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Organ Segmentation

introduction	state of art	GE solution
motivation	UI, tools	achievements
organs	advanced methods	validation

Contents

- Introduction
  motivation, organs
- State of Art
- GE solution

Radiotherapy

Acquisiton
– Position Patient
– Acquire Volumetric Data
– Mark Patient

Simulation
– Structure Contouring
– Field Placement
– Blocks/MLC
– Print DRR's

Planning
– Dose Calculation
– Dose Optimization

Treatment

30-40 min **2 Hours 30 Min.**

Make it faster with automatic segmentation…

Motivation

Speed up RT planning
most of time spent with contouring

Approaches
- speed up manual contouring
  with user control: continuous interaction
- fully automated segmentation
  using latest scientific achievements: only initialization needed

What is segmentation?
separation of a ROI from other tissues
label voxels by tissue type

Approach:
contour-based
region-based

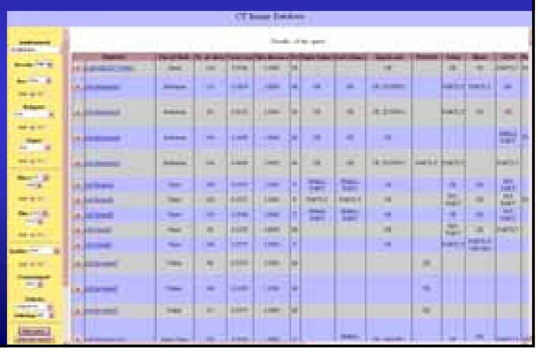
Organs most frequently contoured

Customer survey
- organs to be segmented:
  abdomen: spinal cord, kidneys, liver, spleen
  pelvis: prostate, bladder, rectum,
  head & neck: breast, lungs, thorax,
  head: eyes, optic nerves.
- ranked expectations:
  gain in preparation time,
  avoidance – speed, target – precision & accuracy,
  automation – 1 click to start

Survey conducted during 2 years.

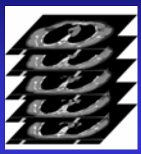
CT database

450 CT volumes, gold standards
Possible to filter by sex, bodypart, organ, slices (nb, distance), quality, contrast agent



Visualization and editing

Scanner slices

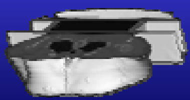


Slice "model" — raw slices, editing in 2D, no build phase

Voxel model

all the data,
any direction can be used,
build: no modification or simple interpolation

Surface model



only partial data,
hardware accelerated display
build: surface extraction,
mesh decimation

- Segmentation needs all the data -> slices or voxel model required.
- Surface model good for visualizing structure form and position .

Structure description

Structure is made up

- volume
  a subset of the original voxels or the acquisition pixels
- surface
  e.g. triangular mesh describing the surface of the structure
- contour
  contours on 2D planes
  e.g. on acquisition slices
  most frequently used

RT Structure Set in DICOM

Structure set
ROI contour sequence
RT ROI observations
...

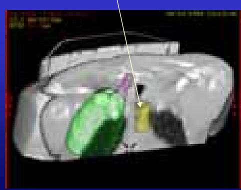
Contents

- Introduction
- State of Art: Segmentation Techniques
  review of various scientific approaches
  contour-based, region-based, most advanced
- GE solution

Manual contouring

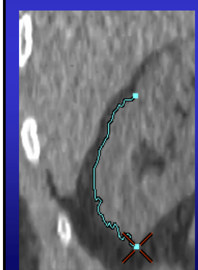
Examples:
- contour drawing:
  freehand, polygon, spline in 2D
- painting:
  freehand with 2D / 3D paintbrush

A defined PTV on 3D view



Speed up manual contouring...

Consecutive CT slices are similar:
interpolation between contours
with "linear distance map" transformation



If structure has visible edge:
- path search: local (AdvSim 5.0) or global (6.0)
  "live wire": spec distance on the image,
  min paths tend to follow edges between 2 points
- active contours

Active contours / Deformable surfaces

Energy minimizing curve / surface (usually closed)
energy = internal + external + inflation constraint
internal ~ smoothness
external ~ guide to image features (edges)
constraint ~ push / pull to user-defined positions (balloon)
user specifies the stopping criteria (e.g. time)

Originally: speed up contouring — Present: automated segmentation
We use its extended version.

