National Science Foundation
WHERE DISCOVERIES BEGIN

TEXAS HEART INSTITUTE
at St. Luke's Episcopal Hospital

UNIVERSITY OF HOUSTON
Founded 1927

MATHEMATICS AND CARDIOLOGY: PARTNERS FOR THE FUTURE

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University of Houston

RICE

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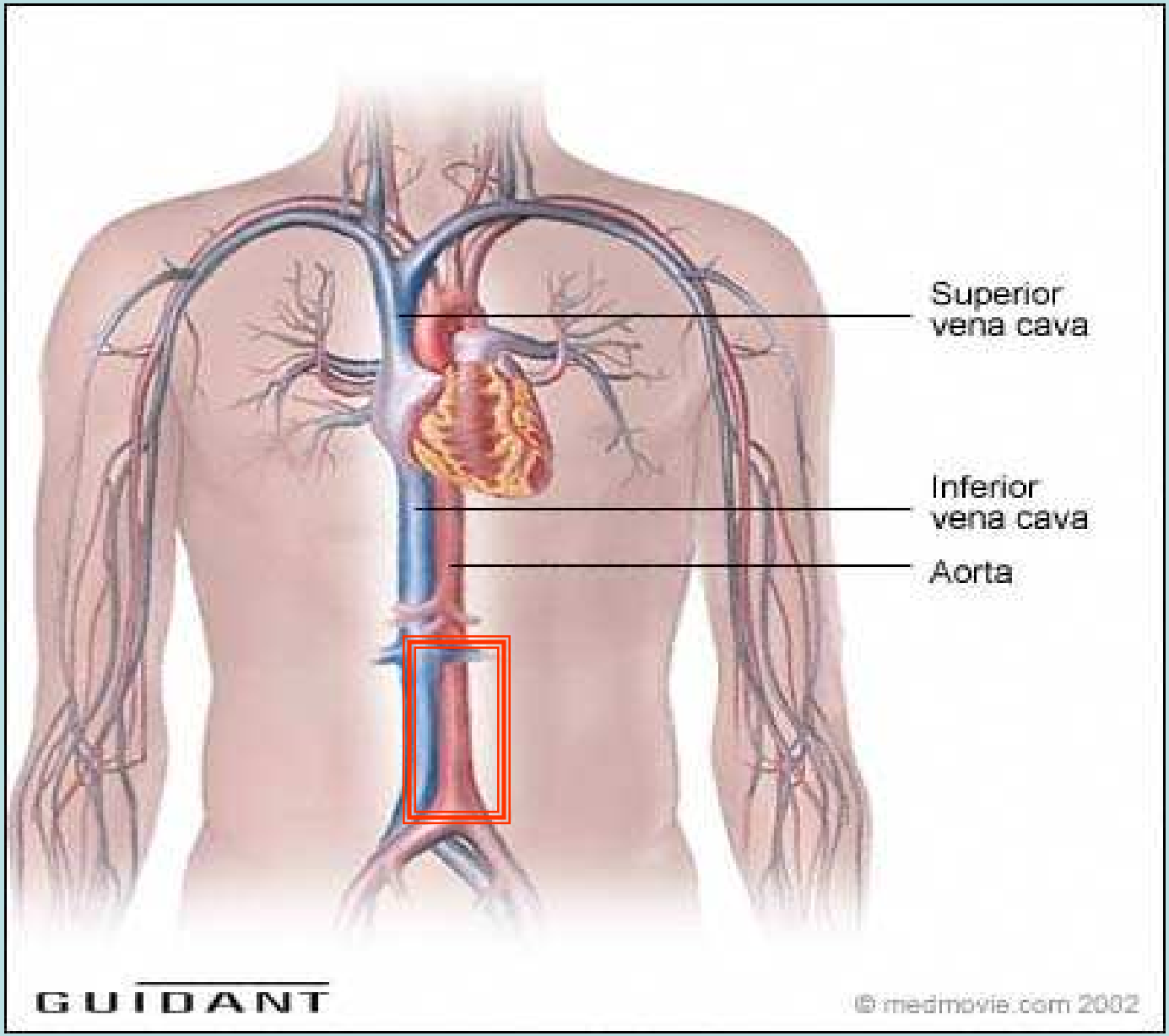
THE UNIVERSITY of TEXAS
HEALTH SCIENCE CENTER AT HOUSTON


