Bioimage Informatics

Lecture 22, Spring 2012

Empirical Performance Evaluation of Bioimage Informatics Algorithms

Image Database; Content Based Image Retrieval

Emerging Applications: Molecular Imaging

Outline

- Empirical performance evaluation of bioimage Informatics algorithm

- Image database; content-based image retrieval

- Introduction to molecular imaging

- Empirical performance evaluation of bioimage Informatics algorithm

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- Introduction to molecular imaging

Overview of Algorithm Evaluation (I)

- Two sets of data are required
  - Input data
  - Corresponding correct output (ground truth)

- Sources of input data
  - Actual/experimental data, often from experiments
  - Synthetic data, often from computer simulation

- Actual/experimental data
  - Essential for performance evaluation
  - May be costly to acquire
  - May not be representative
  - Ground truth often is unknown

Overview of Algorithm Evaluation (II)

- What exactly is ground truth?

  Ground truth is a term used in cartography, meteorology, analysis of aerial photographs, satellite imagery and a range of other remote sensing techniques in which data are gathered at a distance. Ground truth refers to information that is collected "on location." - http://en.wikipedia.org/wiki/Ground_truth

- Synthetic (simulated) data

  Advantages

  - Ground truth is known
  - Usually low-cost

  Disadvantages

  - Difficult to fully represent the original data

Overview of Algorithm Evaluation (III)

- Simulated data

  Advantages

  - Ground truth is known
  - Usually low-cost

  Disadvantages

  - Difficult to fully represent the original data

- Realistic synthetic data

  - To use as much information from real experimental data as possible

- Quality control of manual analysis

Test Protocol Development (I)

- Implementation
  - Source codes are not always available and often are on different platforms.

- Parameter setting
  - This is one of the most challenging issues.
  - A solution is to provide the dataset and ask for researchers to provide results.

- Quantification of performance (e.g. success rate)

Table I
Different Types of Output of a Simple Event Test

Classification	Definition
True positive (TP, true acceptance, true match)	A positive event is correctly identified as positive
True negative (TN, true rejection, true nonmatch)	A negative event is correctly identified as negative
False negative (FN, false rejection, false nonmatch, type I error)	A positive event is incorrectly identified as negative
False positive (FP, false acceptance, false match, type II error)	A negative event is incorrectly identified as positive

Test Protocol Development (II)

- There are several evaluation strategies

1) Common dataset with known ground truth

2) Subjective expert rating

3) Performance evaluation based on consensus

Heimann et al, Comparison and evaluation of methods for liver segmentation from CT datasets, *IEEE Trans. Med. Imaging*, vol. 28, pp. 1251-1265, 2009.

Test Administration

- Comparison of algorithms

  M. Heath, S. Sarkar, T. Sanocki, and K.W. Bowyer, "A Robust Visual Method for Assessing the Relative Performance of Edge-Detection Algorithms" *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 19, No. 12, pp. 1338-1359, 1997.

  Barron, J.L., Fleet, D.J., and Beauchemin, S. Performance of optical flow techniques. *International Journal of Computer Vision*, 12(1):43-77, 1994.

- Large-scale open evaluation of algorithms is often preferred but costly.

Case Study: Evaluation of Edge Detection Algorithms

- A comparison of five algorithms with code available.
- A set of images was collected. 28 images were chosen for the test.
- Results reviewed by 16 volunteers on the same day.
- Consistency among reviewers is controlled for quality.
- Overall, this is a representative expert review based approach.

Examples of Open Benchmarking Datasets

- Berkeley segmentation dataset and benchmark

  "A Database of Human Segmented Natural Images and its Application to Evaluating Segmentation Algorithms and Measuring Ecological Statistics" D. Martin, C. Fowlkes, D. Tal, J. Malik, ICCV2001.

  http://www.eecs.berkeley.edu/Research/Projects/CS/vision/bsds/

- Retrospective image registration project

  "Comparison and evaluation of retrospective intermodality image brain image registration techniques", Journal of Computer Assisted Tomography, J. West et al, vol.21, pp. 554-566, 1997

  http://www.insight-journal.org/rire/

Evaluation of Algorithm Efficiency

- Two complementary approaches

  - Theoretical analysis of computational complexity
  - Empirical evaluation of efficiency

Table II
Commonly Used Time Complexity Terms

If running time of an algorithm is proportional to	Its time complexity is called	Increase in running time when N is increased by 10
1	Constant	0
$\log N$	Logarithmic	2.303
N	Linear	10
$N \log N$	$N \log N$ or linearithmic	23.03
$N^3, N^3, \ldots$	Polynomial	100, 1000, ...
2^N	Exponential	1024

J. F. Dorn, G. Danuser, G. Yang, Chapter 22 Computational processing and analysis of dynamic fluorescence image data, in Methods in Cell Biology, vol. 85, pp. 497-538.