Thresholding

Idea: on CT most structure has typical pixel values (HU)

Works well for bones and air,
Not reliable for soft tissues.

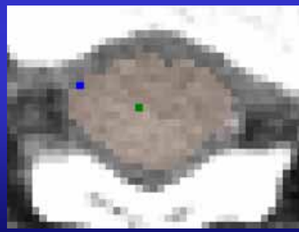
Process chain:

1. range selection
2. ROI / sub-volume selection
3. threshold
4. change topology
   with morphological operators:
   remove bridges, floaters, holes
5. set operators:
   union, intersection
6. smoothing

Basics: Region growing

- Start from a seed point
  candidate voxel: direct neighbor

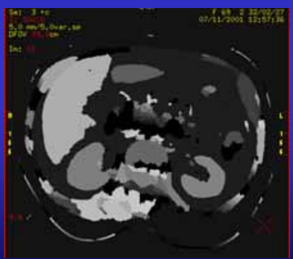
  decision: based on (intensity) difference from seed or border
  + normalization by distance, weighting
  + probabilistic



- Tried for spinal cord, kidneys
  with controlled propagation
  between slices
- Huge drawback:
  no shape control → leakage
- Better results when
  interactively used

Watershed transformation

Idea: partitioning the image
into homogeneous regions



Process:

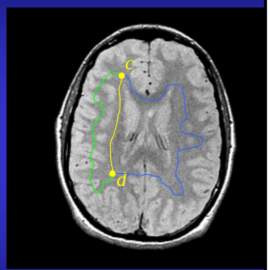
1. smoothing, edge detection
2. compute gradient local minima
   regions:
   initial over-segmentation
3. join shallow regions
   needs interactive help

Tried for many organs,
Require lot of interaction.

Fuzzy segmentation

Basic idea:

- fuzzy adjacency, affinity,
  connectedness
- threshold, seed point



Process:

1. user selects seed points
2. compute fuzzy affinity relation, then
   connectedness values
   w.r.t. the given seeds
3. extract fuzzy connected object
   of given strength

Tried for kidneys with acceptable results,
Works well for brain.

Probabilistic segmentations: a multi-scale example

Image pyramid construction by
smoothing + size reduction

Classification at coarser levels.
misclassification errors reduced !

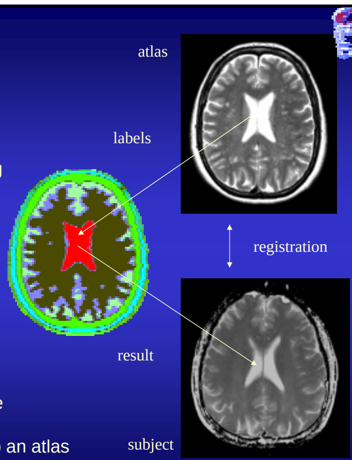
At finer levels: more precise classes
from the coarser level classifications.

Past: probabilistic assignment to make a decision
Present: only speed-up computation -- we use it

Atlas based methods

Pre-process stage:
acquiring data → "ideal"
description of body parts
needs registration + averaging
"Principal Component Analysis"

Process stage:
matching real data
to the atlas,
labeling

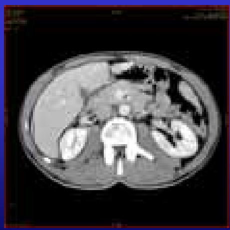


Pro-s: automatic,
many a-priori information =
implicit anatomical knowledge
Con-s:
pathological cases, setting up an atlas

Discussion

Why so many techniques? … segmentation is so hard …

- Missing info on images:
  tissue heterogeneity, voxel correlation, partial volume artifacts,
  additive noise, reconstruction artifacts → *no border, bad quality*
- High inter-observer variability:
  where are the acceptable limits ???

