Large-Scale Computing and Visualization for Cardiopulmonary Imaging

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NIH Shared Instrumentation Grant SIG

- Purpose: NCRR's SIG program supports the purchase of research equipment in the $100,000 to $500,000 price range.
- Eligibility Requirements: 3 or more major users of the equipment who are PIs on active NIH awards funded through P01, R01, U01, R35, R37, DP1, or DP2 mechanisms.

Motivation: Sharing and Collaboration

- The spirit of the IMAG MSM consortium is to promote model sharing and collaboration.
- Major equipment can facilitate and foster interdisciplinary collaboration and research.
- Share the experience of putting together an SIG grant application.
- Demonstrate the scope of the collaboration at UI, and at national (National Biomedical Computation Resource, NBCR-UCSD) and international (NZ Bioeng. Institute) levels.

Equipment Requested

- $480K cluster for computation & visualization
- Bring closer together computing & imaging groups for broader collaboration and data/software sharing.
- 3 needs: data storage, number crunching (both sequential and parallel computing), and visualization.
- Status: reviewed, scored, and pending depending on an appropriation for FY 2008.

Needs for Computing &Visualization

- Data storage:
  - Human lung volume MDCT data: research data 3.2 GB/subject vs clinical data 300 MB/subject.
  - Micro-CT: 90 GB.
  - CFD: 50-60 GB data/case for a 6 generation CT-based airway model.
- Computation (CFD & image matching):
  - Flow in a 16-(or more)generations airway model.
  - 4D registration to establish an atlas of the normal human lung for 4 decades of age range.
- Visualization: CPU memory & graphics cards.

Summary of the Requested Cluster Configuration	
Item	**Description**
110 Compute Nodes	
64bit Linux	110 node (**440 cores**) 64-bit AMD Opteron 280 processors
0.88 TB Memory	2 GB RAM per core, **8** GB RAM per node, sharable on node
27.5 TB Disk	250 GB disk per node for parallel job scratch space
Gigabit Ethernet	Dual gigE interface cards per node
8 Visualization Nodes	
64bit Linux	8 nodes (**32 cores**) 64-bit AMD Opteron 280 processors
0.256 TB Memory	8 GB RAM per core, **32** GB RAM per node, sharable on node.
Disk	250 GB disk per node for job scratch space
High-end Video Card	PNY Quadro FX3400 256MB PCI-Express Video Card
Master Node	
64bit Linux Master Node	master node (4 cores) 64-bit AMD Opteron 280 processors
32 GB Memory	8 GB RAM per core, sharable on node
Disk	250 GB disk for OS and scratch space
Gigabit Ethernet	Dual gigE interface cards – one for message passing and one for command & control
30 TB Storage	
30 TB RAID Storage	4 x RAID storage –16 x 500 GB drives
FC Switch	Dual channel high speed (4GB/s) FC switch
16 bay drive trays	4 x 3U drive tray with rails and cables
Rack, Power, Network, and Compiler	
3 72U Racks	APC Netshelter VX Enclosures
8 Power Dist. Units	APC power distribution units for all racks
3 48 Port gigE Switch	Nortel 5510-48T 48 port 10/100/1000 Gigabit Ethernet switch
In-rack LCD	1U in-rack LCD monitor, keyboard, mouse
3 48 Port Console Servers	AlterPath 48 port console servers for system administration
Compilers	Intel FORTRAN compilers
Cluster tool kit	TeamHPC Cluster Management Toolkit
Linux	Red Hat Linux
Sun N1 Grid Engine	Sun N1 (commercial) Grid Engine software package

Major Users by Topic

Topic	Grant	Major Users	Percent of Resource
1. Pulmonary Air Flow	R01 EB 005823 R01 HL 064368	Lin[1], Hoffman[2], Tawhai[3], McLennan[4]	25%
2. Lung Mechanics	R01 HL 079406	Reinhardt[5], Christensen[6], Hoffman[2], McLennan[4]	10%
3. Image Matching	R01 HL 064368 R21/R33 EB 004126	Christensen[6], Reinhardt[5], Sonka[7], Hoffman[2], McLennan[4]	20%
4. Lung Morphometry	R01 HL 064368 R01 HL 080285	Hoffman[2], McLennan[4], Reinhardt[5], Tawhai[3], Christensen[6]	15%
5. Cardiovascular Imaging	R01 HL071809 R01 EB004640	Sonka[7], Wahle[8], Saha[9], Beichel[10]	10%
6. New Projects	See the note below	New Users	20%
Total:			**100%**

