Optimization and the Wisconsin Institutes of Discovery

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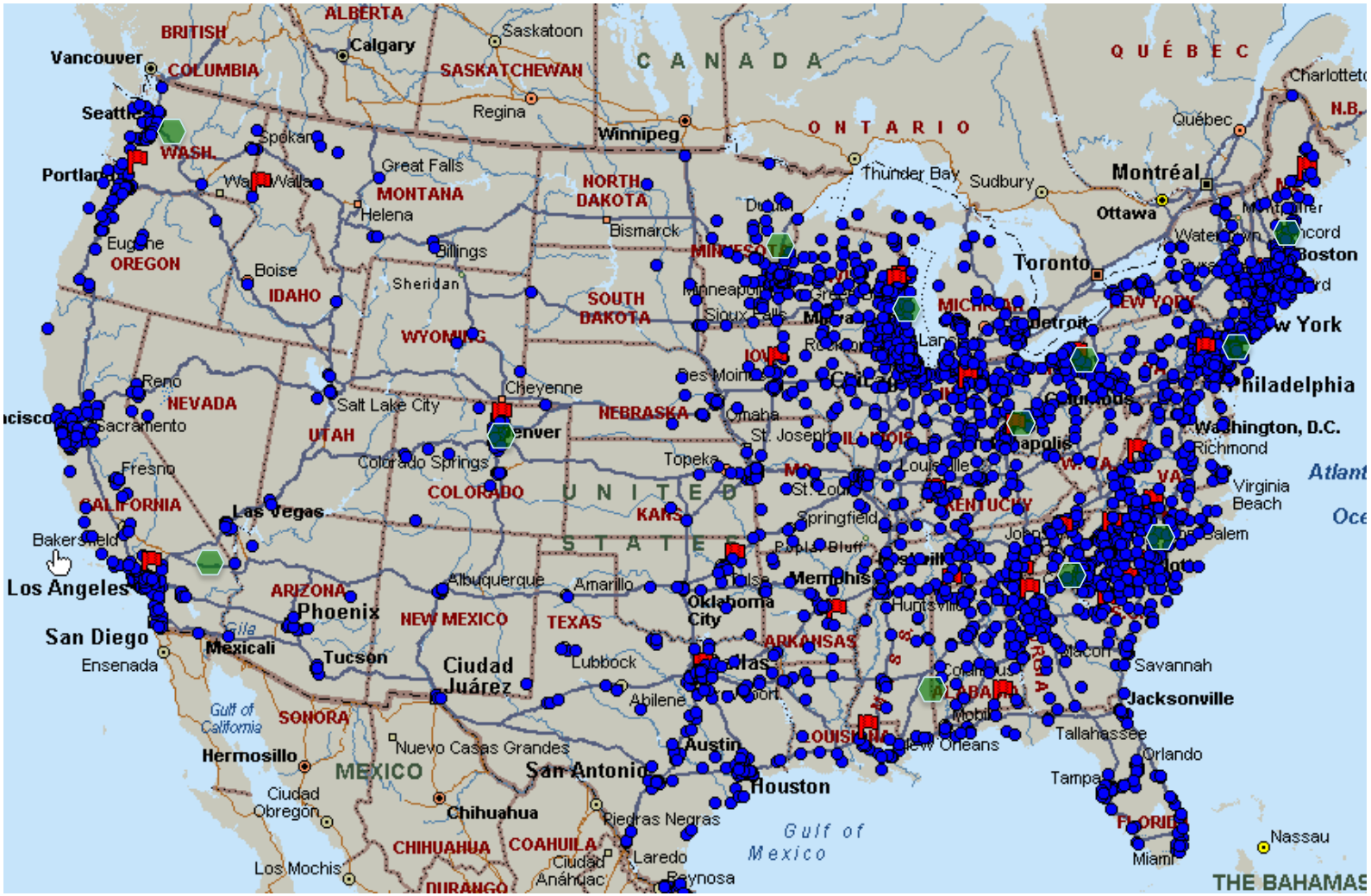
Collaboration with Jeff Linderoth, Jim Luedtke, Ben Recht, Steve Wright and others.