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Contents

- Introduction
- State of Art
- GE solution:
  our approach,
  validation process,
  achievements: method + evaluation results

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Organ specific approaches

Idea:
anatomical knowledge must be explicitly included

Method:
inventive combination of many algorithms,
core: further developed deformable surface

Duration:
from customer survey … to full validation: 3 years

Team:
Image Processing Group + Radiology Clinic at Szeged University
nb 1 in medical image proc in Hungary + GE equipments
on-site R&D helped by clinical evaluation

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Validation: Method expectations

Automated segmentation
- Should be as good as manu
  → measure for baseline
- Should meet clinical require
  → organ-specific evaluatio
- Should fulfill the segmentati
  based on clinical literature r

CTQs
- high accuracy:
  specifity and sensitivity as T
- high precision:
  inter-op. reproducibility, intra
- semi-automation, high-spee

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Validation: Comparison

Measures for baseline — manual
- Gold standard created for each organ
  manual segmentation by 3 medical experts, randomized
  repeated 3 times by one expert
  differences → establish consensus: calibration
- Assessment on manual segmentation
  assess shape to measure accuracy: compute TP, FP, FN volume fractions
  assess variation to measure precision: inter-op. reproducibility, intra-op. repeatability

Evaluation process — auto
- Measures taken
  each segmented organ validated by 3 different experts, 1 expert repeats 3 times
  mean and variance of the measures computed -> statistical table
- Comparison
  with manual segmentation: accuracy, precision
  with clinical requirements: replies to specific questions
  with CTQs: accuracy, precision, automation, memory usage, extensibility

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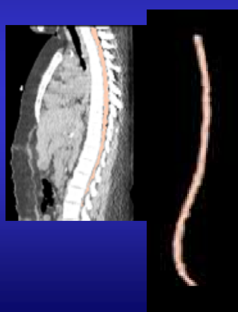
Spinal cord: segmentation

✓ only one seed point needed
✓ automatic stop when cord ends in spine



✓ normal image quality

✓ even on fuzzy image quality

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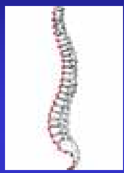
Spinal cord: method

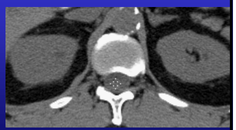
Difficulties:

- leakage at open vertebrae
- definition of extent is subjective

Complex method:

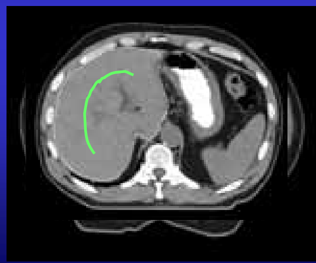
- automatic stopping at head / pelvis
  head: count bony voxels, detect changes
  pelvis: detect change in curvature
- active contour +
  controlled propagation between slices

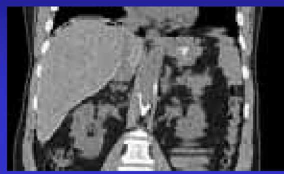




Liver: segmentation

✓ only 1 point or curve needed
✓ fully 3D method
✓ corrects artifacts of breathing





Liver: method

Difficulties:

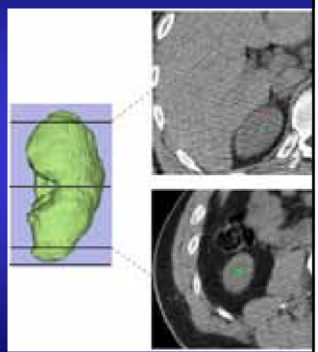
- hard to see its boundary → leakage
- high variance in shape & size
  (left caudal lobe)
  → need to handle topology changes
- moving during the respiratory cycle

Method:

- pre-proc: smoothing + rib cage
- core: deformable surface
  with statistics around seed
- post-proc: precision enhancement

Kidney: segmentation

✓ 2 points to start
✓ fully 3D method
✓ corrects artifacts of breathing



Kidney: method

Difficulties:

- touched by neighboring organs of similar HU → leakage
- high variance in shape & size
  shape is highly curved with protrusions & indentures → missing "C" ends
- kidney = parenchyma ?
- moving during the respiratory cycle