- *It should be noted that, because some jobs can run simultaneously on this cluster, there is likely room for expansion of the above time allotted to each project as well as time for expansion of projects. The above estimates are highly conservative for planning purposes.*
- *"Topic 6" aims for training and recruiting new users, supporting new NIH-funded projects and including a broad base of users from other related research programs on campus.*
- *The superscript under the "Major Users" column denotes the major user ID number.*

NIH Awards Benefited from Cluster

PID	NIH Grant Number	Project Title	PI	Academic Affiliation
1	R01 EB005823	Multiscale Simulation of Gas flow Distribution in the Human Lung	Ching-Long Lin	Mechanical Engineering
2	R01 HL064368	Image and Model Based Analysis of Lung Disease	Eric A. Hoffman	Radiology and Internal Medicine
3	R01 HL079406	Regional Lung Mechanics by 3D Image Registration	Joseph Reinhardt	Biomedical Engineering
4	R21/R33 EB004126	NIREP: Non-rigid Image Registration Evaluation	Gary Christensen	Electrical & Computer Engineering
5	R01 HL080285	Quantitative CT-Based Lung Atlas of the Mouse	Eric A. Hoffman	Radiology and Internal Medicine
6	R01 HL071809	Highly Automated Analysis of Cardiovascular MR Data	Milan Sonka	Electrical & Computer Engineering
7	R01 EB004640	Graph-Based Medical Image Segmentation in 3D and 4D	Milan Sonka	Electrical & Computer Engineering

Growing Collaboration

- NIH BRP, 1999-2010 (PI, Hoffman)
- I-CLIC, *Iowa Comprehensive Lung Imaging Center*, 2004 (Director, Hoffman)
- IIBI, *Iowa Institute for Biomedical Imaging*, approved by the Board of Regents, the State of Iowa, October 2007 (Director McLennan and co-Director Sonka)

I-CLIC: Director Dr. Hoffman

Multi-Detector row CT (MDCT) & Micro CT scanner

Future plan: vertical MRI (SIG)
Dr. Edwin van Beek
(UI Physician and MRI expert)

Partnership members and I-CLIC Grand Opening (2004)

IIBI: Dr. McLennan and Dr. Sonka

- A collaborative venture between UI College of Medicine and College of Engineering to foster multidisciplinary research.
- http://www.engineering.uiowa.edu/news/newsDetail.php?newsID=105
- http://www.biomed-imaging.uiowa.edu/
- The 200,000-square-foot facility located at the planned

Institute for Biomedical Discovery ($120 million).

Multiscale Simulation of Gas flow Distribution in the Human Lung

C.-L. Lin

High-Performance Computing & Flow Physics

E. A. Hoffman

CT Imaging & Lung Physiology

G. McLennan

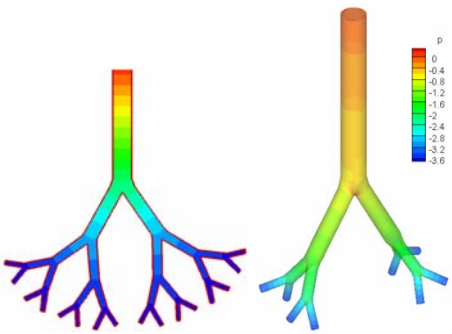
Bronchoscopy & Pulmonary Physician

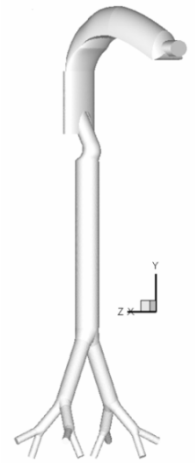
M.H. Tawhai

Lung Physiome & Geometric Modeling

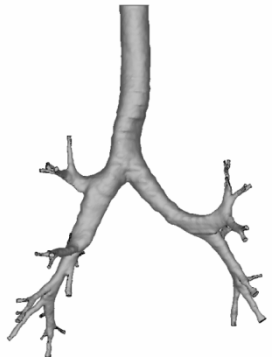
Then and Now

Gambit (manual)