Plant and Customers



Supply chain/ business strategy models

- Multiple manufacturing facilities, many customers
- Can transport (widgets) assembled / disassembled
- Location of distribution centers
- Assignment of customers to manufacturing facilities and distribution centers

What if's?

- Where to locate distribution centers?
- Close a manufacturing plant?
- Drop customers?
- Use FedEx?

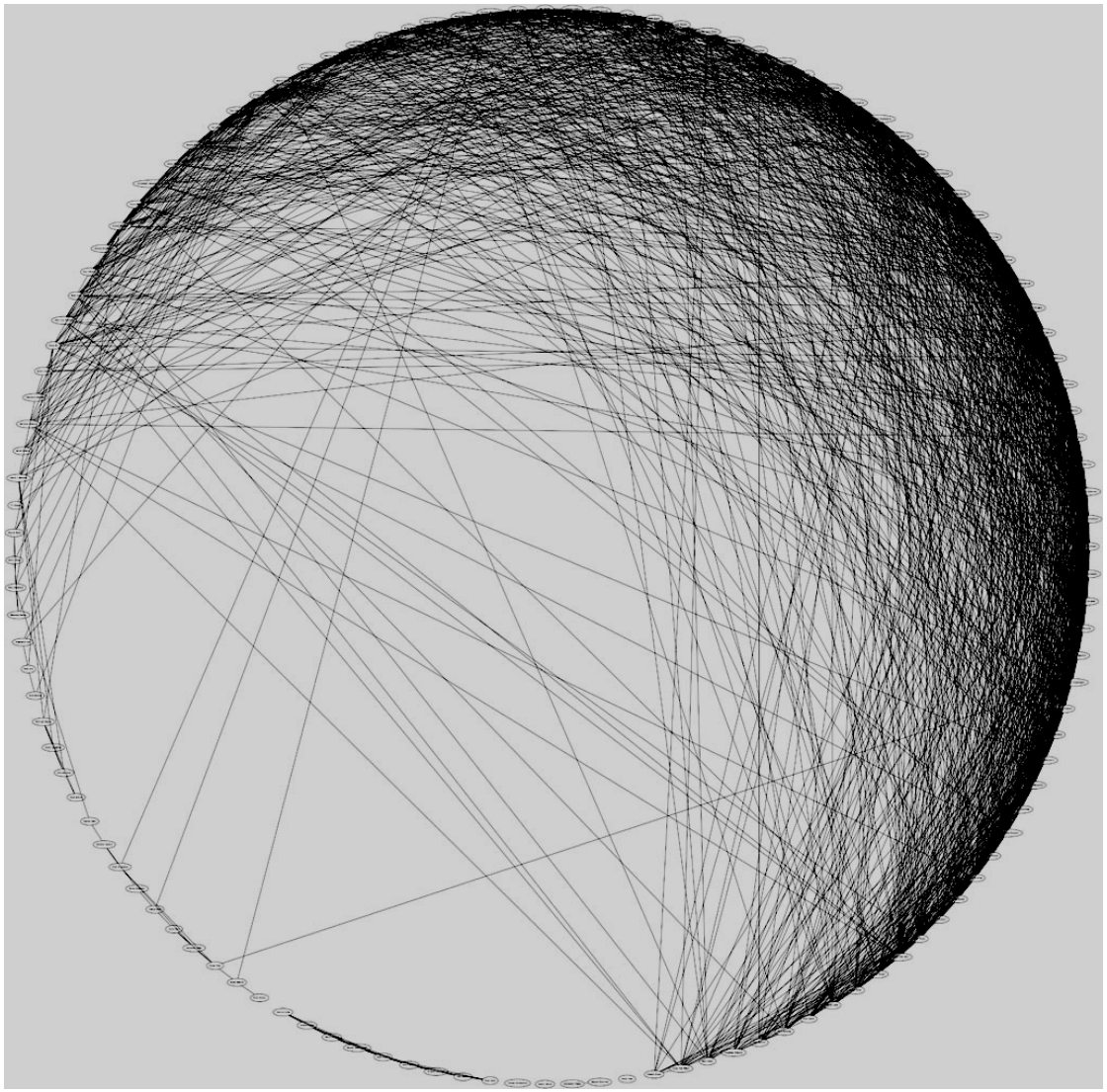
The model

- Team of 10 people to collect and validate data and model runs
- Piecewise linear costs, large numbers of binary variables
- Model is a mixed integer model with 16 million binary choices
- Model can take up to 20 hours to solve on high end workstation
- Model predicts changes in operations leading to $1.2 million in savings
- Model should be extended to incorporate changes in transportation rates, uncertainties in demand
- Model facilitates informed discussion of real issues and is credible due to data integrity

Issues

- Models are critical to making hard business decisions
- Model needs enough detail so solutions are realistic
- Computation is hard - many possibilities!
- Need large scale solvers