Superior
vena cava
Inferior
vena cava
Aorta
GUIDANT
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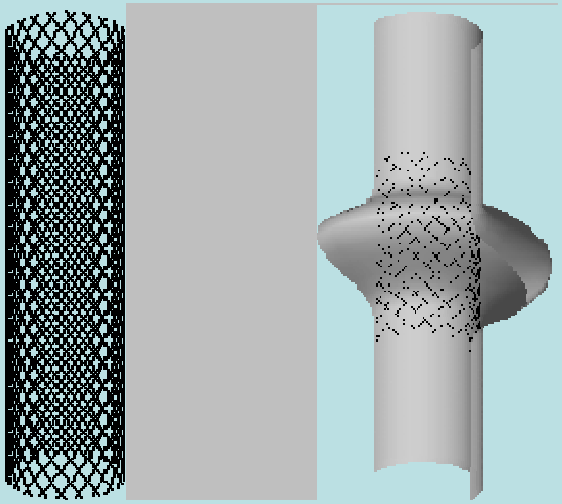
Aneurysm is characterized by the formation of sac-like protrusions of weakened sections of blood vessels that can rupture and be fatal. There is a 90% mortality rate associated with an out-of-hospital AAA rupture. Until recently, surgery has been the only treatment to prevent the aneurysm from rupturing. Since most of the patients are 55 or older and high risk, undergoing general anesthesia is not a solution.

Within the past ten years an innovative non-invasive procedure, which requires only local anesthesia, has been developed. The new procedure entails inserting a catheter into an artery and directing it to the site of the aneurysm. Placed in the catheter is a spring-like device called a stent, which serves to hold open the weakened artery and to exclude the aneurysm from circulation. This lowers the probability of rupture and promotes aneurysm shrinking due to thrombosis caused by the lack of blood supply to the aneurysm tissue.



The procedure is still considered experimental and reports of mid- or long-term outcomes indicate structural and positional changes of the stent, including buckling, kinking and migration. To improve the procedure, optimal stent design depending on the patient's anatomy and a study of the optimal anchoring strategies are needed.

e.

PROBLEM

FLUID-STRUCTURE INTERACTION BETWEEN
BLOOD FLOW AND ARTERIAL WALLS IN
HEALTHY AND DISEASED STATES

ANALYSIS OF FLUID-STRUCTURE INTERACTION CAN:

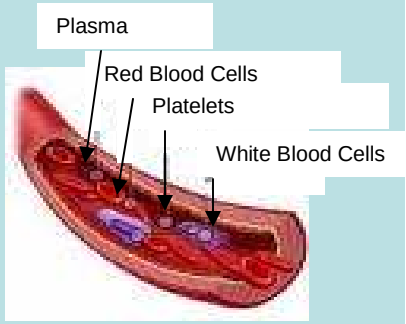
1. Help predict initiation of disease

2. Help improve treatment of disease

- aortic abdominal aneurysm (AAA) repair
- coronary artery disease (CAD) repair.

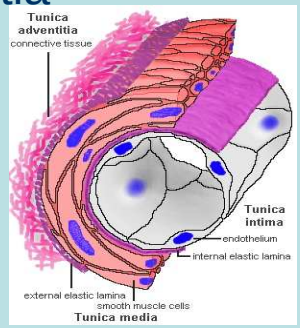
} Prostheses design for non-surgical treatment of AAA and CAD

DIFFICULT PROBLEM TO STUDY: MULTI-PHYSICS AND MULTI-SCALE NATURE



- BLOOD has complicated rheology: red blood cells, white blood cells and platelets in plasma (relevant at small scales)

- VESSEL WALLS have complex structure: intima, media, adventitia (+ smaller scales layers); different mech. char.

