Image Processing in Radiation Therapy

Dr. sc.nat. Stefan G. Scheib
Varian Medical Systems, Imaging Laboratory, Baden-Dättwil, Switzerland
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Agenda

- Varian Medical Systems Imaging Laboratory
- The Cancer Problem in a Nutshell
- Radiation Therapy in a Nutshell
- Imaging Modalities used in Radiation Therapy
- Automatic Image Segmentation
- Cone Beam CT
- Treating Moving Tumors
- Summary
Varian Medical Systems

- Varian Medical Systems (VMS) is based in Palo Alto Ca. - the heart of the silicon valley
- World’s leading manufacturer of radiotherapy systems and software for treating cancer
- A leading supplier of X-ray tubes and flat panel detectors for image reception
- VMS employs approx. 4’800 people
- 60+% world market share
- See also www.varian.com
Varian Medical Systems Imaging Laboratory

- Imaging Center of Excellence in VMS
- 140 Employees:
  - 34% software engineering
  - 20% electrical and embedded engineering
  - 16% research and physics
  - 13% software quality engineering
  - 10% product support engineering
  - 5% project management and technical publication
- Responsible for the design and production of:
  - Radiotherapy Image Acquisition devices
  - Image- and Data-Management systems
  - Configuration of Server/Clients for Europe
VMS Imaging Laboratory, Baden-Dättwil

We are here
## The Cancer Problem in a Nutshell

- We are all aware of the problem
  - 31,000 new cases per year in Switzerland (7·10^6 inhabitants)
  - 15,000 patients per year die in Switzerland due to their cancer
  - 40% of us will face the diagnosis cancer in their lifetime

- What can we do?
  - Improved cancer prevention (e.g. smoking)
  - Early diagnosis (e.g. screening)
  - High quality treatment options
    - Surgery
    - Radiation Therapy (responsible for about 50% of all local tumor eradictions)
    - Chemotherapy
  - Research efforts (e.g. improved networking)

*Data extracted from: National Cancer Programme Switzerland 2005 - 2010, oncosuisse*
Radiation Therapy in a Nutshell

- Important weapon against cancer
  - 50% of all cancer patients get radiation therapy
  - 50% of all successful cancer treatments due to radiation therapy
- Using ionizing radiation (X-ray, γ-ray, electrons, protons, …)
- Concentrate radiation dose to tumor while sparing healthy tissue.
  Radiobiological rational of radiation therapy:

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TCP (green), NTCP (red)

TCP: Tumor Control Probability
NTCP: Normal Tissue Complication Probability
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Radiation Therapy in a Nutshell

- Achromatic 3-field bending magnet
- Bremsstrahlungs Target
- Flattening Filter and Scattering Foils
- Ionization Chamber
- Asymmetric Jaws
- Multileaf Collimator
- Gridded Electron Gun
- Accelerator Tube
- Energy Switch
- On-Board Imaging System (kV)
- MV Portal Imager
Radiation Therapy in a Nutshell
Imaging Modalities used in Radiation Therapy

- Diagnosis and Treatment Follow-up:
  - Ultrasound
  - X-ray radiography
  - Computer Tomography (CT – used also for treatment planning and dose calculation)
  - Nuclear Magnetic Resonance (MRI, MRA, MRS, fMRI, …)
  - Functional Imaging (PET, PET-CT, SPECT, SPECT-CT)

- At time of treatment (up to 35 daily treatment fractions):
  - X-ray radiography – patient set-up
  - Fluoroscopy – tumor motion verification
  - Cone Beam CT (CBCT) – patient set-up, adaptive treatment
  - MV radiography – patient set-up
Imaging Modalities used in Radiation Therapy

- **MV Imaging**
  - 2D matching

- **kV Imaging**
  - 2D matching
  - Motion detection – fluoroscopy

- **kV Imaging**
  - Cone Beam CT (CBCT)
  - 3D matching
Imaging Modalities used at time of treatment
Smart Segmentation

- Automatic segmentation based on CT images
- Reduce time for contouring in treatment planning
- Relevant structures for radiotherapy
- Acceptable quality
- Less than 2 minutes per CT
- Male pelvis and thorax
- Head & Neck – under development
Smart Segmentation – Male Pelvis

- Bladder
- Prostate
- Rectum
- Femoral Heads (incl. Shafts)
Image Processing – Automatic Segmentation