References on Performance Evaluation

[1] K. Bowyer, P. J. Phillips, Empirical evaluation techniques in computer vision, IEEE Press, 1998.

[2] H. I. Christensen, P. J. Phillips, Empirical evaluation techniques in computer vision, World Scientific, 2002.

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Requirements of Bioimage Data Management (I)

- Biological studies routinely generate large volumes of image data.
  - Images are often the most important experiment data.
  - Requirements: storage/backup; data management.
  - Use of image databases is often critical, especially for large imaging centers.

- High dimensions: 3D + time + multiple colors
  - Requirements: data retrieval; visualization

- A wide variety of proprietary image formats and imaging setting metadata.
  - Requirements: compatibility; flexibility; standardization

Requirements of Bioimage Data Management (II)

- For large scale projects and for data sharing, web-based distributed data access and analysis are required.

- Bioimage analysis often generates large volumes of intermediate results.
  - Storage and organization
  - Version control to track progress and to avoid conflicts

- To summarize, main requirements
  - Effective, reliable, user-friendly image data management, especially retrieval control
  - Integration and control of image analysis ← difficult

Overview of Image Database (I)

- Image databases are essential to a wide range of applications.
  - Digital library
  - Multimedia repository
  - Medical imaging
  - Security and surveillance

- Image database research has a long history.
  - Started since the 1970s
  - Two communities involved: database management + computer vision
  - A recent trend is the development of multimedia databases.

Overview of Image Database (II)

- Two classes of image retrieval techniques

  - Text-based image retrieval (metadata based image retrieval)
    $\rightarrow$ Based on image name/title, annotation

  - Content-based image retrieval $\rightarrow$ Based on image features extracted using computer-vision techniques

- Actual systems often use both techniques and require user interaction.

Text-Based Image Retrieval

- This solution comes mainly from the database management community.
- Text-based image retrieval is common.
- Image annotation can be a laborious and costly process.
- It would not be feasible to capture all the image information by text.
  - The information of interest is often application-specific.

Content-Based Image Retrieval

- This solution comes from the computer vision community.
- Detection of image features is required.
- Commonly used features
  - Color
  - Texture
  - Shape

	Feature	ADL	AltaVista	Amore	ASSERT	BDLP	Blobworld	CANDID	C-bird	CBVQ	Chabot	CHROMA	Circus	Compass	Diogenes	DrawSearch	Excalibur	FIDS	FIR	FOCUS	FRIP	ImageFinder	ImageMiner	ImageRETRO	ImageRover	ImageScape	iPURE	Jacob
	Keywords	*		*		*					*				*										*			
	Face Detection														*											*		
	Layout				*		*		*			*						*		*	*		*		*	*	*	
Shape	No details available		*														*											
Shape	Other								*												*			*				
Shape	Elementary descriptors				*		*		*	*										*	*		*			*	*	
Shape	Bounding box/ellipse																						*				*	
Shape	Curvature scale space																											
Shape	Elastic models																											
Shape	Fourier descriptors															*										*	*	
Shape	Template matching			*																								
Shape	Edge direction histogram																											
Texture	No details available		*														*					*						
Texture	Other																											
Texture	Edge statistics				*				*					*				*							*			*
Texture	Local binary patterns																	*								*		
Texture	Random field decomposition															*											*	
Texture	Atomic texture features				*		*	*					*								*		*		*	*		*
Texture	Wavelet, Gabor, Fourier	*								*								*	*									
Color	No details available		*														*					*						
Color	Other					*			*															*		*		
Color	Dominant colors			*				*	*			*											*			*		
Color	Region histogram				*		*																					
Color	Color coherence vector																											
Color	Color moments				*											*					*			*			*	
Color	Correlation histogram													*														
Color	Global/subimage histogram								*	*	*		*	*				*		*				*	*			*
Color	Eigen image																											
	Reference	[90]	[2]	[58]	[71]	[13]	[14]	[38]	[46]	[75]	[61]	[43]	[66]	[11]	[92]	[69]	[22]	[8]	[88]	[20]	[39]	[35]	[41]	[86]	[70]	[44]	[1]	[15]

Veltkamp, R.C. & Tanase, M. (2002). A Survey of Content-Based Image Retrieval Systems. In O. Marques & B. Furht (Eds.), *Content-based image and video retrieval,* pp. 47-101. Kluwer.

