C.S. Peirce and the Philosophy of Medical Imaging

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Introduction

Prostate Cancer

- a leading cause of cancer-related death in men
- technology and techniques advancing rapidly
- challenges of communication between physicians, radiologists, surgeons, technicians, and patients
- Peirce's philosophy illuminates the interpretation of images and the process of diagnosis

Status Quo: Naive Realism

- status quo is unreflective naive realism
  - prostate cancer is a single unchanging thing
  - images mirror reality
  - diagnosis is deduction from image to the thing itself
- ignores and obscures the work done to reconcile conflicting information and changing knowledge

A Pragmaticist Approach

- Peirce's philosophy is a fruitful alternative
  - prostate cancer understood in terms possible experiments and habits of mind
  - diagnosis involves deduction, induction, and abduction
  - medical imaging as a semiotic process
- practical tools for better communication
- feedback between theory and practise

Prostate Cancer

Past

- prostate first described 1536, first depicted 1538
- prostate cancer histology 1853
- first prostatectomy 1904
- hormone treatments won Nobel Prizes in 1966 and 1977
- modern therapies started mid-20th century
    - radium implants
    - brachytherapy
    - external beam therapy
    - chemotherapy

Present

- prostate-specific antigen (PSA) measurements
- ultrasound guided biopsy
- radiotherapy
- radical retropubic prostatectomy
- emphasis on sparing nerves and healthy tissue for better quality of life
- smaller tumours detected earlier
- treatment can be postponed in favour of surveillance

Future

- trend toward focal therapy
  - cryotherapy
  - high-frequency ultrasound
  - requires millimetre accuracy
- wider range of imaging options
- other treatments targeting only cancer cells

Continuing Change

"if one can define accurately all of the conceivable experimental phenomena which the affirmation or denial of a concept could imply, one will have therein a complete definition of the concept, and *there is absolutely nothing more in it*" ('What Pragmatism Is' 5.414)

prostate cancer has changed dramatically, and continues to change

Case Study: Multi-Modal Medical Imaging

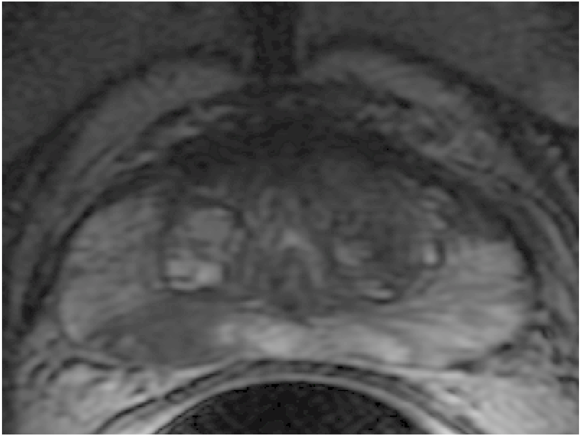
Image-Guided Prostate Cancer Management

- CIHR Team for Image-Guided Prostate Cancer Management (IGPC)
  - a series of projects to advance prostate cancer treatment
  - funded by Canadian Institutes of Health Research
  - compares ultrasound, MRI, and pathology
  - wide range of techniques, including machine vision
- comparison is difficult
  - the prostate is not rigid
  - imaging, surgery, and pathology change its shape
  - changes in shape are difficult to reconcile across images

Magnetic Resonance Imaging (MRI)

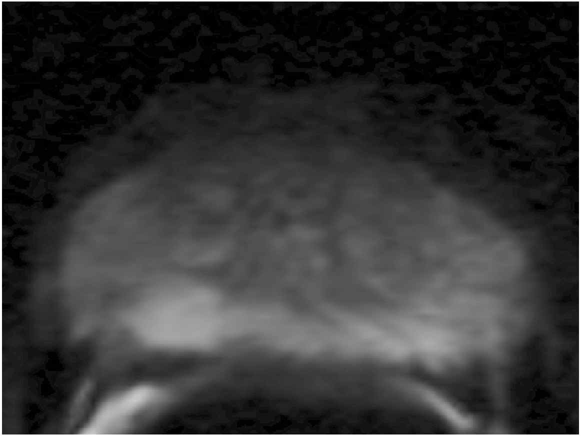
- powerful magnet aligns the spins of hydrogen nuclei (protons)
- a radio pulse flips the spins
- protons "relax" to the previous alignment and emit radio signals
- signals are reconstructed into 2D or 3D images
- differences in relaxation distinguish tissues and structures
- different MRI "sequences" for different uses