- How to obtain data, get data into model, verify data integrity - more tools and models
- Interplay between model, data and decision maker is critical
- Visualization helps in motivating the answers

Facebook: a friend wheel



- visual representation of relationships between the friends of any one person
- constructed by placing friends equidistant from each other on circumference of circle
- line segments are drawn between each point if those people are friends with each other
- Order to reduce amount of ink used

QAP (Koopmans and Beckman)

Given n facilities $\{f_1, \ldots, f_n\}$, n locations $\{l_1, \ldots, l_n\}$:
Determine to which location each facility must be assigned
$p : \{1, \ldots, n\} \mapsto \{1, \ldots, n\}$ is an assignment whose cost is

$$c(p) = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} d_{p(i),p(j)}$$

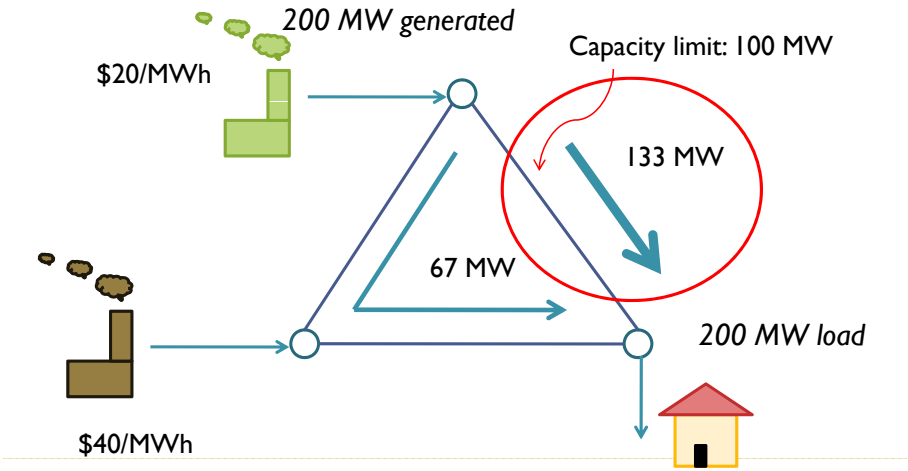
$$\text{QAP} : \min c(p) \text{ subject to } p \in \Pi_n$$

QAP is known to be strongly NP-hard

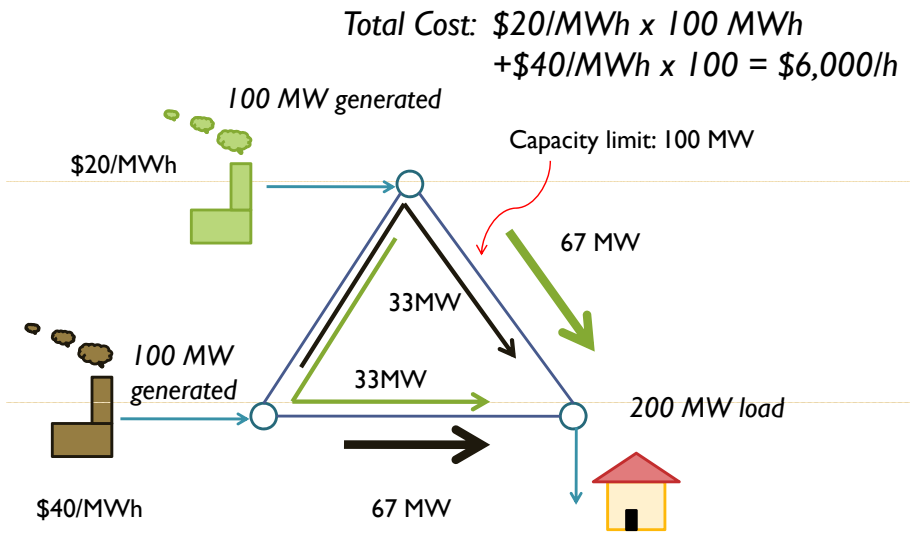
- n is the number of friends of a given individual
- $w_{i,j} = 1$ if i is a friend of j, and 0 otherwise
- $d_{r,s}$ is the distance from location r on the circle circumference to location s

