

Interactive (real-time) Re-Planning

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Making the discoveries that defeat cancer



Real Time Planning

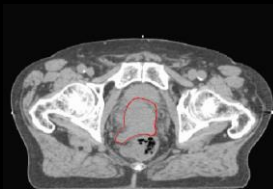
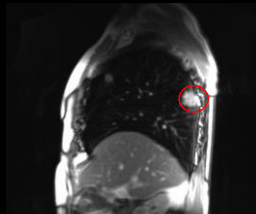
Automated **planning** is a branch of artificial intelligence that concerns the realization of strategies or **action sequences**, typically for execution by intelligent agents or **autonomous robots**.

In **known environments** with available models, planning can be done offline. Solutions can be found and **evaluated prior to execution**. In **dynamically unknown environments**, the strategy often needs to be revised **online**. Models and policies must be adapted.

The dynamically unknown environment

Lung: 4D MRI

Prostate: Daily CT



The Task

Patient scheduled for 10-20 minute treatment

- Optimal treatment for the anatomy observed at **this** time
- **Not** the anatomy we once observed before
- Original Plan is almost certainly not optimal (pelvic, lung)

What is real-time?

System that responds to events or signals within a **predictable** time after their occurrence; specifically the response time must be within the maximum allowed

Plan of the day ? Re-Planning

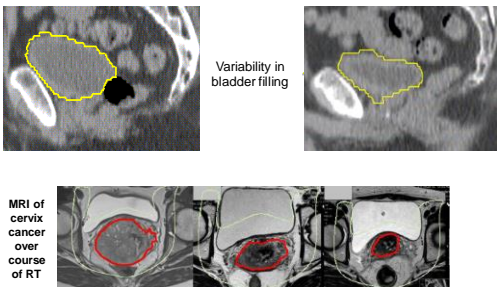
Plan of the 'beam' ?

Plan of the 'segment' (arcs)?