Demo (I): QBIC

- QBIC: query by image content
  http://wwwqbic.almaden.ibm.com/
- The first commercial content-based image retrieval system.
- Features supported
  -Color, shape, texture

Demo (II): Contemporary Engines

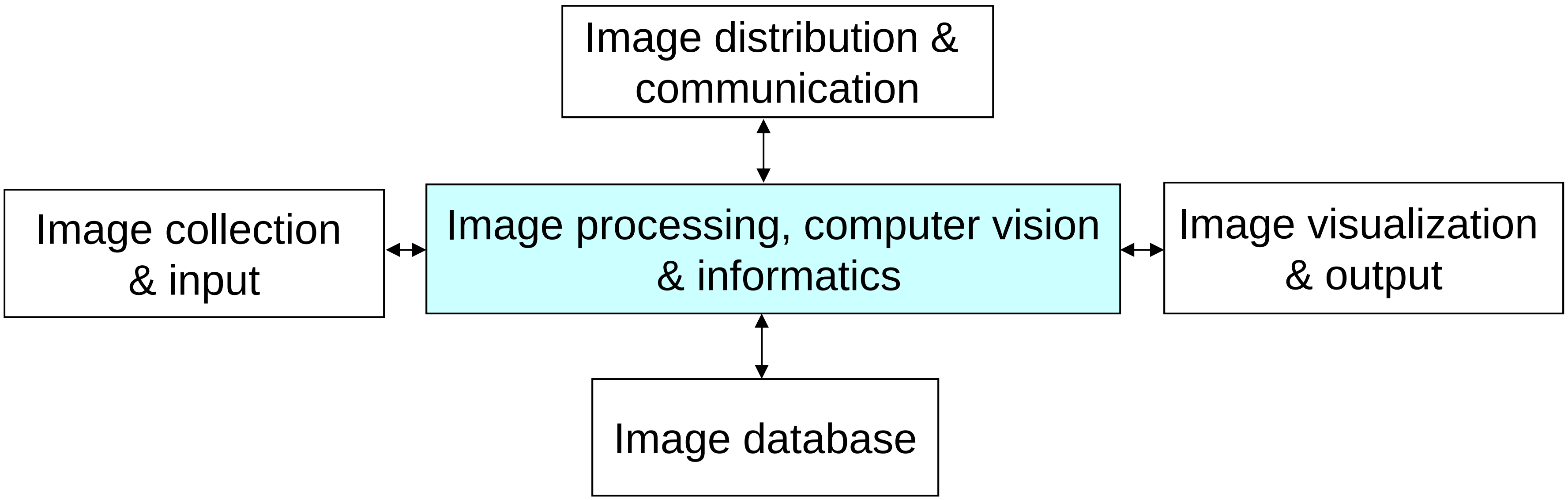
- Google image search engine
  - http://images.google.com
- Research engine example I: INRIA CBIR
  - http://www-roc.inria.fr/cgi-bin/imedia/circario.cgi/demos
- Research engine example II: CIRES
  - http://amazon.ece.utexas.edu/~qasim/cires.htm

Current Status of CBIR

- Multiple commercial systems are available.
- Performance of truly content-based retrieval is not yet satisfactory.
- Performance of computer vision is a major constraint.

Concept of Bioimage Information Systems

- Few commercial systems are available.
- Bioimage databases are part of a bioimage information system.



Adapted from S.K. Chang & A. Hsu, Image information systems, *IEEE Tran. Knowledge & Data Engineering*, vol.4, pp. 431-442, 1992.

Current Status of Bioimage Database (II)

- Examples of academic database tool systems
  - BISQUE http://www.bioimage.ucsb.edu/bisque
  - OME http://www.openmicroscopy.org/site
- Examples of bioimage databases
  - Human protein atlas http://www.proteinatlas.org/
  - Allen brain atlas http://www.brain-map.org/

References on General Image Databases

[1] H. Tamura & N. Yokoya, Image database systems: a survey, *Pattern Recognition*, vol. 17, no.1, pp. 29-43, 1984.

[2] Y. Rui, T. S. Huang, S. F. Chang, Image retrieval: current techniques, promising directions, and open issues, *J. Visual Communication and Image Representation*, vol. 10, pp. 39-62, 1999.

[3] R. C. Veltkamp & M. Tanase, A Survey of Content-Based Image Retrieval Systems. In O. Marques & B. Furht (Eds.), *Content-based image and video retrieval,* pp. 47-101, Kluwer Academic Publishers, 2002.