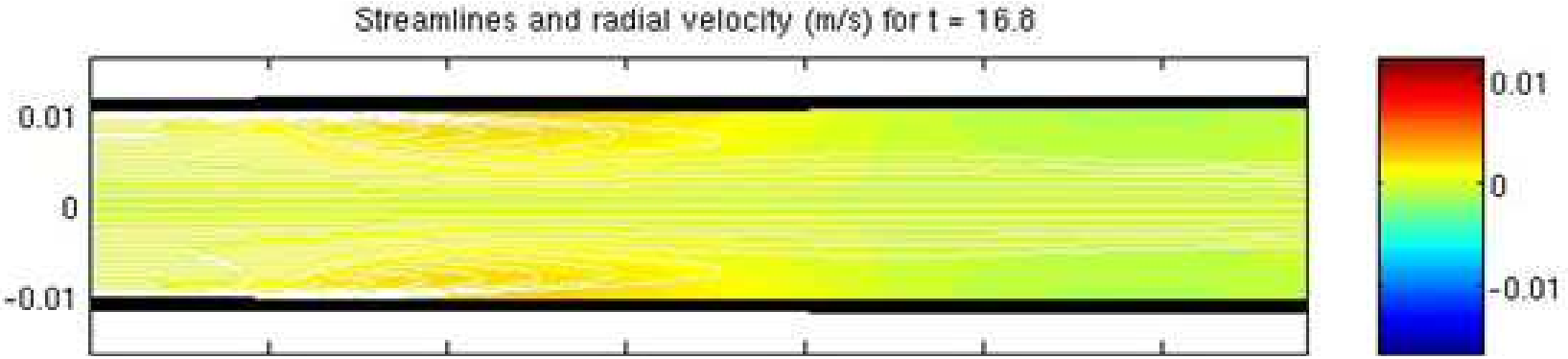


- Challenging to model.

- INTERACTION (COUPLING) exceedingly complicated.

COUPLING BETWEEN BLOOD FLOW AND VESSEL WALL MOTION

- NONLINEAR COUPLING: density of the arterial walls is roughly the same as density of blood
  - algorithms developed for other applications, e.g. aeroelasticity, UNSTABLE;
    - novel ideas and algorithms needed
- TWO TIME SCALES: fast traveling waves in arterial walls and slow bulk blood flow velocity
  - resolving both scales accurately requires sophisticated methods
- COMPETITION BETWEEN “HYPERBOLIC” AND “PARABOLIC” EFFECTS (wave propagation vs. diffusion)
  - resolving the two different effects requires different techniques



COMPREHENSIVE STUDY OF FLUID-STRUCTURE INTERACTION IN BLOOD FLOW

(medium-to-large arteries: laminar flow and Re away from the turbulent regime)

ANALYSIS

- Fundamental properties of the interaction and of the solution.
- Derivation of new closed, effective models.

COMPUTATION

- Design of a numerical algorithm ("kinematically coupled") with a novel operator splitting approach (hyperbolic/parabolic) with improved stability properties.
- Models allowing two different structures (stent modeling).
- Fluid-cell-structure interaction algorithm

VALIDATION AND TREATMENT

- Experimental validation.
- Application to AAA repair and coronary angioplasty with stenting.

TEXAS MEDICAL CENTER HOUSTON

STUDY OPTIMAL PROSTHESIS DESIGN FOR AAA REPAIR

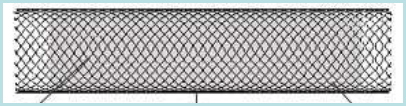
METHODS

- EXPERIMENTAL MEASUREMENTS OF PROSTHESES MECHANICAL PROPERTIES (Ravi-Chandar, UT Austin)
- MATHEMATICAL MODELING OF PROSTHESES MECHANICS AND DYNAMICS
- COMPUTER SIMULATIONS
- EXPERIMENTAL VALIDATION

RESULTS LEAD TO NEW STENT-GRAFT DESIGN

MODELING AND COMPUTATION PRODUCED:

•RESULTS FOR FLEXIBLE bare Wallstent.



- Wallstent 10 times more elastic than aorta: large radial displacements ANGIO
- large stresses and strains near anchoring (possibility of migration) PLAY MOVIE

Next slide →

POOR PERFORMANCE ➡ NO LONGER USED

•RESULTS FOR FABRIC-COVERED STENT-GRAFTS

- graft is stiff; elastic exoskeleton tends to pulsate: possibility for suture breakage
- stiff graft: elevated local transmural pressure COMPARISON MOVIE