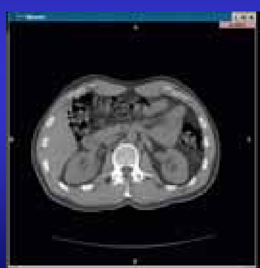
Method:

- pre-proc: smoothing + model + barrier to separate from spine / rib muscles
- core: deformable surface (diff. parameters) with statistics around seed
- post-proc: cutting weak edges if leakage automatically detected

Spleen: segmentation

✓ only 1 point or curve needed
✓ fully 3D method

A curve input of the algorithm



Result of the algorithm

Spleen: method

Difficulties:

- hard to see its boundary → leakage
- high variance in shape & size
  → need to handle topology changes
- tiled homogeneity

Complex method:

- pre-proc: smoothing + rib cage
- core: deformable surface (diff parameters) with statistics around seed

Bladder: segmentation

Difficulties:

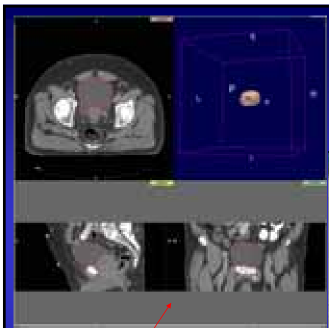
- extremely hard to see its boundary
- very high variance in shape, size & location
- imaging artifacts due to pelvic bones (arms)

Previous tried methods:

- probabilistic clustering
- 3D adaptive merge & split

New method:

- interactive 3D interpolation



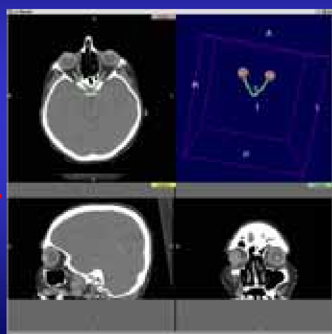
Bladder: demo 3D interpolation

Input axial, sagittal and coronal slice

Result of the algorithm

Eyes: segmentation

Three input points



Result of the algorithm

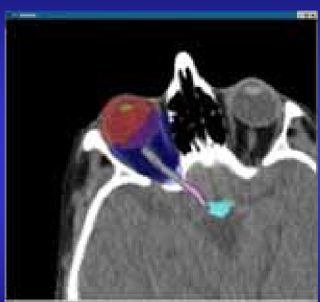
Eyes: method

Clinical needs:

- eye balls + lenses
- optic nerves

Difficulties:

- hardly visible organs
- nerve traversing bone
- mutual positions



Method:

- 1-1 point in the eye ball
  + 1 point in optic chiasm
  segments all the 7 organs
- uses geometrical models
  + localization based on image intensity

Validation results: Speed

	Nb of studies	Running time / study	Running time / slice
spinal cord	31	9 sec	0.1 sec
liver	40	22 sec	0.2 sec
left kidney	51	9 sec	0.1 sec
right kidney	54	8 sec	0.1 sec
spleen	55	14 sec	0.1 sec
	CTQ		< 0.5 sec

Validation results: Precision

	Precision	intra-op	inter-op
spinal cord	manual	93%	92%
	auto	*95%*	*95%*
liver	manual	96%	94%
	auto	*95%*	*94%*
left kidney	manual	94%	93%
	auto	*93%*	*92%*
right kidney	manual	92%	93%
	auto	*95%*	*91%*
spleen	manual	-	-
	auto	*93%*	*95%*
	CTQ	>95%	>90%

Validation results: Accuracy

	Accuracy	TPVF	FPVF	FNVF
spinal cord	manual	98%	2%	2%
	auto	*98%*	*3%*	*2%*
liver	manual	96%	3%	4%
	auto	*86%*	*5%*	*16%*
left kidney	manual	94%	7%	6%
	auto	*88%*	*15%*	*12%*
right kidney	manual	93%	6%	7%
	auto	*91%*	*16%*	*9%*
spleen	manual	-	-	-
	auto	*86%*	*11%*	*13%*
	CTQ	>90%	<10%	<10%

Thank you for your attention

introduction

motivation

organs

state of art

UI, tools

advanced methods

GE solution

achievements

validation