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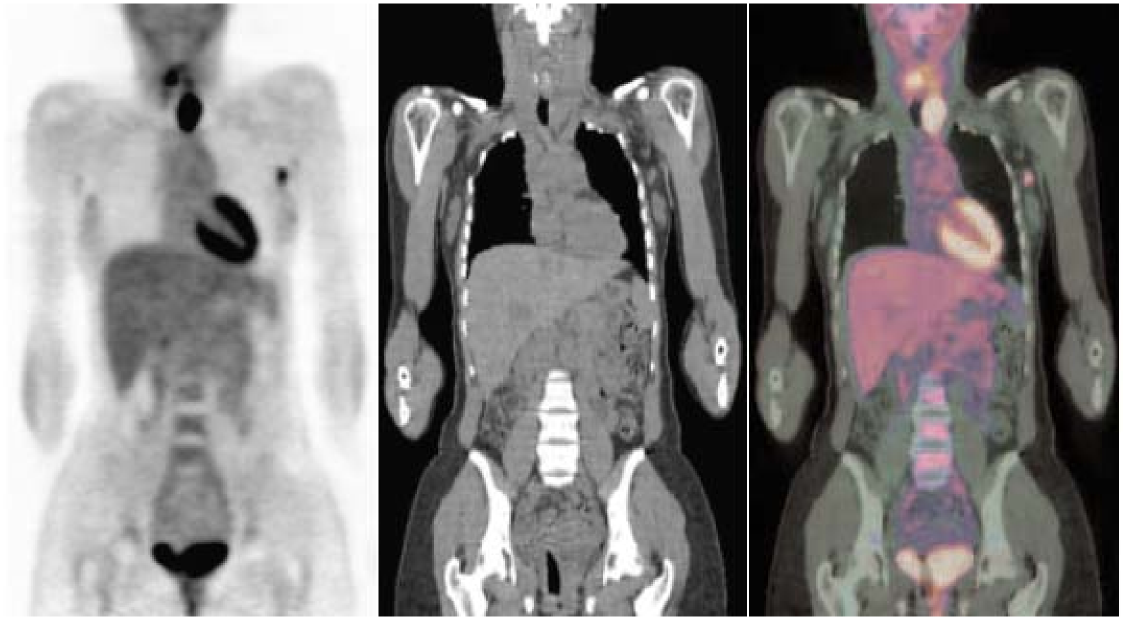
Molecular Imaging: an Example



http://www.medical.siemens.com/siemens/zh_TW/rg_marcom_FBAs/files/brochures/Jan_Grimm_Molecular_Imaging.pdf

- Human or animal models; Imaging with molecular specificity.
- Molecular imaging is a convergence of medical imaging and biological imaging, especially in developing and applying specific molecular probes.
- Molecular imaging focuses on disease applications.

Overview of Molecular Imaging (I)

- Molecular imaging is considered as a new development of radiology. It aims to visualize processes of interest at the cellular and molecular level within living subjects, especially humans.

- Traditionally, medical imaging mainly focuses on morphological, anatomical, and/or physiological changes.

- But it is often too late when these changes become detectable.

- The main driving force of molecular imaging is the radiology community.
    - Early detection
    - Direct monitoring of disease progression
    - Direct monitoring of treatment outcomes

Overview of Molecular Imaging (II)

- Definition 1: Molecular imaging is the in-vivo characterization and measurement of biological processes at the cellular and molecular level.

R. Weissleder & U. Mahmood, Molecular imaging, *Radiology*, 219:316-333, 2001.

- Definition 2: Molecular imaging techniques directly or indirectly monitor and record the spatiotemporal distribution of molecular or cellular processes for biochemical, biological, diagnostic, or therapeutic applications.

ML Thakur, BC Lentle, SNM; Radiological Society of North America (RSNA). Joint SNM/RSNA Molecular Imaging Summit Statement. *J. Nucl. Med* 46:11N–13N, 2005.

Overview of Molecular Imaging (III)

- Basic elements of molecular imaging

  - Molecular probes: high-sensitivity, high-specificity.

  - Signal amplification strategy.

    1) DNA→ mRNA → Protein

    2) By accumulation

  - Signal collection strategy→ modality selection.

Overview of Molecular Imaging (IV)

- Molecular imaging modalities
  - PET, SPECT, CT, MRI, Ultrasound, Optical Imaging
  - These modalities are used in combination with specific molecular tracers.
- Applications
  - Cancer
  - Cardiovascular diseases
  - Neurological disease
- Research in molecular imaging became well publicized in the late 1990s.
- Most of the molecular imaging programs in the US are established after 2005. H. J. Otero et al, Molecular imaging programs in the US, *Academic Radiology*, vol. 14, pp. 125-131, 2007.

Questions?