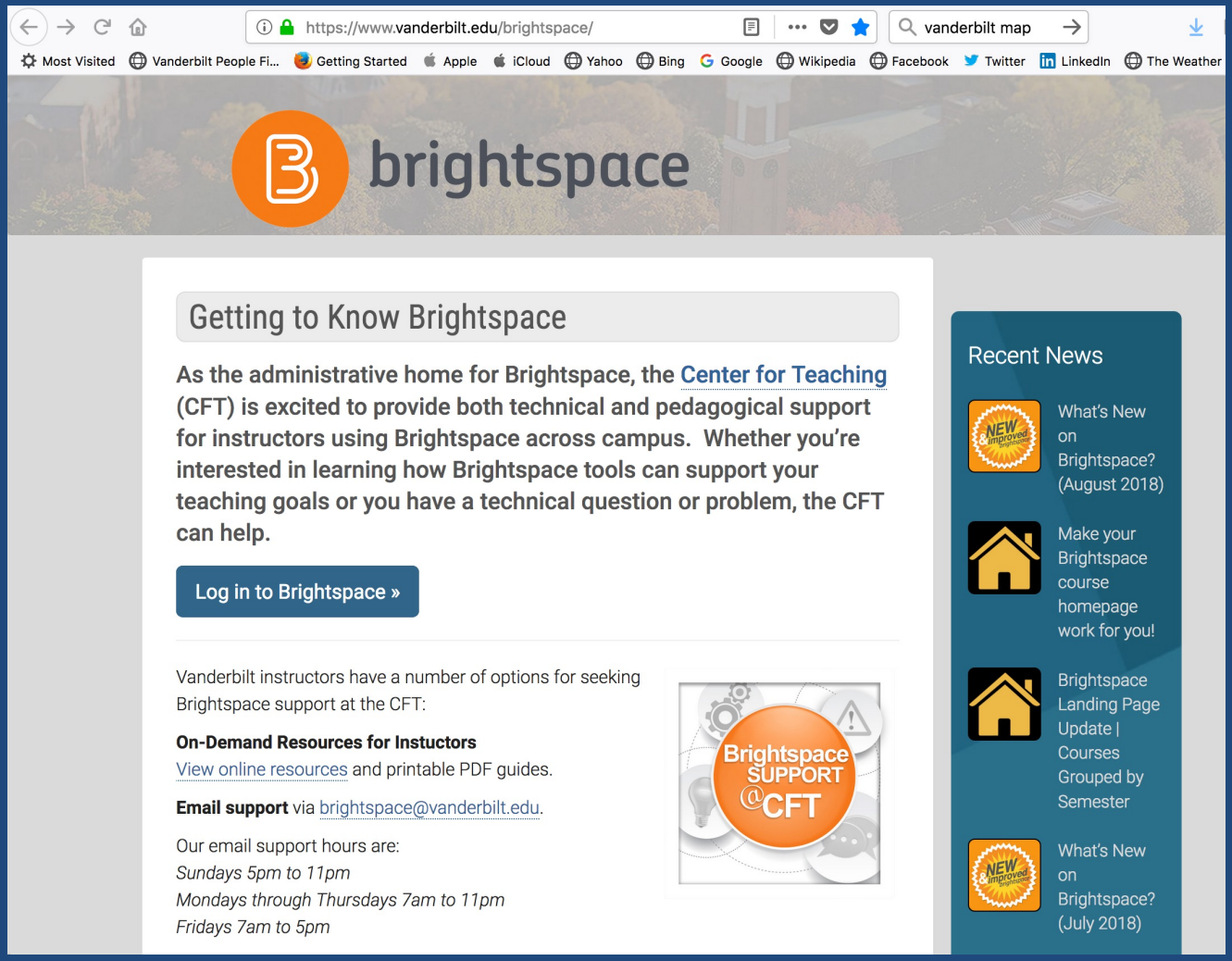
- Lecture notes posted on Brightspace
- No single textbook covers what we need
  - *Fundamentals of Medical Imaging* by Suetens (Cambridge, 2017)
  - *Functional Magnetic Resonance Imaging* by Huettel, Song, and McCarthy (Sinauer Associates, 2004)
  - *Emission Tomography: The Fundamentals of PET and SPECT* by Wernick and Aarsvold (Elsevier, 2004)
- Individual book chapters and articles