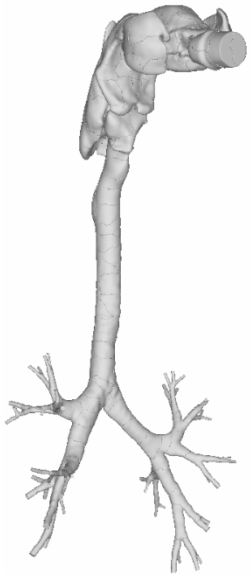




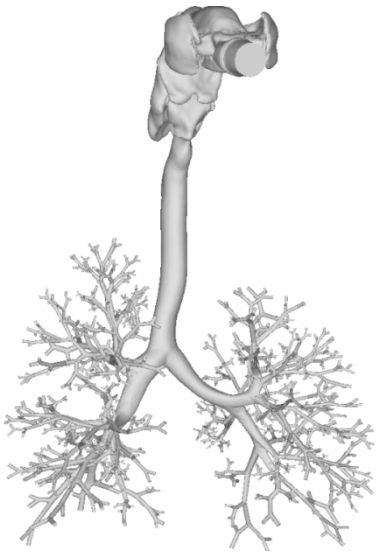
2004



2005



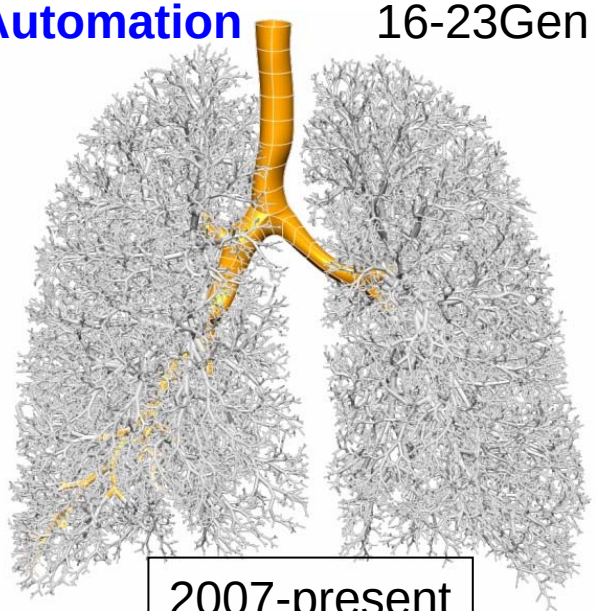
2006



2006-2007

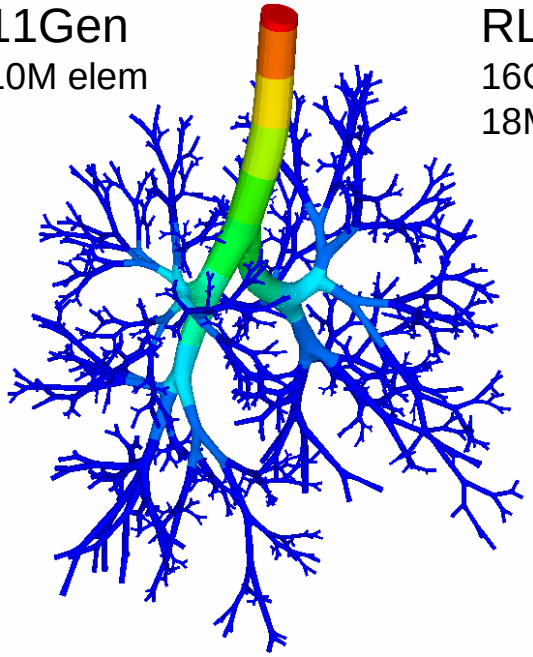