Transmission switching

Opening lines in a transmission network can reduce cost



(a) Infeasible due to line capacity



(b) Feasible dispatch

Need to use expensive generator due to power flow characteristics and capacity limit on transmission line

Determine which subset of lines to open at any given hour

The basic model

$\min_{g,f,\theta}$	$c^T g$	generation cost
s.t.	$g - d = Af, f = BA^T\theta$	A is node-arc incidence
	$\bar{\theta}_L \leq \theta \leq \bar{\theta}_U$	bus angle constraints
	$\bar{g}_L \leq g \leq \bar{g}_U$	generator capacities
	$\bar{f}_L \leq f \leq \bar{f}_U$	transmission capacities

with transmission switching (within a smart grid technology) we modify as:

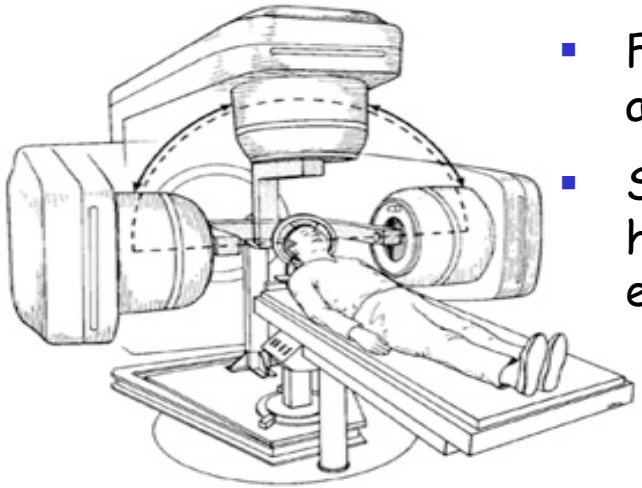
$\min_{g,f,\theta}$	$c^T g$	
s.t.	$g - d = Af$	
	$\bar{\theta}_L \leq \theta \leq \bar{\theta}_U$	
	$\bar{g}_L \leq g \leq \bar{g}_U$	
either	$f_i = (BA^T\theta)_i, \bar{f}_{L,i} \leq f_i \leq \bar{f}_{U,i}$	if i closed
or	$f_i = 0$	if i open

Use EMP to facilitate the disjunctive constraints (several equivalent formulations, including LPEC)

