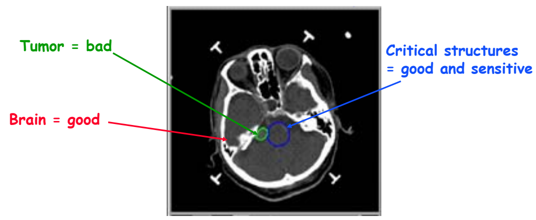
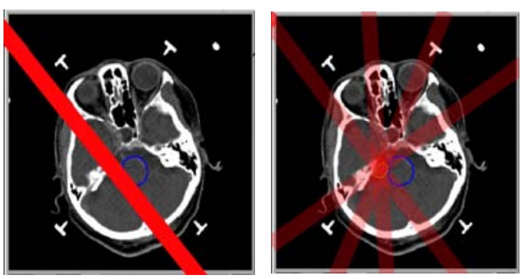
Radiosurgical Planning

Radiosurgery

Minimally invasive procedure that uses an intense, focused beam of radiation as an ablative surgical instrument to destroy tumors



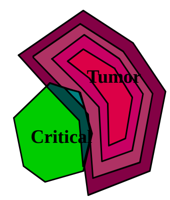
The Radiosurgery Problem

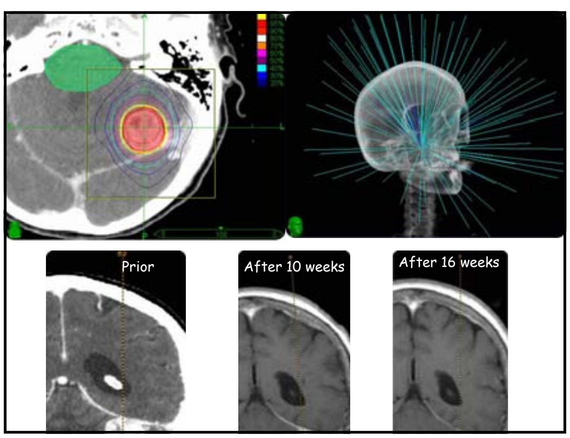


Dose from multiple beams is additive

Treatment Planning for Radiosurgery

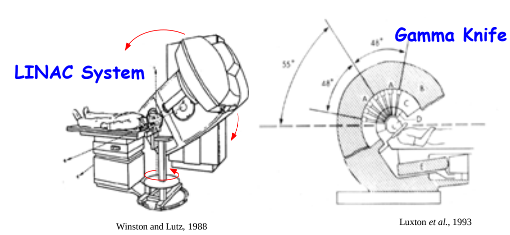
- Determine a set of beam configurations that will destroy a tumor by cross-firing at it
- Constraints:
  - Desired dose distribution
  - Physical properties of the radiation beam
  - Constraints of the device delivering the radiation
  - Duration/fractionation of treatment





Conventional Radiosurgical Systems

- Isocenter-based treatments
- Stereotactic frame required

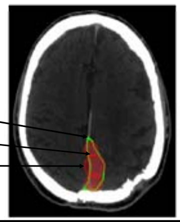


Isocenter-Based Treatments

- All beams converge at the isocenter
- The resulting region of high dose is spherical

Nonspherically shaped tumors are approximated by multiple spheres

- "Cold Spots" where coverage is poor
- "Hot Spots" where the spheres overlap
- Over-irradiation of healthy tissue



Stereotactic Frame for Localization

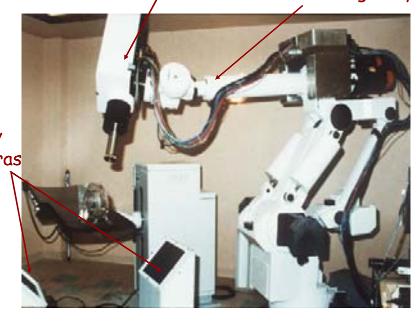
- Painful
- Fractionation of treatments is difficult
- Treatment of extracranial tumors is impossible