Automation

16-23Gen

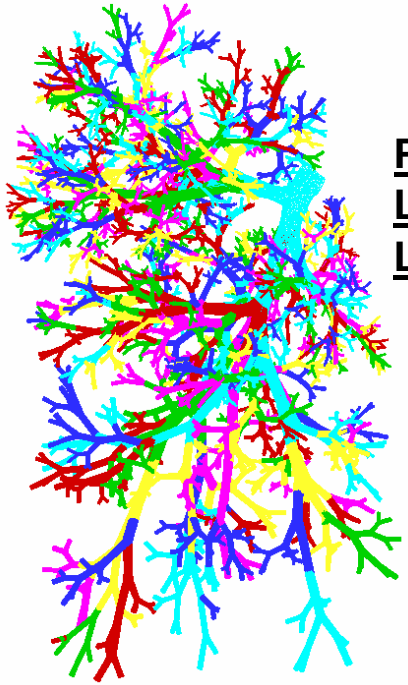


2007-present

11Gen
10M elem



RLL
16Gen
18M elem



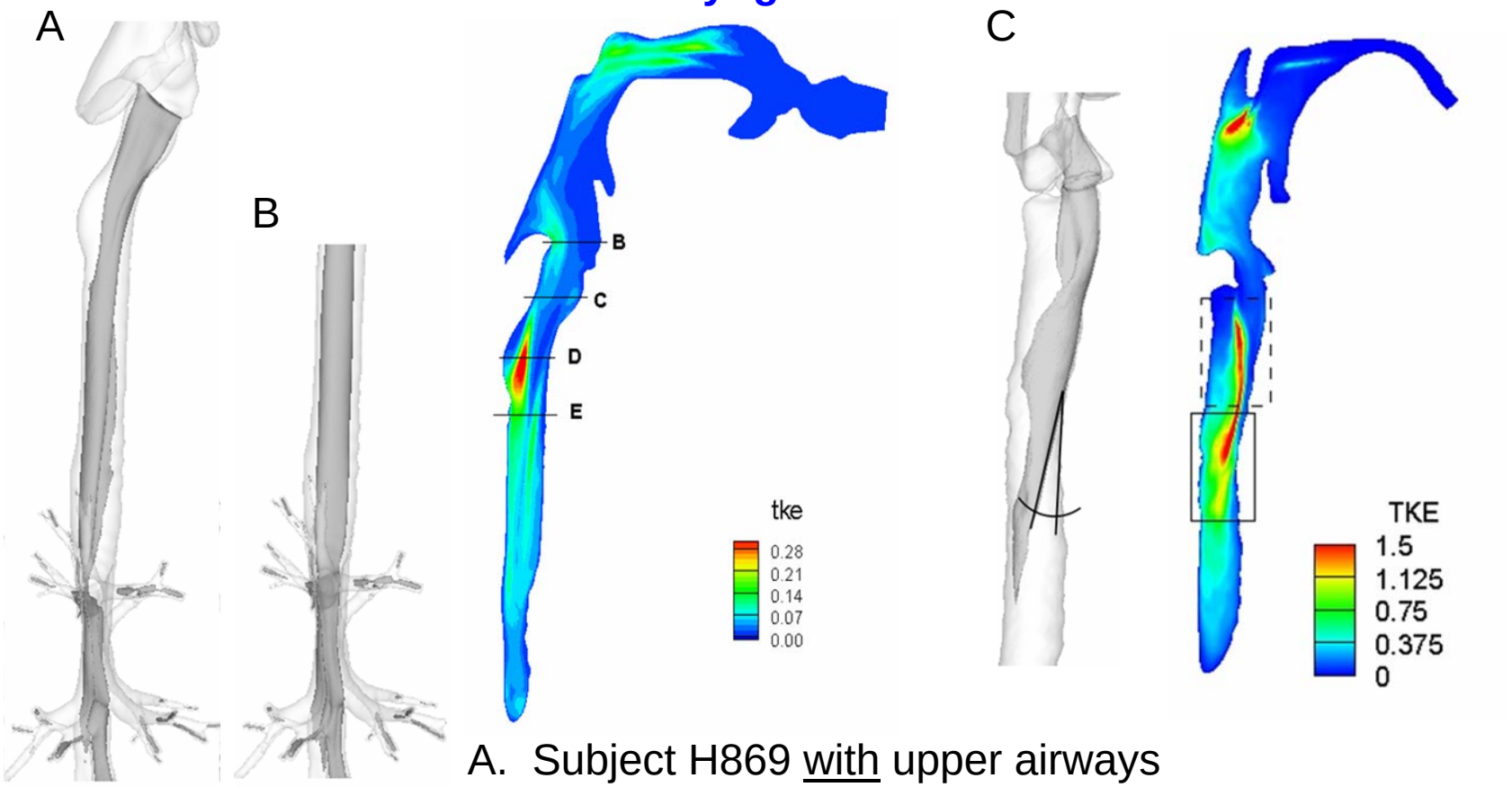
Right Lower Lobe

Computer Time in Service Unit (SU)