T2 Weighted MRI



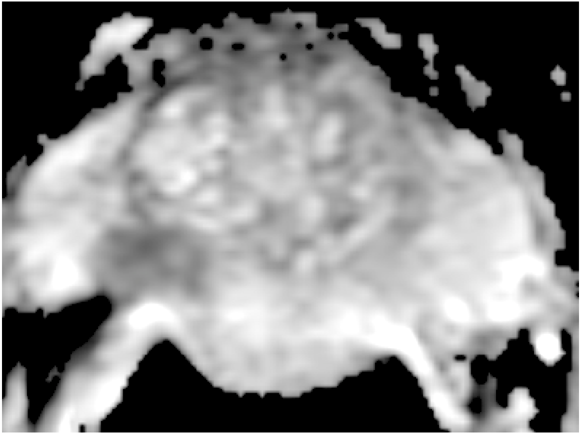
- primarily distinguishes fat from water
- peripheral zone tumours expected to be hypointense (i.e. darker)

Diffusion Weighted MRI



- measures diffusion of water in tissues
- tumours have higher cell density and are expected to be hyperintense (i.e. brighter)

Apparent Diffusion Coefficient (ADC) MRI

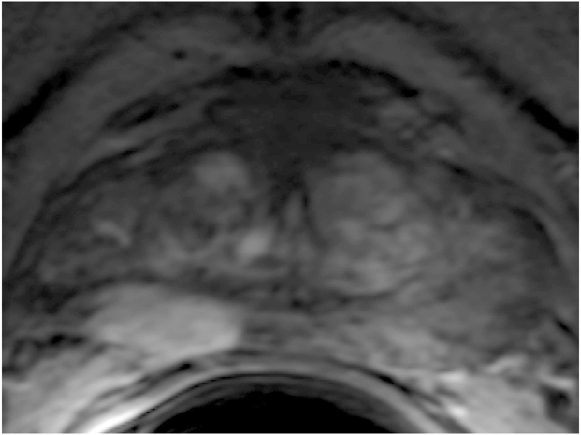


- composite of several diffusion measurements
- tumours expected to be hypointense (i.e. darker)

Contrast MRI

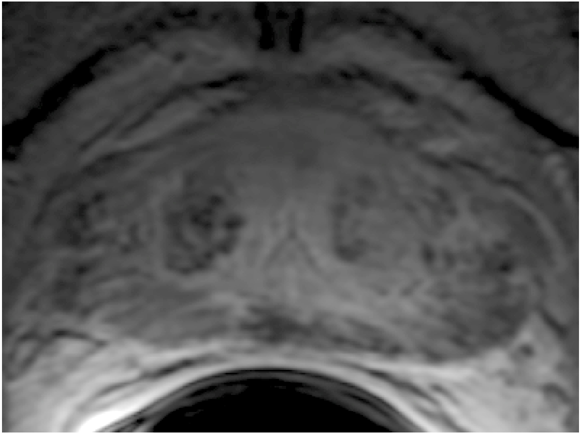
- inject a contrast agent, such as gadolinium, into an artery
- gadolinium-rich blood appears as hyperintense (i.e. brighter)
- images captured in intervals of several seconds over three minutes
- tumours expected to be hypervascular (i.e. more blood vessels)

Early Phase Contrast MRI



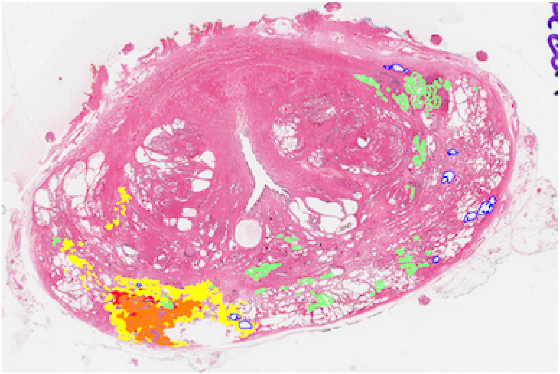
- tumours should show “wash in” (i.e. become brighter) as they take up blood earlier than surrounding tissue

Late Phase Contrast MRI



- tumours should show “wash out” (i.e. become darker) as they push out blood earlier than surrounding tissue

Annotated Whole Mount Pathology



- whole prostate is removed
- treated, stained, fixed in a block of wax, sliced into thin sections, photographed, analyzed
- cancerous cells are distinguished and annotated

Discussion: The Logic of Medical Imaging

Ideal vs. Usual

- these figures are from an ideal case, where signs align
- status quo is to think of diagnosis as deduction from signs to disease
- but signs are usually incomplete or contradictory

Induction

- radiologists have years of training and experience
- from this they induce complex and subtle rules, building habits of mind
- novel cases require new habits