The CyberKnife

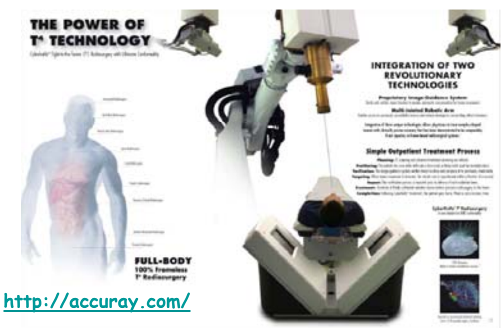
linear accelerator

robotic gantry

X-Ray cameras



CyberKnife (Accuray)



http://accuray.com/

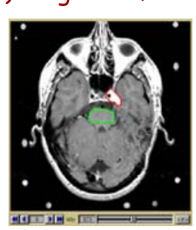
Treatment Planning Becomes More Difficult

- Much larger solution space
  - Beam configuration space has greater dimensionality
  - Number of beams can be much larger
  - More complex interactions between beams
- Path planning
  - Avoid collisions
  - Do not obstruct X-ray cameras

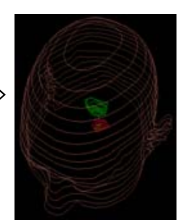
→ Automatic planning required (CARABEAMER)

Inputs to CARABEAMER

(1) Regions of Interest:



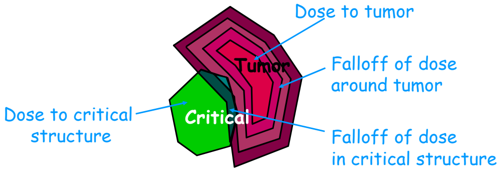
Surgeon delineates the regions of interest



CARABEAMER creates 3D regions

Inputs to CARABEAMER

(2) Dose Constraints:



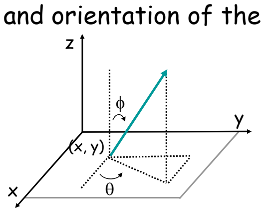
(3) Maximum number of beams

Basic Problem Solved by CARABEAMER

- Given:
  - Spatial arrangement of regions of interest
  - Dose constraints for each region: $a \leq D \leq b$
  - Max number of beams allowed: N (~100-400)
- Find:
  - N beam configurations (or less) that generate dose distribution that meets the constraints.

Beam Configuration

- Position and orientation of the radiation beam



- Amount of radiation or **beam weight**
- Collimator diameter

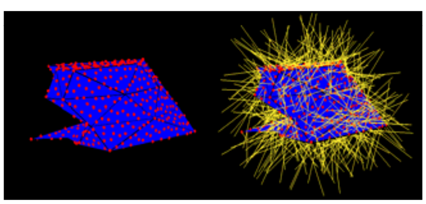
→ **Find 6N parameters that satisfy the constraints**

CARABEAMER's Approach

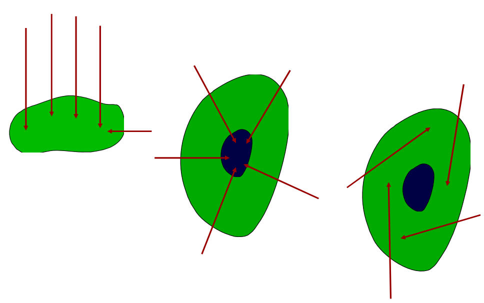
1. Initial Sampling:
   Generate many (> N) beams at random, with each beam having a reasonable probability of being part of the solution.
2. Weighting:
   Use linear programming to test whether the beams can produce a dose distribution that satisfies the input constraints.
3. Iterative Re-Sampling:
   Eliminate beams with small weights and re-sample more beams around promising beams.
4. Iterative Beam Reduction:
   Progressively reduce the number of beams in the solution.