Estimation of SU				
	5-6 Generation (Fine Mesh)	**11 Generation (Coarse Mesh)**	**11 Generation (Fine Mesh)**	**16 Generation (Fine Mesh)**
# Airway branches	~ 109	~ 7,700	~ 7,700	~ 245,749
# Node points	454,165	1.5 million	~ 32 million (= 7,700 × 4,200)	~ 1 billion (= 245,749 × 4,200)
# Points/branches	~ 4,200	~ 210	~ 4,200	~ 4,200
SU for one breathing cycle	~ **267**	~ **1,068**	**~18,861** (2.2 years on a single CPU)	~**601,972** (69 years on a single CPU; 57 days on 440 CPUs)

Multiscale Effects for Individualized Medicine : Large Upper Airways

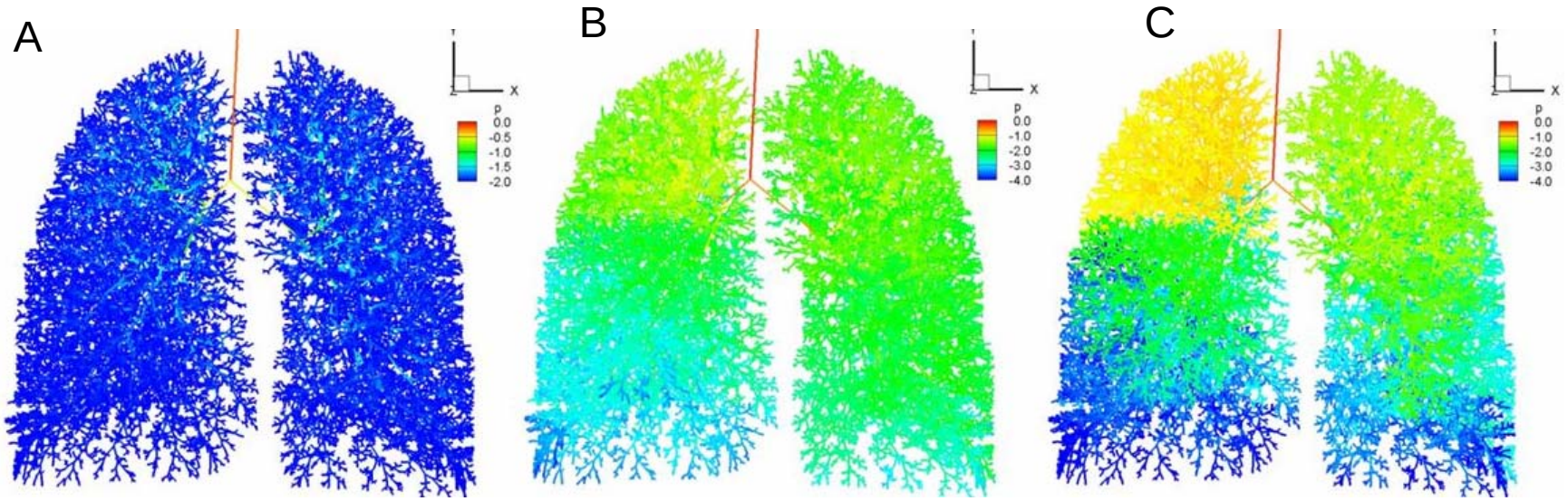
Turbulent Laryngeal Jet



A. Subject H869 with upper airways
B. Subject H869 without upper airways
C. Subject H1016 with upper airways

Multiscale Effects for Individualized Medicine: Regional Ventilation

Pressure Contours (1D flow model)