Plan of the 'second' ? Iterative Adaptation

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graph TD; A[Plan of the day ?] --> B[Re-Planning]; B --> C[Iterative Adaptation]; C --> D[Plan of the 'second' ?];
```

Clinical Re-Planning Scenarios



Computers have changed dramatically....



Year 2000 - ASCI White
Lawrence Livermore National Laboratory

Computers have changed dramatically



Year 2014 - 22nm Processor
Available on Amazon!

Computers have changed dramatically



2000

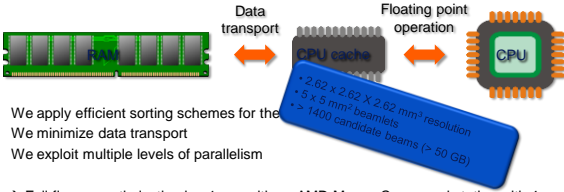


2014

- Pro: Massive increase in computer power
- Con: High-Performance applications harder to develop

Ultrafast treatment planning

The most important aspect is efficient data handling on modern hardware
Ziegenhein et al. 2008 Speed optimized influence matrix processing in inverse treatment planning tools Phys. Med. Biol. 53.



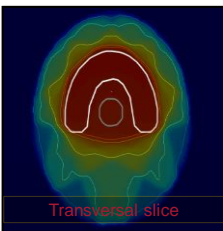
- We apply efficient sorting schemes for the
- We minimize data transport
- We exploit multiple levels of parallelism

→ Full fluence optimization in ~1 sec with an AMD Magpy Cours workstation with 4 CPUs and 128 GB memory (cost ~4500 €)

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Local dose adaptation strategies
(Interactive Dose Shaping: IDS)

Key concept: Modification & Recovery

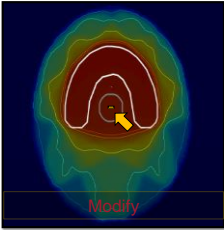


Transversal slice

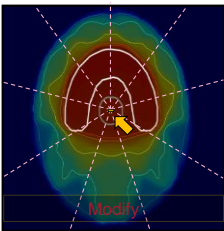


3D phantom plan: 9 beams

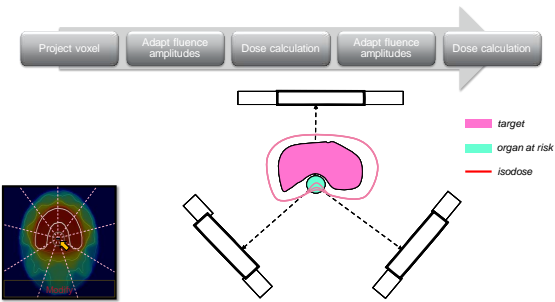
Key concept: Modification & Recovery



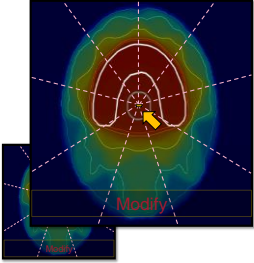
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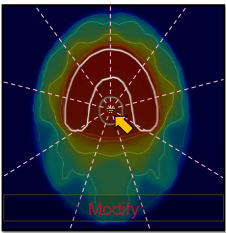
Key concept: Modification & Recovery



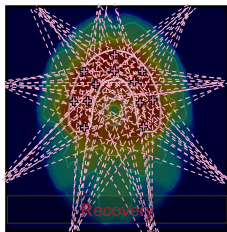
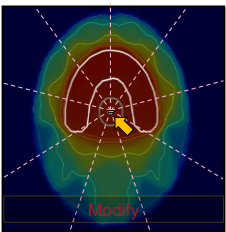
Key concept: Modification & Recovery



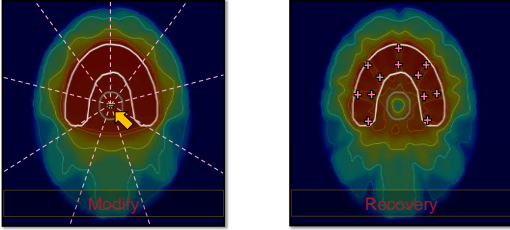
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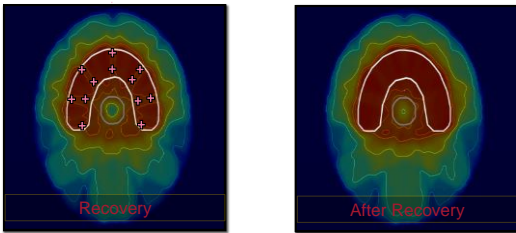