Initial Beam Sampling

- Generate even distribution of target points on the surface of the tumor
- Define beams at random orientations through these points

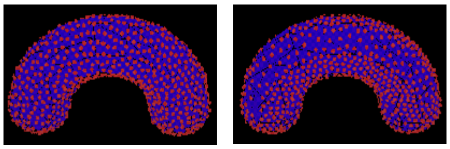


Deterministic Beam Selection is Less Robust

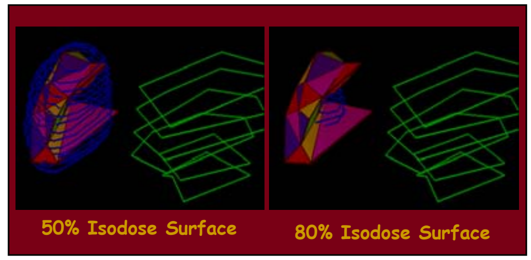


Curvature Bias

- Place more target points in regions of high curvature



Dose Distribution Before Beam Weighting



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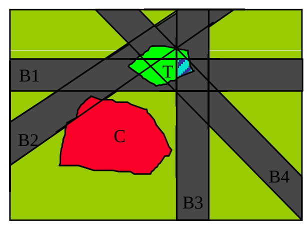
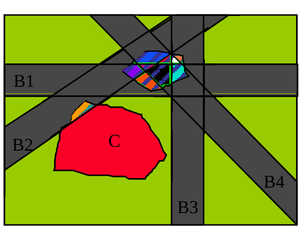
Beam Weighting

- Construct geometric arrangement of regions formed by the beams and the tissue structures
- Assign constraints to each cell of the arrangement:
  - Tumor constraints
  - Critical constraints

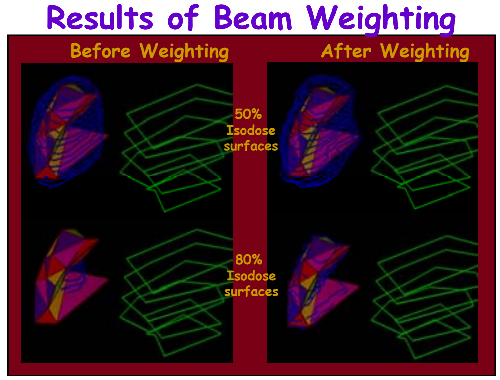


Linear Programming Problem



- 2000 ≤ Tumor ≤ 2200
  - 2000 ≤ B2 + B4 ≤ 2200
  - 2000 ≤ B4 ≤ 2200
  - 2000 ≤ B3 + B4 ≤ 2200
  - 2000 ≤ B3 ≤ 2200
  - 2000 ≤ B1 + B3 + B4 ≤ 2200
  - 2000 ≤ B1 + B4 ≤ 2200
  - 2000 ≤ B1 + B2 + B4 ≤ 2200
  - 2000 ≤ B1 ≤ 2200
  - 2000 ≤ B1 + B2 ≤ 2200
- 0 ≤ Critical ≤ 500
  - 0 ≤ B2 ≤ 500

Results of Beam Weighting



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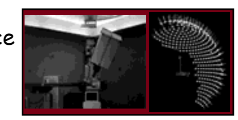
Plan Review

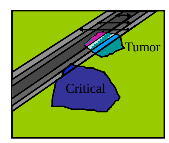
- Calculate resulting dose distribution
- Radiation oncologist reviews
- If satisfactory, treatment can be delivered
- If not...
  - Add new constraints
  - Adjust existing constraints

Treatment Planning: Extensions

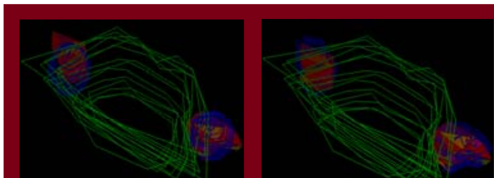
- Simple path planning and collision avoidance