Contact information

- Offices
  - Institute of Imaging Science (VUIIS)

    Medical Center North AAA3108
    (vuiis.vanderbilt.edu/contact.html) 322-8353
- Office hours on Zoom
  - Wednesday: 1:00-2:00pm or by arrangement

Course material is on Brightspace
https://brightspace.vanderbilt.edu



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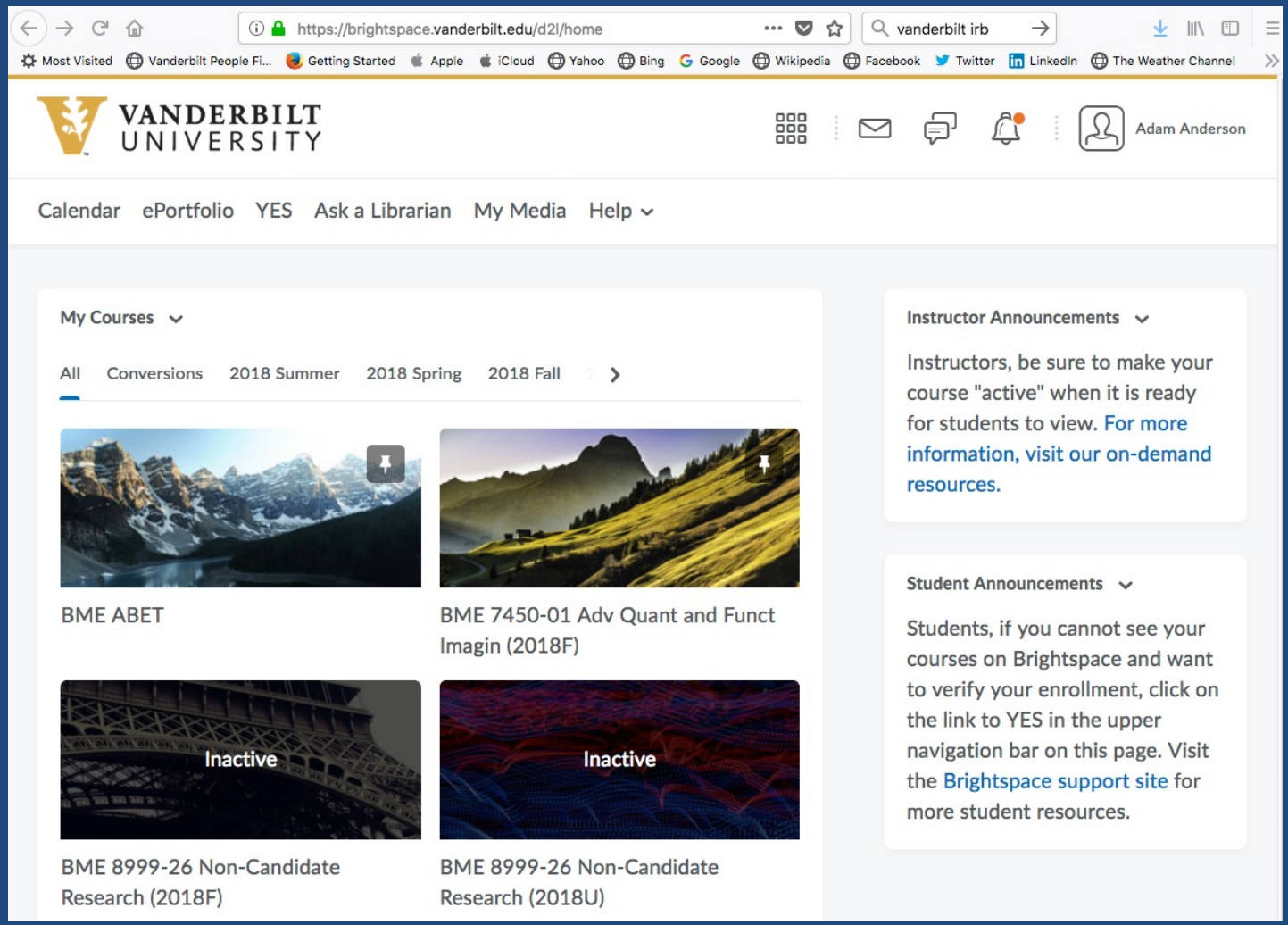