➡ NON-UNIFORM STIFNESS MINIMIZES STRESS AT ANCHORING

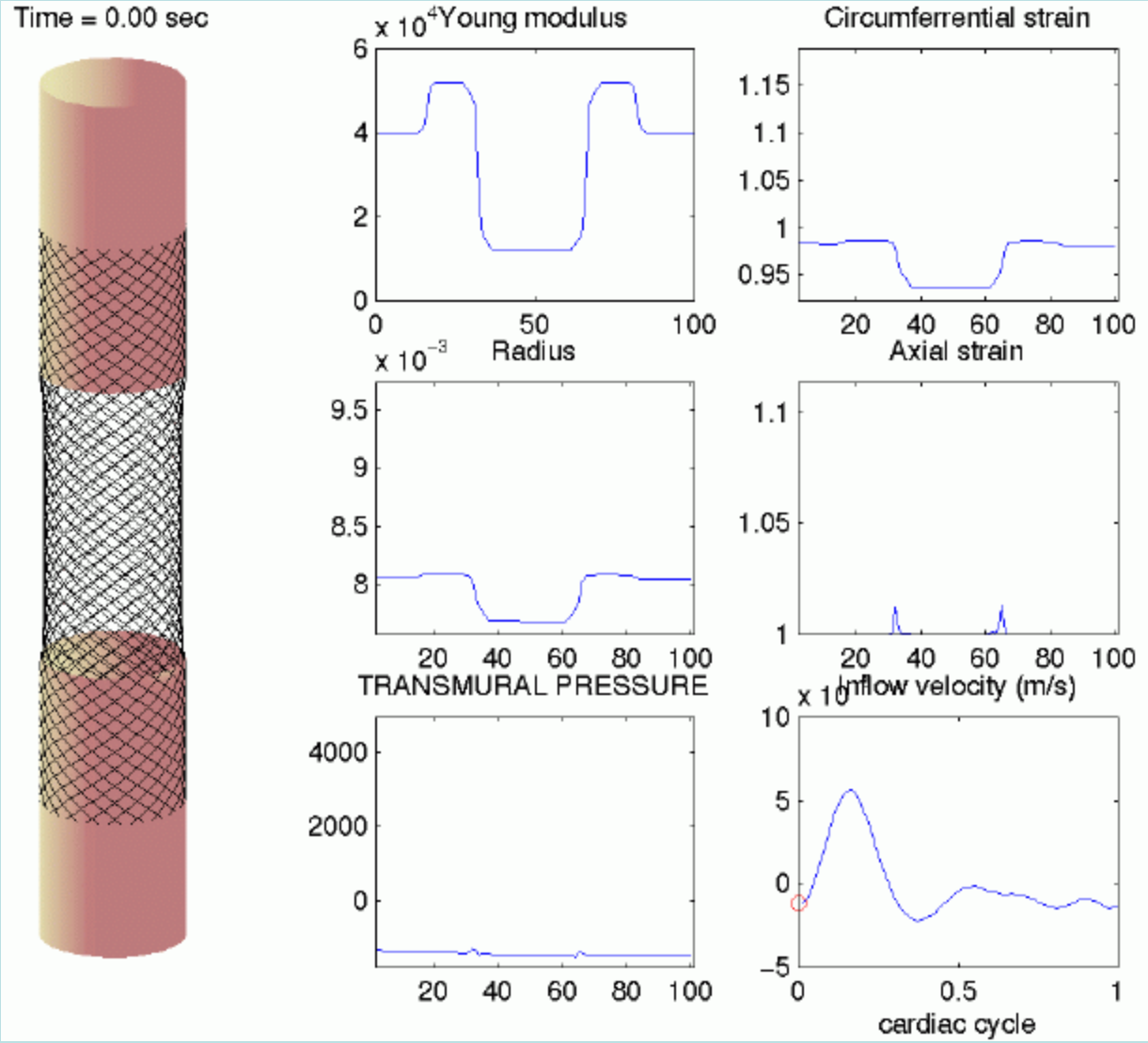
[1] Canic, Krajcer, Lapin, Endovascular Today (2006)

[2] Canic, Krajcer, Chandar, Mirkovic, Lapin, Texas Heart Institute Journal (2005)

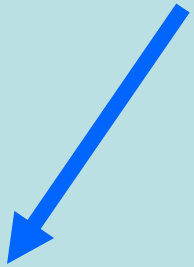
[3] R. Wang and K. Ravi-Chandar, Mechanical response of an aortic stent I and II *Journal of Appl. Mechanics,* (2004.)

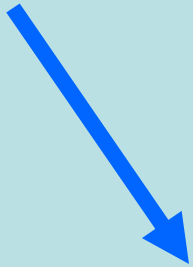
[4] SIAM News, Vol. 37 No. 4 (2004) Dana McKennzie

AAA Walstent (compliant)