- Automatic collimator selection



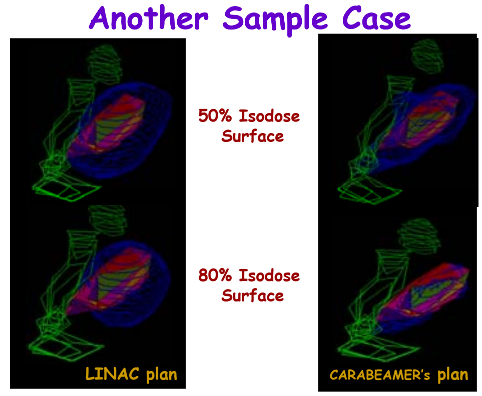
Evaluation on Sample Case



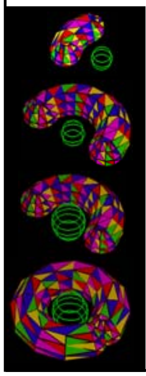
Linac plan
80% Isodose surface

CARABEAMER's plan
80% Isodose surface

Another Sample Case



Evaluation on Synthetic Data



$2000 \le D^T \le 2400$, $D^C \le 500$

$2000 \le D^T \le 2200$, $D^C \le 500$

$2000 \le D^T \le 2100$, $D^C \le 500$

X

n = 500

n = 250

n = 100

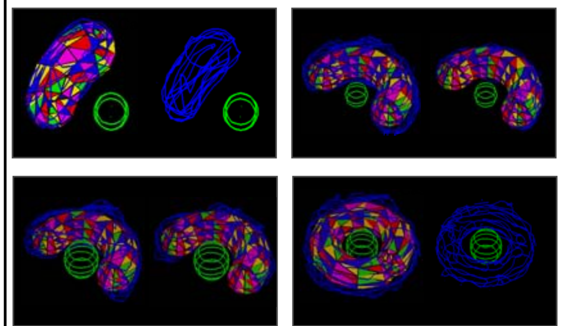
X

Constraint Iteration / Beam Iteration

X

10 random seeds

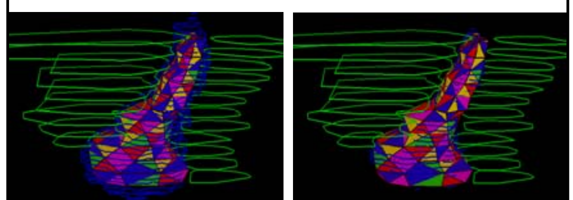
Dosimetry Results



Average Run Times

	Case 1 Beam	Case 1 Constr	Case 2 Beam	Case 2 Constr	Case 3 Beam	Case 3 Constr	Case 4 Beam	Case 4 Constr
2000-2400								
n = 500	:20	:41	:03:30	:05:23	:04:36	:06:45	3:06:12	1:40:55
n = 250	:20	:40	:03:32	:05:33	:04:11	:07:19	3:09:19	1:44:18
n = 100	:35	:51	:04:28	:07:19	:05:03	:07:06	3:35:28	1:41:19
2000-2200								
n = 500	:32	:50	:05:50	:08:37	:23:51	:13:05	25:38:36	6:33:02
n = 250	:29	:59	:05:50	:08:42	:24:44	:12:16	27:55:18	7:11:01
n = 100	:43	:01:02	:08:53	:10:43	:33:02	:21:06		176:25:02
2000-2100	:01:34	:01:41	:48:54	:27:39	3:26:33	1:03:06	53:58:56	44:11:04
	:01:28	:01:31	:40:49	:24:43	3:22:15	1:07:12		84:21:27
	:02:21	:02:38	1:57:25	1:02:27	7:44:57	5:06:29		

Evaluation on Prostate Case



50% Isodose surface 70% Isodose surface

Cyberknife Systems

Contact Stanford Report

News Service / Press Releases

Stanford Report, July 25, 2001

Patients gather to praise minimally invasive technique used in treating tumors

By MICHELLE BRANDT

When Jeanie Schmidt, a critical care nurse from Foster City, lost hearing in her left ear and experienced numbing in her face, she prayed that her first instincts were off. "I said to the doctor, `I think I have an acoustic neuroma (a brain tumor), but I'm hoping I'm wrong. Tell me it's wax, tell me it's anything,'" Schmidt recalled.