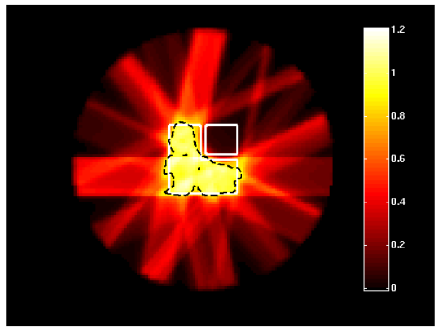
Optimal Yacht Rig Design

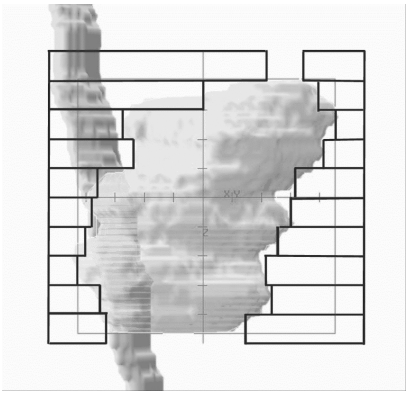
- Current mast design trends use a large primary spar supported laterally by compression and tension members: the rig
- Reduction in either the weight of the rig or the height of the VCG will improve performance
- Complementarity feature is Hooke's Law
- Design must work well under a variety of weather conditions
- Problems solvable, local solutions, hard
- Southern Spars Company (NZ): improved from 5-0 to 5-2 in America's Cup!

Conformal Radiotherapy

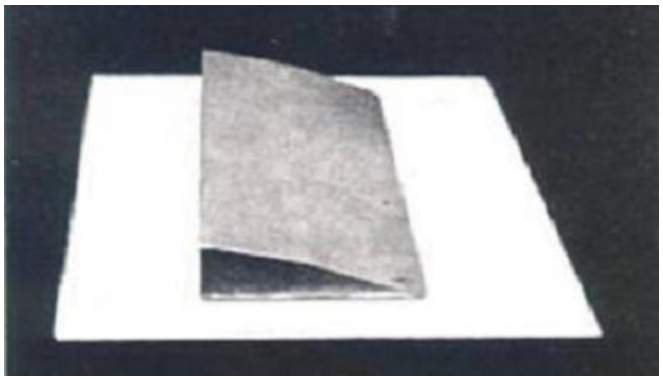


- Fire from multiple angles
- Superposition allows high dose in target, low elsewhere