MATHEMATICAL MODELING AND COMPUTATION



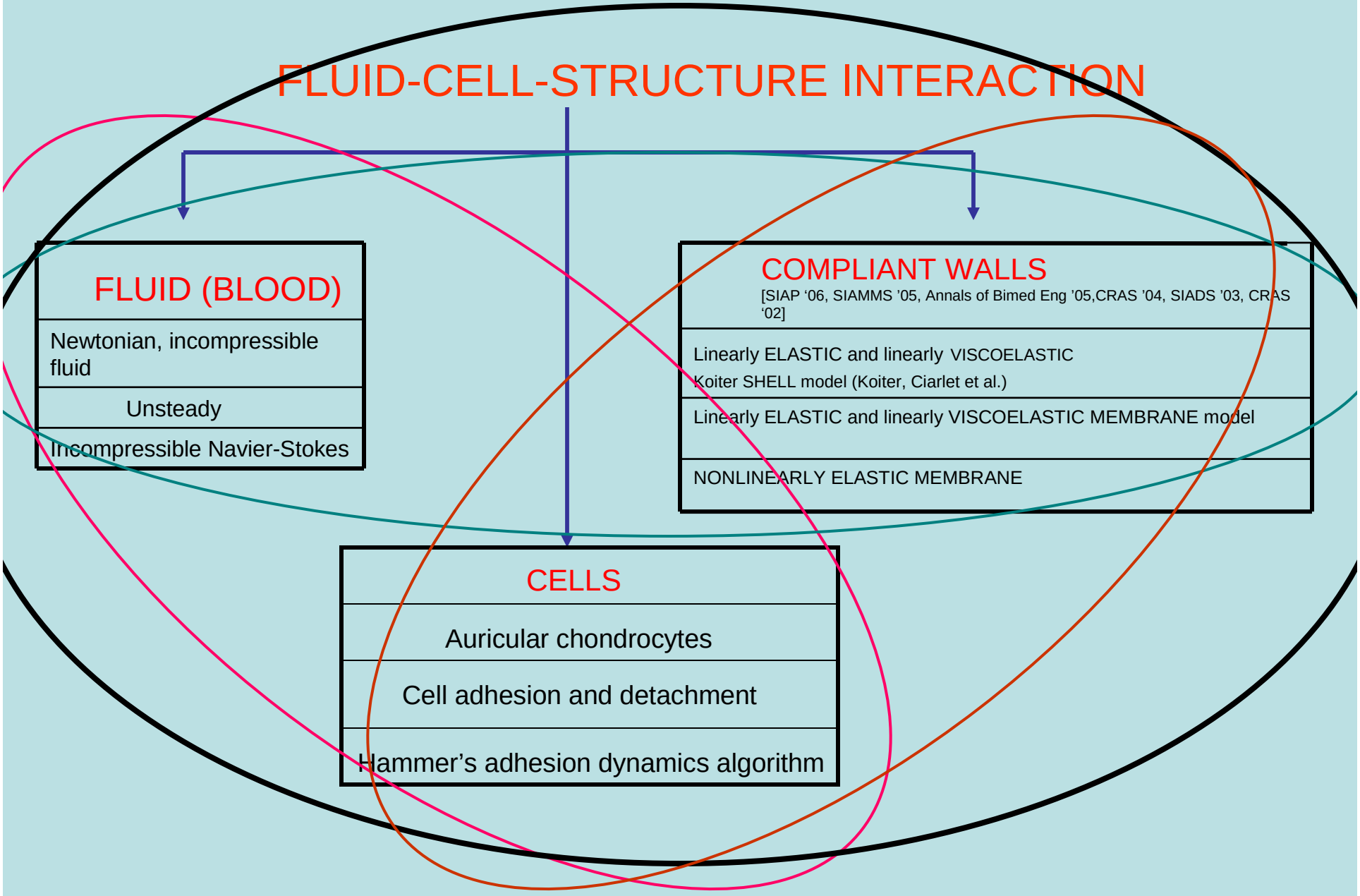


DETECT DEVICE'S STRUCTURAL DEFICIENCIES

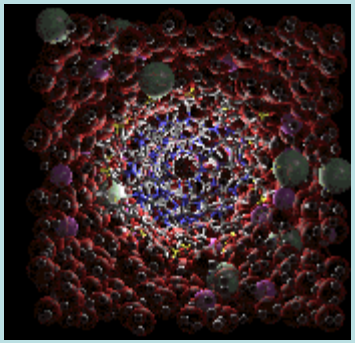
SUGGEST IMPROVED DEVICE DESIGN

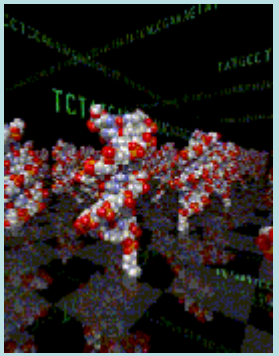
MATHEMATICAL PROBLEM

FLUID-CELL-STRUCTURE INTERACTION



MATHEMATICAL FLUID-STRUCTURE INTERACTION IN BLOOD FLOW





B. Montgomery Pettitt

Hugh Roy and Lille Cranz Cullen Distinguished Professor of Chemistry, Physics, Computer Science, Biology and Biochemsitry,