Abduction

- radiologists have to ask "what if?" questions, e.g.:
  - lesion is hypovascular in T2 but not seen in diffusion
  - what if this is tumour that is not hypervascular?
  - deduction: less wash-in and wash-out with contrast
  - induction: use contrast imaging
- reason from a result and a case to a new or modified rule
- the tumour might be different from the ideal
- change habits of mind, require new experiments

Clinician and Community

- clinicians use deduction, induction, and abduction to make diagnoses
- the wider community develops better technologies and techniques
- IGPC as an example:
  - abduction: what if MRI can detect prostate cancer better than ultrasound?
  - deduction: MRI should detect more prostate cancer than ultrasound when both are compared to pathology
  - induction: multi-modal imaging experiments to test the deduction

Praxiography

- Annemarie Mol, *The Body Multiple*
- case study of atherosclerosis (i.e. hardening of the arteries) in the legs
- observed patients, doctors, nurses, technicians, etc.
- points out the diversity of “enactments” by which the disease is experienced
- distribution and coordination of enactments illuminates the work done to bring these experiences together

Semiosis

- medical images and reports are clearly systems of signs
  - diagrammatic reasoning
  - perception and perceptual judgement
  - biosemiotics?
- what can Peirce teach us about this aspect of medical imaging?
- topic of ongoing research ...

Tools for Clear Communication

Theory and Practise

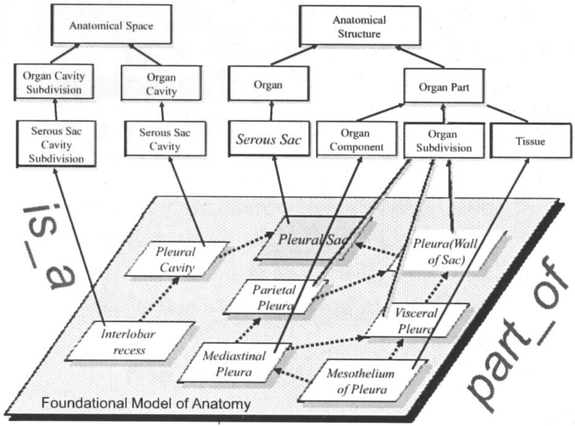
- virtuous cycle
  - we apply our theoretical understanding to practical applications
  - complexities of practical application drive our theoretical research
- good theory and tools support better abductions, better diagnoses
- practical applications:
  - biomedical ontologies
  - structured reporting

Biomedical Ontologies

Biomedical Ontologies: Terms

- “an ontology” as a carefully constructed system of terminology for a domain
  - Gene Ontology
  - Protein Ontology
  - Foundational Model of Anatomy
  - Common Anatomical Reference Ontology
  - Infectious Disease Ontology
  - Ontology for Biomedical Investigations
  - many more . . .
- terms have globally unique identifiers
  - example: FMA:9600 “prostate”
    - http://purl.obolibrary.org/obo/FMA_9600
- terms have textual and logical (formal, computable) definitions
- widely used in biomedical informatics

Biomedical Ontologies: Relations and Reasoning



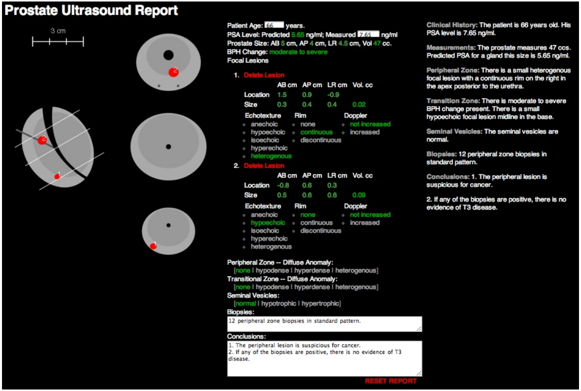
- well-defined logical relations form a network
- examples: "is a" (subtype), "part of"
- computers can follow links to draw inferences

Structured Reporting

Unstructured Reporting: Status Quo

- radiologists use “narrative reports”
  - idiosyncratic terminology and organization
  - very hard to search and analyze
- pathologists tend to use long forms
- we have developed a prototype software tool for structured reporting in prostate cancer

Structured Reporting: Prototype



- diagram, form, and textual report
  - easy to translate into other languages
  - data is easy to search and analyze
- we strive to balance consistency with flexibility

Conclusions

Conclusions

- Peirce's philosophy is a fruitful alternative to status quo
  - deduction, induction, abduction
  - individual and community reasoning
  - ongoing work on semiosis and perception
- constructive feedback between
  - theory and practise
  - philosophy and medicine
- applications to
  - biomedical ontologies
  - structured reporting