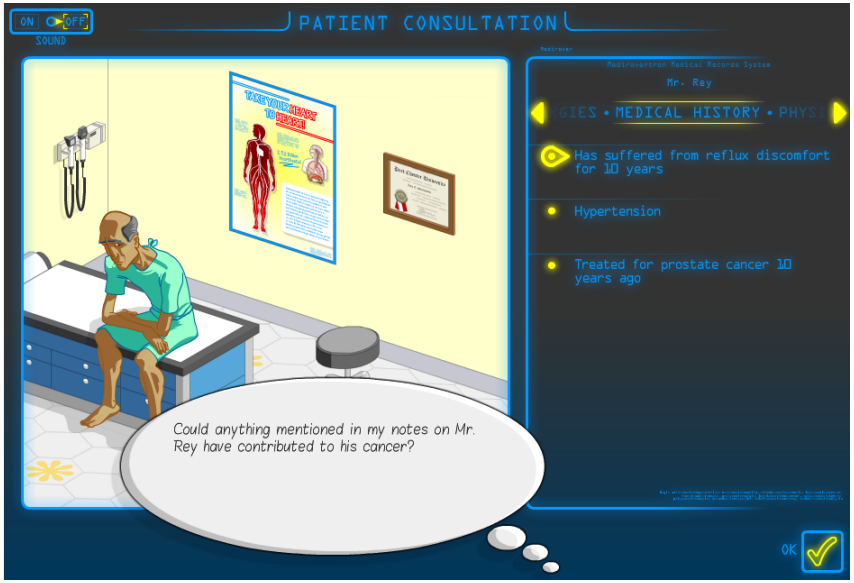


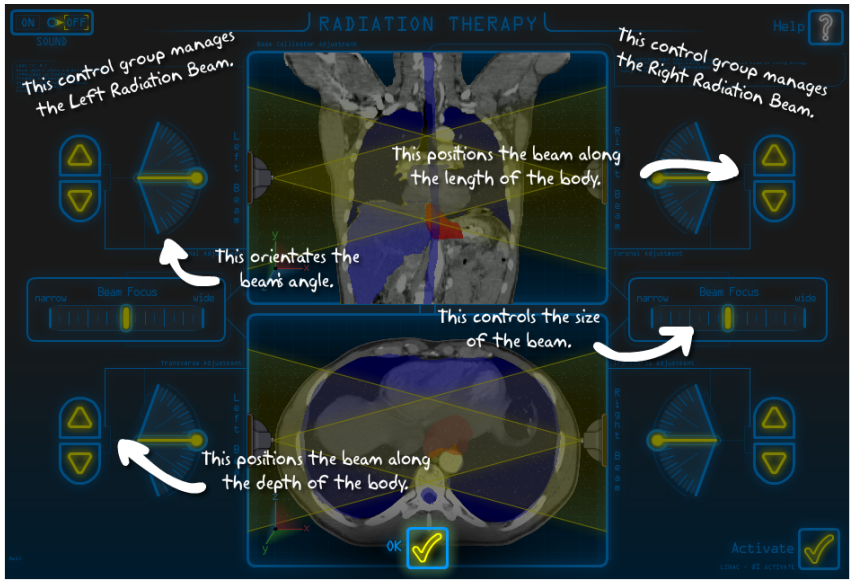


- Beam shaping via collimator
- Gradient across beam via wedges

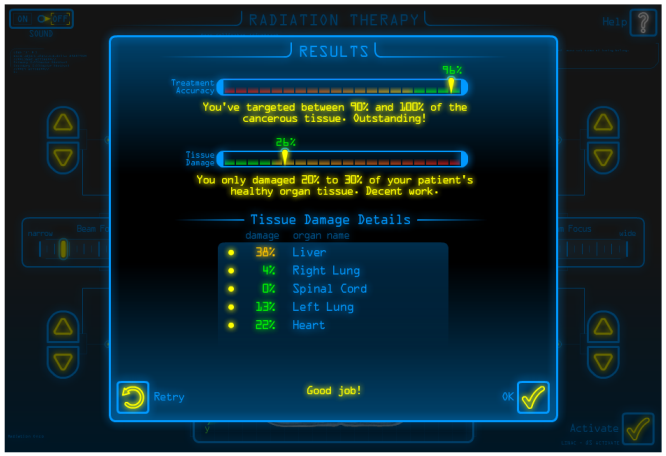


An Oncology Game





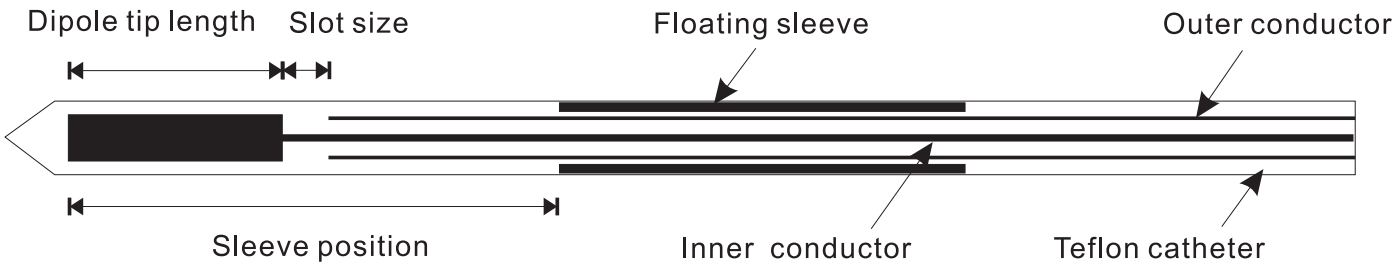
- Game developed by the Educational Research Challenge Area (ERCA) of the Wisconsin Institutes of Discovery
- Coming soon to a web browser near you!