It wasn't wax, however, and Schmidt – who wound up in the Stanford Hospital emergency room when her symptoms worsened – was quickly forced to make a decision regarding treatment for her tumor.

On July 13, Schmidt found herself back at Stanford – but this time with a group of patients who were treated with the same minimally invasive treatment that Schmidt ultimately chose: the CyberKnife. She was one of 40 former patients who met with Stanford faculty and staff to discuss their experiences with the CyberKnife – a radiosurgery system designed at Stanford by John Adler Jr., MD, in 1994 for performing neurosurgeries without incisions.

"I wanted the chance to thank everyone again and to share experiences with other patients," said Schmidt, who had the procedure on June 20 and will have an MRI in six months to determine its effectiveness. "I feel really lucky that I came along when this technology was around."

The CyberKnife is the newest member of the radiosurgery family. Like its ancestor, the 33-year-old Gamma Knife, the CyberKnife uses 3-D computer targeting to deliver a single, large dose of radiation to the tumor in an outpatient setting. But unlike the Gamma Knife – which requires patients to wear an external frame to keep their head completely immobile during the procedure – the CyberKnife can make real-time adjustments to body movements so that patients aren't required to wear the bulky, uncomfortable head gear.

The procedure provides patients an alternative to both difficult, risky surgery and conventional radiation therapy, in which small doses of radiation are delivered each day to a large area. The procedure is used to treat a variety of conditions – including several that can't be treated by any other procedure – but is most commonly used for metastases (the most common type of brain tumor in adults), meningomas (tumors that develop from the membranes that cover the brain), and acoustic neuromas. **Since January 1999, more than 335 patients have been treated at Stanford with the CyberKnife.**

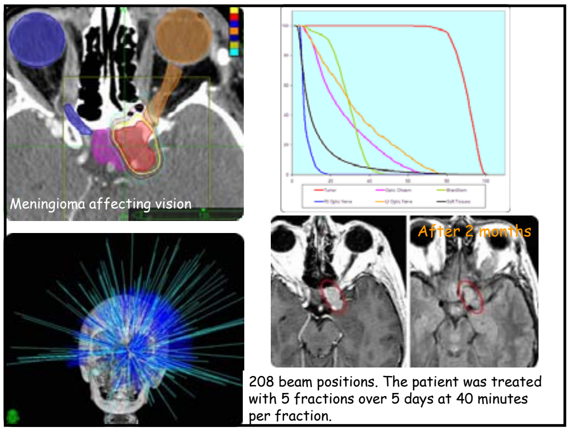
May 2010

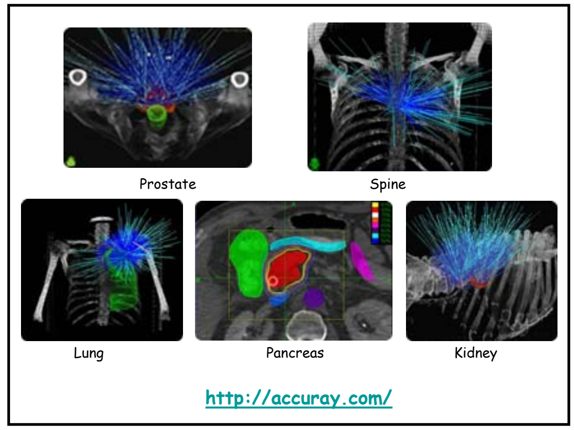
Number of CK installations: 182

Installation locations: 24 countries
http://www.accuray.com/CyberKnifeCenters/index.aspx

Patients treated to date: Over 100,000? (40,000 in May 2008)

Indications: Brain, spine, lung, prostate, liver, pancreas (most common)


Meningioma affecting vision
After 2 months
208 beam positions. The patient was treated with 5 fractions over 5 days at 40 minutes per fraction.


Prostate
Spine
Lung
Pancreas
Kidney
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