Director of the Institute for Molecular Design

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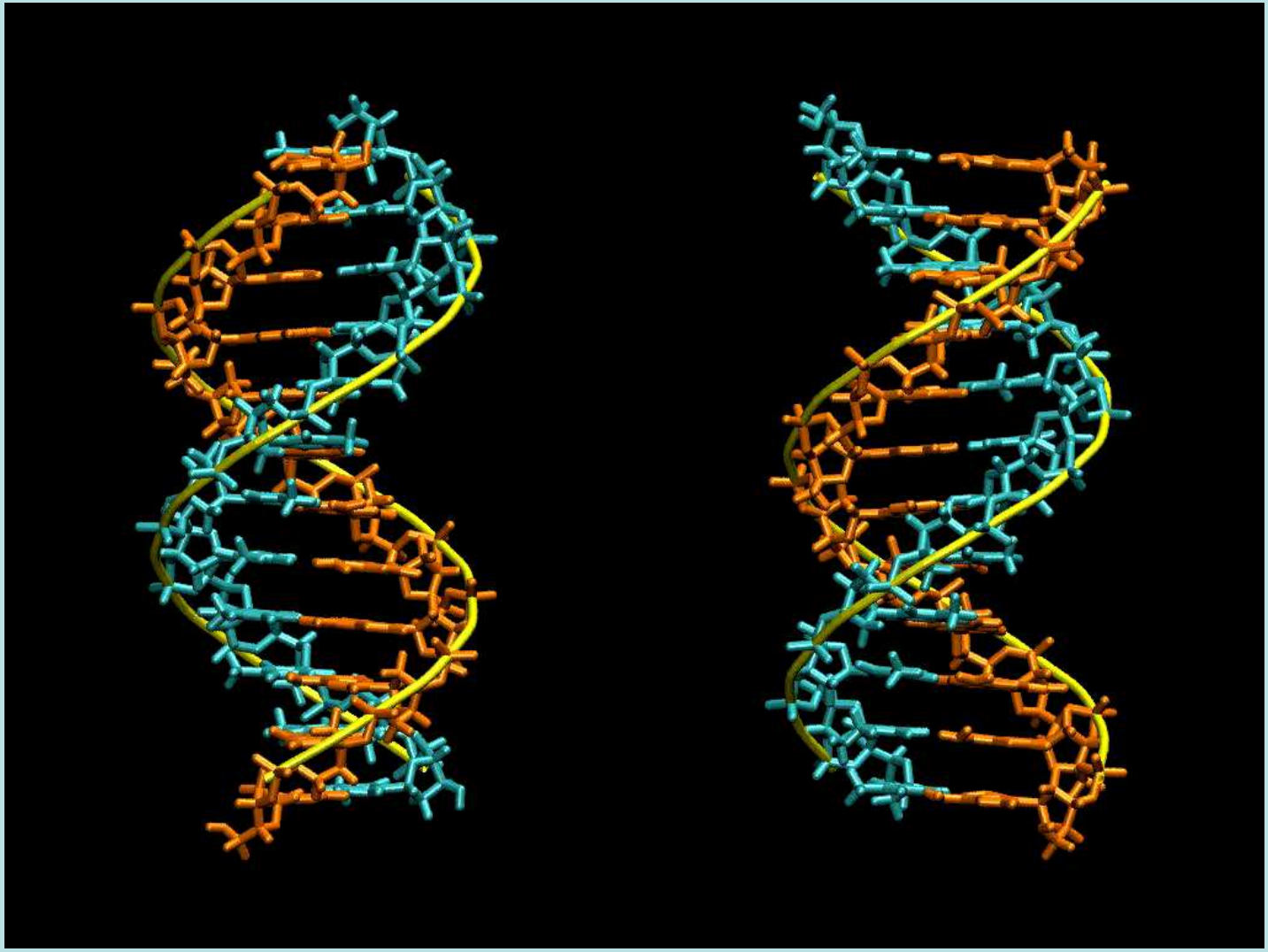
Effects of anisotropic environments on DNA and Proteins

Computational methods to investigate solution systems with couplings and correlations at many disparate length and time scales

Simulation of fundamental structure and dynamics of the liquid state: Most difficult is the question of ionsin aqueous solution and biomolecular solutions