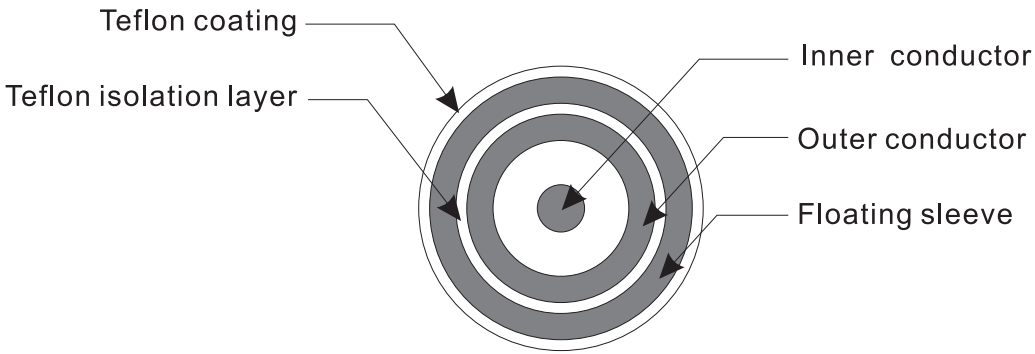


Simulation-based optimization problems

- Computer simulations are used as substitutes to evaluate complex real systems.
- Simulations are widely applied in epidemiology, engineering design, manufacturing, supply chain management, medical treatment and many other fields.
- The goal: Optimization finds the best values of the decision variables (design parameters or controls) that minimize some performance measure of the simulation.
- Other applications: calibration, design optimization, inverse optimization

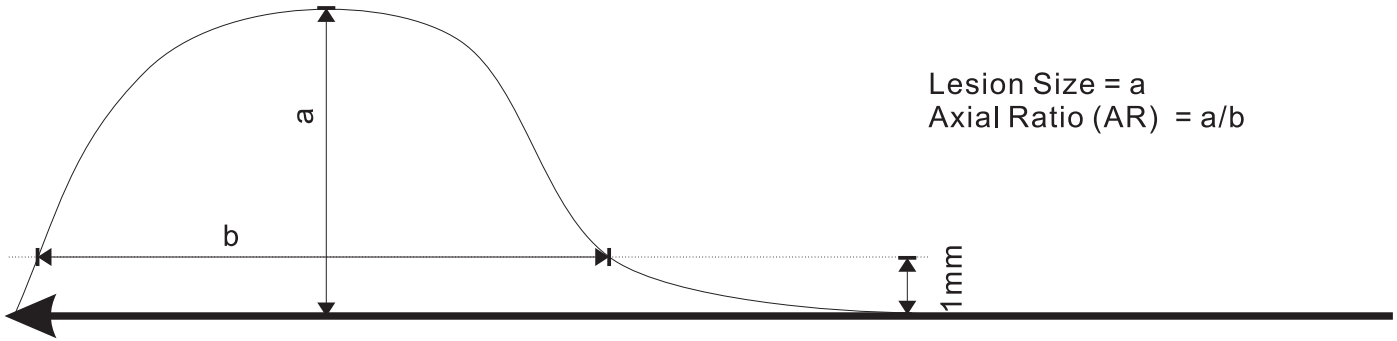
Design a coaxial antenna for hepatic tumor ablation





Simulation of the electromagnetic radiation profile

Finite element models (COMSOL MultiPhysics v3.2) are used to generate the electromagnetic (EM) radiation fields in liver given a particular design



Metric	Measure of	Goal
Lesion radius	Size of lesion in radial direction	Maximize
Axial ratio	Proximity of lesion shape to a sphere	Fit to 0.5
S_{11}	Tail reflection of antenna	Minimize

Issues

- Complex interactions of different types of models
- Large scale solution, in "real time"
- Models to aid in data collection/verification
- Uncertainties in data and model
- Moving effective models into practice - getting the checks done!

Conclusions

- Optimization models effective for large scale planning/operations
- Design optimization possible in conjunction with "expert" simulations
- Must treat uncertainties both in data and model
- New model paradigms (e.g. complementarity, conic programming, stochastic programming) effective for treating uncertainties and competition
- Engaged teams (including embedded optimizers) are most effective for timely, relevant solutions

Wisconsin Institutes of Discovery

- Two world-class biomedical research institutes
- Foster new approaches to biological and medical programs at the boundary of biotechnology, information technology and nanotechnology
- New building funded from Mortgridge gift, WARF and State of Wisconsin
- Private arm: Mortgridge Institute of Discovery
- Ongoing funding from State

- Epigenetics or how genes are activated or inactivated
- Tissue engineering scaffold research
- Health Technology Design in the Living Environments Laboratory
- Systems Biology, an integrated, "system level" understanding of living organisms
- Optimization