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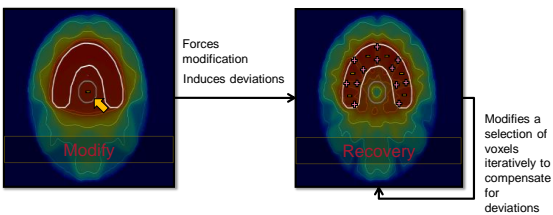
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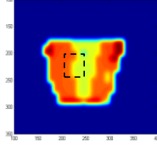


- ✓ Modification & Recovery takes typically < 1 second
- ✓ Relies on ultra-fast dose calculation

Ultra-fast photon dose calculation

Pencil beam photon dose calculation¹⁾

- Take advantage of locality of fluence updates
- Performed in discrete spatial domain
- Optimized for CPU



For a fluence patch of **2.5 x 2.5 cm** with a pixel size of **0.5 mm**:

- Dose calculation takes **5 ms** for all beams

No pre-computed dose influence data

¹⁾ Peter Ziegenhein 2012. *Application of Ultra-Fast Dose Calculation in Real-Time Interactive Treatment Planning* (AAPM 2012, 54th Annual Meeting)

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DYNAPLAN
 (Graphical Interface - TPS)

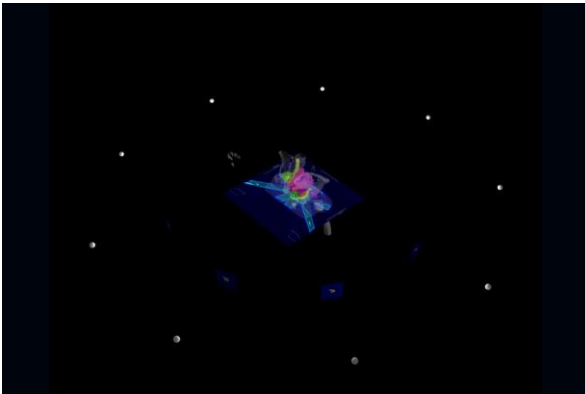
Challenges

User interface requirements

- Intuitive 3D interaction
- Responsive system
- Ultra-fast algorithms
- Negligible latency

Platform requirements

- Feasible on desktop PC
- Scalable to HPC
- Multiplatform

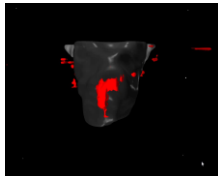


3D dose visualization

Real-time marching cubes (MC)

CPU
runtime \approx 30
ms

GPU
runtime MC \approx 4 ms
with transport \approx 30 ms



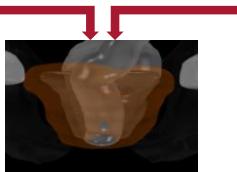
- ✓ Quick assessment of dose distribution
- ✓ Enables 3D dose manipulation tool

Interactive Dose Shaping - Dynaplan

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Image processing
3D UI

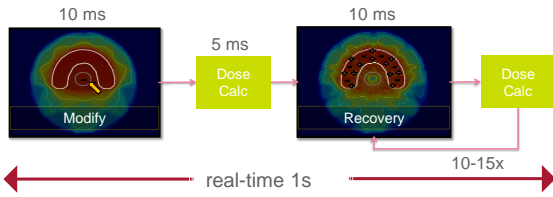


Local Planning
heuristic

IDS - Main Principle

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Not based on an optimization loop
No need for an objective function
Guided forward planning method

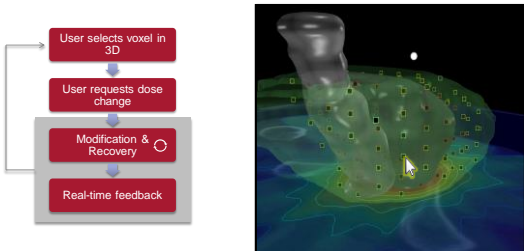


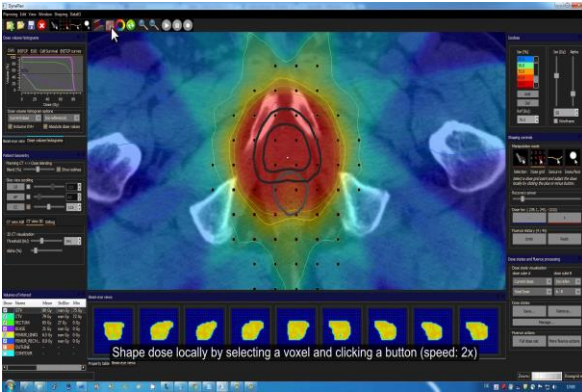
3D dose adaptation tools

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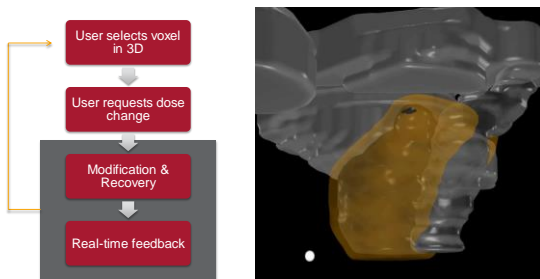