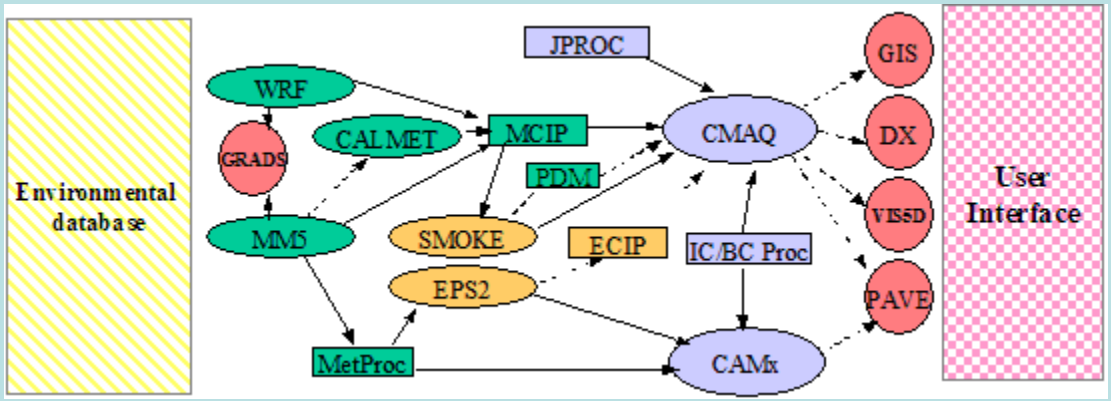
Computational methods to explore phase transitions in saline solution and protein folding in multicomponent systems.



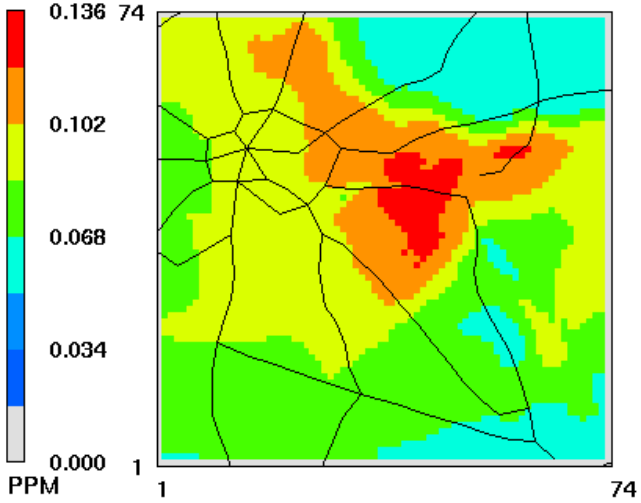
Air Quality Modeling
Dr. Daewon Byun
Director, Institute for Multi Dimensional Air Quality Studies

The modeling paradigm that incorporates different meteorological models, two emission inventory models, and two chemical transport models were used, along with assorted supporting pre- and inter-processing programs. The primary analysis tools are based on the Community Multiscale Air Quality (CMAQ) modeling system which is the latest Eulerian air quality model made available by the U.S. EPA. CMAQ employs the best available techniques for advection, diffusion, and complex chemical transformation of a variety of pollutants. The system consists of three primary components (meteorology, emissions, and a chemical transport model) and several interface processors.

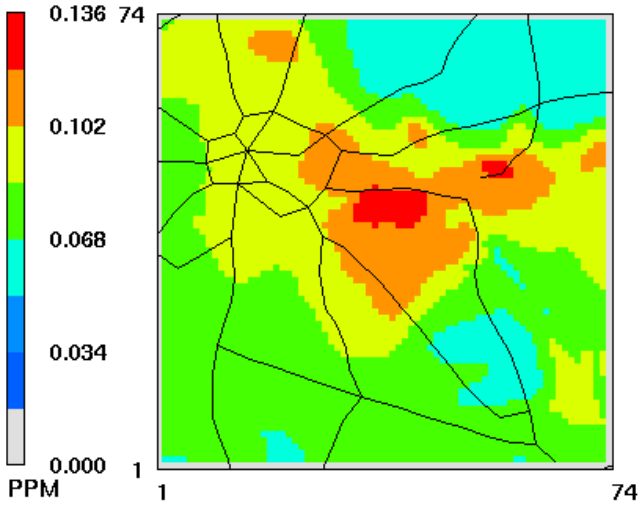
The arrows show the flow of data through the modeling system.