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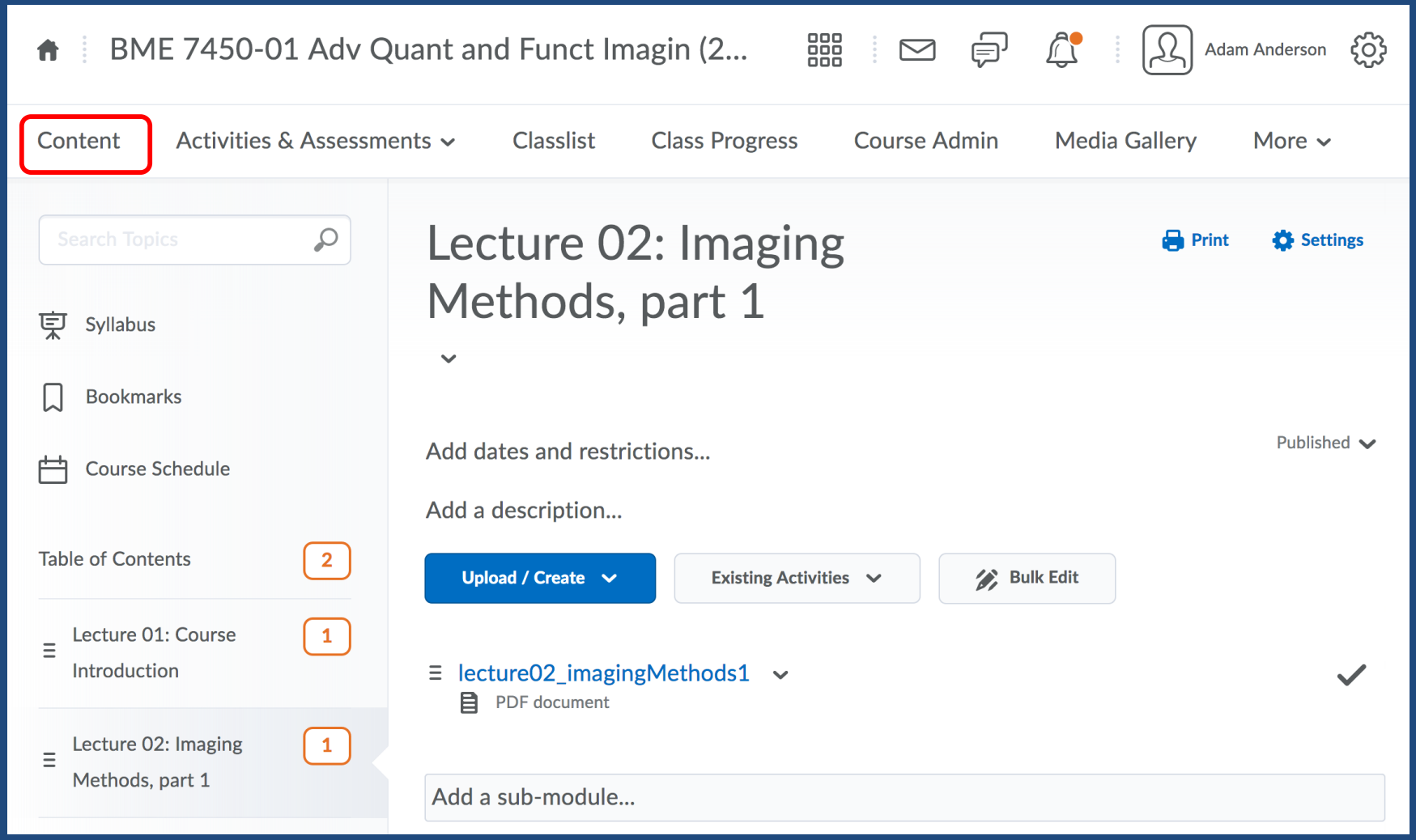

References

- B.H. Kevles, Naked to the Bone: Medical Imaging in the Twentieth Century (Addison-Wesley, 1997).
- A.B. Wolbarst, Looking Within: How X-Ray, CT, MRI, Ultrasound, and other Medical Images Are Created, and How They Help Physicians Save Lives (Univ. California Press, 1999).