3D dose adaptation tools

Single voxel manipulation

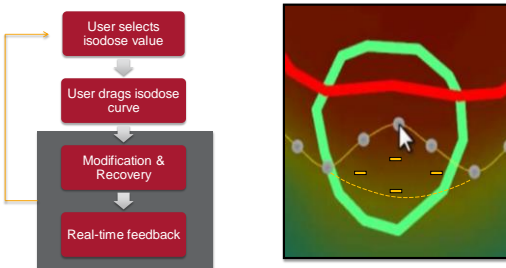




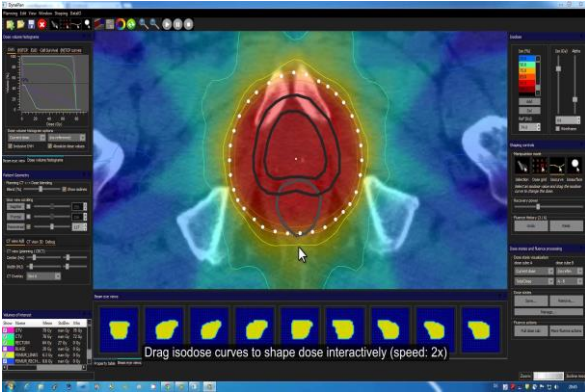
Single voxel manipulation



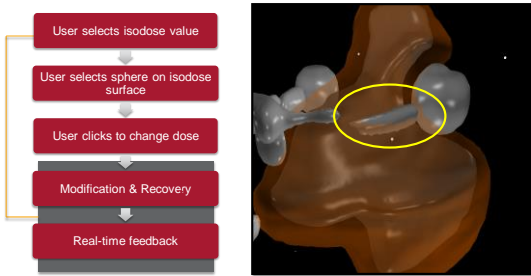
Isodose curve manipulation¹⁾



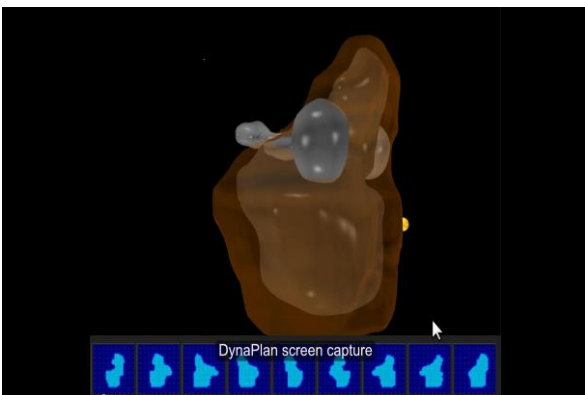
¹⁾ C. P. Kamerling 2012 Isodose curve manipulation for interactive dose shaping (AAPM 2012)



3D isodose surface manipulation¹⁾



¹⁾ C.P. Kamerling 2013 A 3D isodose surface manipulation tool for interactive dose shaping (ICCR 2013)



Outlook Online adaptive RT

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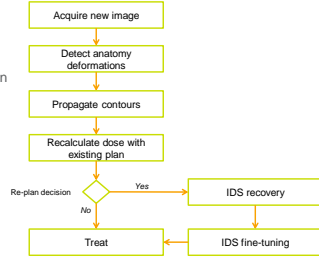
Fast IDS dose calculation enables online adaptive approach

Challenges image processing:

- Fast and accurate deformable registration and contour propagation
- Quick visual assessment

Challenges IDS

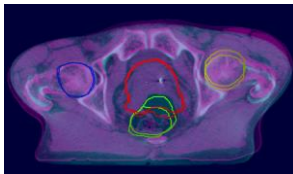
- Develop DMR tool which aims at restoring the old plan for the new geometry or
- Find potential improvements automatically



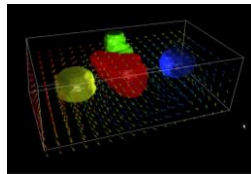
Outlook Online adaptive RT

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Detect anatomy deformations in Dynaplan



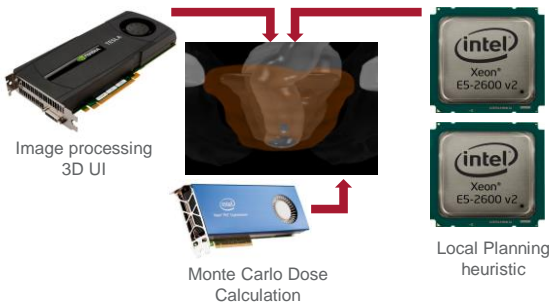
Propagated contours



3D deformation field

Interactive Dose Shaping - Dynaplan

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Conclusions

Conclusions

- Real time re-planning/adaptation will be possible at almost all relevant time scales
- Prerequisite: Accurate and reliable image information
- Current bottleneck: fast image processing
- Challenges: Integration with IGRT technologies
Level of QA plan verification

ICR The Institute of Cancer Research

CANCER RESEARCH UK

in partnership with The ROYAL MARSDEN NHS Foundation Trust



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Dr. Peter Ziegenhein
Dr. Corijn Kamerling
Katrin Welsch
Sven Pirner

Making the discoveries that defeat cancer