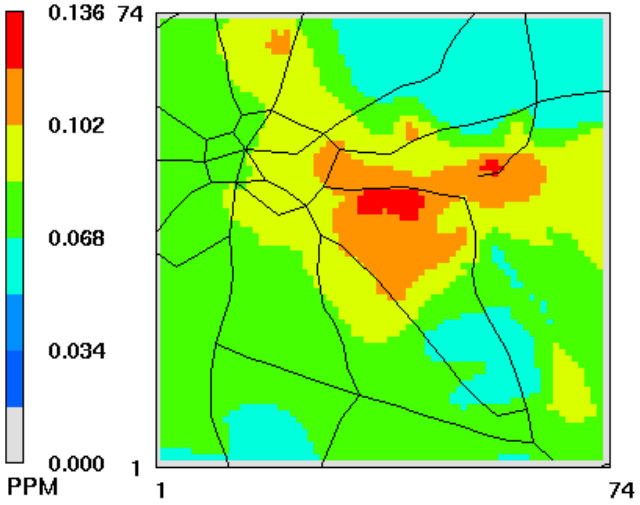
Mobile Reductions – 2007 Control Case – Aug 31



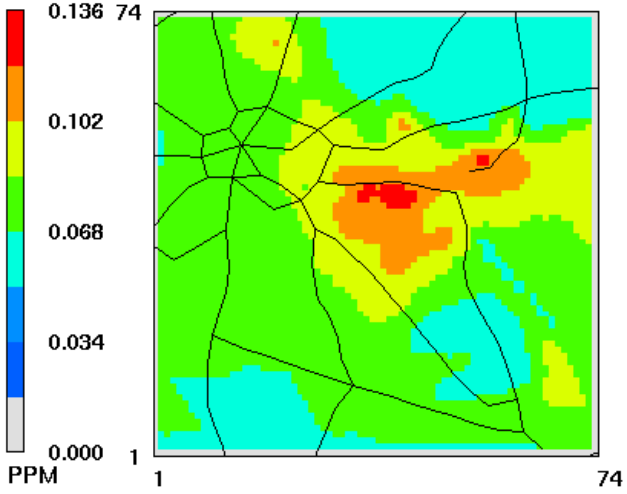
0% Reduction – 136 ppb



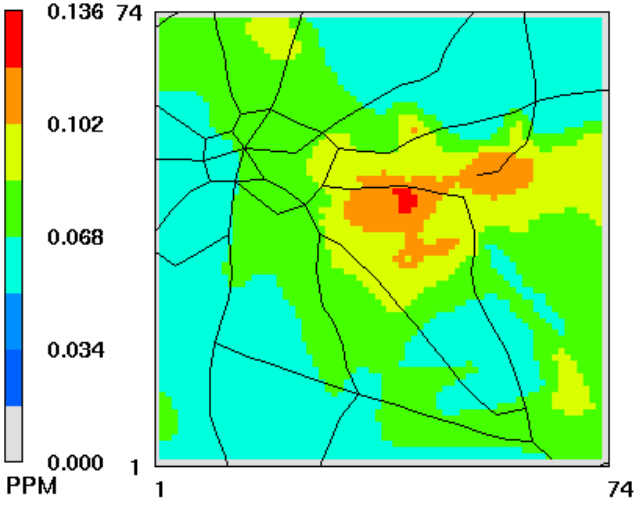
25% Reduction – 133 ppb



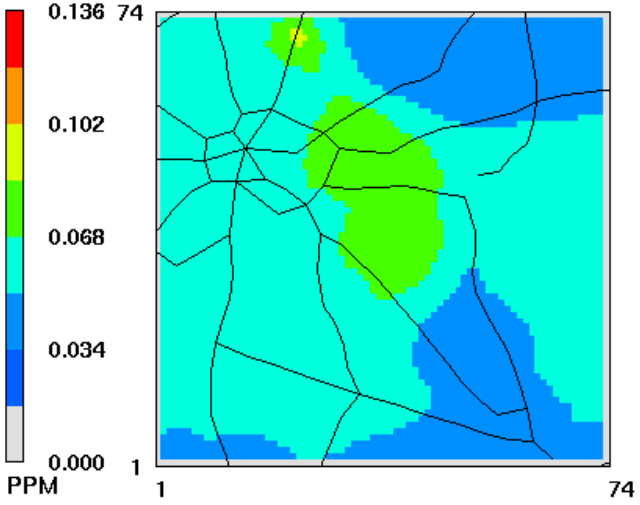
50% Reduction – 131 ppb



75% Reduction - 129



100 % Reduction – 127 ppb



0% mob, 0% pt – 88 ppb

Public Health Task Force

1 km