- **Anatomic Knowledge**
  - Rules
  - Reference System
  - Patterns
  - Predefined Shapes

- **Pre-Segmentation**

- **Anatomic Orientation**
  - Body Region, Position, Gender
  - Anatomic Points
  - Navigation Table

- **Structure Segmentation**

- **Image Processing Library**
  - Body, Bones, Air / Lung
Typical Cone Beam CT (CBCT) scan

- 3D image generated from series of 2D images taken around a single axis of rotation
- 350...650 projections 1024x768 pixels (40x30cm)
- 360° gantry rotation in 60 s
- Reconstruction to 2.5 mm thick slices with $512^2$ pixels
Typical Cone Beam CT (CBCT) images
Chances and challenges in CBCT

+ Imaging under Treatment Conditions
  + kV imaging device mounted on the linear accelerator
  + Patient in same position (…) as in treatment
  + Soft tissue contrast for tumour positioning
  + Image of the day – dose of the day

- Cone-beam technology is delicate
  - Scatter problem increases with cone angle
  - Image reconstruction algorithms
  - Image artefacts due to beam hardening, patient breathing, …
Treating moving tumors

- Treating moving targets is challenging
- Two concepts to decrease PTV:
  - Beam gating
  - Tumor tracking using MLC and/or couch
- Scepticism about external surrogates (e.g., RPM™)
- Use On-Board Imager® (OBI) to view internal surrogates
- Develop a software tool (IMR – Intra-fraction Motion Review) to combine OBI and RPM™ information
Pre-Treatment – Tissue Texture Tracking
Marker and Tissue Texture Tracking

Template matching:
- Define template in reference image and extract template
- Search template on subsequent images using cross correlation function
- Motion signal: Marker amplitude

Reference Template
Pre-Treatment – Diaphragm Tracking
Algorithmic Details – Diaphragm Tracking

- Search area (ROI)
- Convolution kernel
- Detected peak positions
- Signal: Max diaphragm extension
- Polynomial fit
Radiation therapy is an important treatment modality in the battle against cancer.

We expect radiation therapy to be even more important in the future due to:

- Improved diagnostic imaging modalities prior and post treatment
- Improved imaging modalities during treatment
- New treatment strategies like beam gating and beam tracking
- Online imaging verification of dose application
- Adapted treatment based on improved imaging and image processing during treatment
- Improved beam delivery systems
Thank you for your interest and attention

"We've given you a brain scan and we can't find anything."
Radiation Therapy in a Nutshell

- **IMRT** – Intensity Modulated Radio Therapy
  - To conform the dose to the target in 3D

- **IGRT** – Image Guided Radio Therapy
  - To place the target within the dose volume
  - To reduce the treatment margin
  - To verify and add up dose distribution of the day

- **DART** – Dynamic Adaptive Radio Therapy
  - To correct the treatment for changes in the patient
  - To further reduce the treatment margin
Atlas Based Segmentation

- Traditional segmentation methods classify voxels based on their intensity values.
- Difficulties when parts or entire region of interest is not clearly separate from neighbouring intensities (i.e., bladder/prostate border, brainstem...).
- Classification of two different objects where intensity distributions are alike (i.e., two bones) needs to be separately solved.
Atlas Based Segmentation

- Atlas based segmentation methods use priori knowledge in a form of an atlas which consists of pre-deliniated and labeled structures and patient image data.
- Atlas is registered to the patient image so that a mapping exists from the image to the atlas.
- Intrapatient variability (shape, size and location of organs) requires the use of non-rigid registration of the atlas for correct mapping.
- Not ‘the final solution for all segmentation problems’ – the intrapatient variability means (most likely) that no single generic atlas will perfectly fit to all possible patients.
Pre-Treatment: Marker Tracking
Preliminary Results

**Internal Motion**
- Diaphragm
- Template
- Marker

**External Motion**
- RPM amplitude
- Beam ON / OFF
- Gating thresholds

1) Motion signal comparison
   ![Graph showing motion signal comparison](image)
   
   \[ R_{PM}^2 = 0.9735 \]

2) Phase shift (external vs. internal)
   
   Phase Shift 1 %

3) Correlation RPM / internal
   
   ![Graph showing correlation](image)
   
   \[ R^2 = 0.9735 \]