Semantic Tagging and its Applications

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Articles added to PubMed, 1990-2010
Articles on p53, 1990-2010
Articles on erlotinib (Tarceva), 1990-2010
Consequences of information growth in medicine

- New information rate constant-linear with time
- Rate of accrual, even on specialized topics, greatly exceeds practitioner capacity
- Exacerbated by drive to increase productivity
- Productivity, not optimality of care, determines reimbursement
- 5000-15000 cross sectional images per day typical load

**New information sources/practices must come with a zero or negative time cost to be acceptable to practitioners**
CT scans

- Measures electron density
- One person = 50-100M cubic millimeters = approximate size of a CT dataset
- On basis of density alone can distinguish air, fat, soft tissue, calcification/bone, and foreign bodies – rest must be understood by reference to human anatomy
- HMC (400 beds): applicable to 120 CT scans per day
Human variability in 2D

Age
Gender
Color of hair, skin, etc.
Lighting
Foreign bodies
Human variability in 3D CT scans

- Age
- Amount of fat vs. muscle
- Variability in size/shape/position/pose of organs
- Gender

- Administration of intravenous/oral contrast

- Effects of disease: organ enlargement/shrinkage/texture change/treatment effects/skeletal deformity
Three women – axial sections at the carina/iliac crests
Human variability: the movie

Regression Forests for Efficient Anatomy Detection and Localization in CT Studies

A. Criminisi, J. Shotton, D. Robertson and E. Konukoglu
Microsoft Research Ltd, CB3 0FB, Cambridge, UK

In Medical Computer Vision: Recognition Techniques and Applications in Medical Imaging workshop @ MICCAI, Beijing, 2010

http://research.microsoft.com/projects/medicalimageanalysis/
Semantic tagging is organ labeling

- What voxels are in the (left kidney, liver, femur, T9 vertebra, ...)?
- Historically, the focus was on delineating boundaries, first manually (Live Wire) and then semiautomatically, using texture, intensity, shape, edge models but with initialization left to the user.
- Over the past 2-3 years, researchers have turned their attention to eliminating the manual initialization steps, allowing complete automation of the organ labelling process. **Rough localization** is a recognition or image understanding problem.
- Visual feedback is still required.
Rough localization – state of the art

- Liver – Casiraghi et al. IEEE CBMS 2008
- Esophagus – Feulner et al (SCR/MSR) MICCAI 2010 – machine learning
- Heart, great vessels – Ecabert et al. (Philips) Med IA, 2011 model based, machine learning
- Prostate/rectum – Chen et al. (RPI) Med IA, 2011 locate pelvic bones, use model
Rough localization – Criminisi, Kunokoglu

- Goal – localize a bounding box for each organ, using only manually defined training set (so potential to work generally)
- No normalization performed
- Compute many image features at multiple scales at each voxel
- Train multiple regression trees to predict the offset of an organ bounding box from the current voxel using randomized feature sets
- Ensemble prediction using highest-confidence voxels
- Mean error 1-2 cm – runs in seconds
- Generalization to spine – incorporate Markov process
From rough localization to semantic tagging

- Focus of most segmentation studies over past decade
- Combination of characteristic intensities, shape/appearance models, boundary detectors, level sets methods works well — estimate of bounding box highly informative
Clinical requirements for semantic tagging

- Zero user time
- Display results for quick sanity check
- Feedback/correction
Four applications of semantic tagging

- Semantic tagging turns the image “blob” into a parseable data container with uniquely informative components, much like NLP does with free text
- A deformable atlas of human anatomy
- Detecting changes over time, cross-modality registration
- Osteoporosis and fracture risk
- Quantitative metrics of size, structure, texture: lung, heart, kidney volumes, coronary artery calcification, ...
A deformable atlas of human anatomy

- Semantic tagging, followed by “pretty good” organ segmentation, can give local affine maps between portions of an image set and corresponding portions of an atlas.
- These affine maps can be stitched together to form a globally continuous map from image to atlas, so that each point in the image set corresponds to a known point in the atlas.
- Annotated images from the atlas can now be used to automatically annotate the patient’s images.
- Precision of the registration need not be perfect.
What nerves have been injured in these patients?

Two patients with leg weakness: 9 yo girl with history of hernia repair; 49 yo woman with history of ovarian cancer.

Questions: (a) where are we; (b) what muscles are affected; (c) which nerve innervates them all?
CT and atlas images

CT through upper right thigh

Atlas image (www.imaios.com)

CT and atlas images -- note differences in amount of fat. With semantic tagging, a click on the left image could show the corresponding point on the right image.
Registration and semantic tagging

- Both intramodality (across time) and intermodality registration algorithms within the same patient are highly developed and successful in most cases.
- Image comparison is often a much more tedious and error-prone task than diagnosis.
- Manual initialization is often required, breaking the zero cost rule.
- Rough localization could replace the manual initialization step, facilitating comparison of images over time.
57 yo woman with multiple sclerosis

Left: 2011, image 403/28  
Right: 2007, image 5/12

There is appearance of new lesions (red arrow) and subtle interval volume loss (blue arrows).
Rough initialization can facilitate image comparison

- Because the initialization is done algorithmically, registration can be performed before the images are viewed.
- Linked cursor or image warping can be used to facilitate visual comparison
- Subtraction of appropriately normalized images can highlight areas of (possible) change
Osteoporosis – decreased bone mass

- 1.5M vertebral fractures per year (US), 180K NHP, $18B
- Immobility, pain, mortality
- Preventable (diet, exercise, quit smoking)
- Treatable (medication, fall prevention, etc.)
- Underdiagnosed
- DXA screening has low compliance rate
- Frequently missed by radiologist on CT
Osteoporotic fracture in a 66 yo woman

Density at time of fx:

T12 = 105
L4 = 81

Density 5 months later:

T12 = 109
L4 = 54
Osteoporosis and semantic tagging

- Identify patients with low bone density for additional evaluation -- density by vertebra, thickness of cortical bone, aggregate indices, ...
- Understand results of treatment (mobilization vs. rest, medication, etc.)
- ST makes screening possible at essentially no additional cost to the healthcare system
Quantitative metrics: density/texture

- Liver – fatty liver; cirrhosis
- Bone – osteoporosis
- Lens – cataracts
- Lung – COPD
- Blood vessels – atherosclerotic calcifications
- (MRI applications)
Quantitative metrics: size

- Heart – heart failure, wall thickness
- Lung – asthma/chronic bronchitis
- Liver – cirrhosis, hypertrophy
- Kidney – early renal failure
- Muscle – injury, training effects
Future work

- Improvements in rough localization algorithms (normalization, patient subsetting, increased numbers...)
- Extensions to other body parts (neck, brain, extremities)
- Validation on image sets with significant pathology
- How to represent/store the results of ST?
- New applications and demonstration of clinical utility
Conclusions

- Semantic tagging is the “last mile” of medical image segmentation.
- Significant progress has been made in the last 2-3 years.
- When medical image sets can be parsed, a rich variety of information becomes available that may assist in the management of chronic disease and the early detection of organ damage.
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