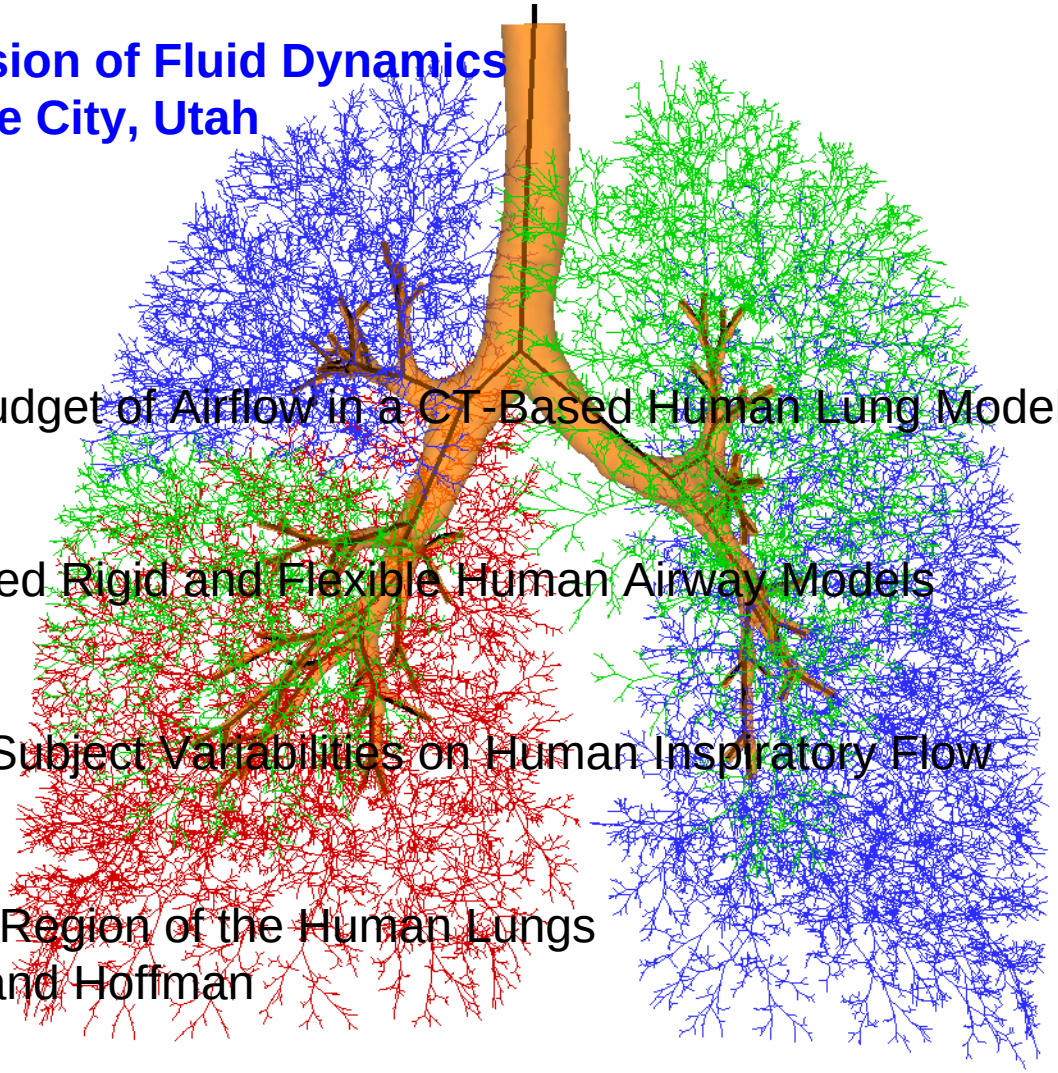


A. Uniform pressure boundary condition
B. Uniform velocity boundary condition
C. CT-lobe-based regional ventilation

1D-3D Coupled Simulations

60th Annual Meeting of the Division of Fluid Dynamics
November 18–20, 2007; Salt Lake City, Utah

Session GD: Biofluids VII
Chair: Michael Plesniak



•Airway Resistance and Energy Budget of Airflow in a CT-Based Human Lung Model.
Lin, Tawhai, and Hoffman

•Comparison of Air flow in CT-Based Rigid and Flexible Human Airway Models
Xia, **Lin**, Tawhai, and Hoffman

•On the Effects of Intra- and Inter-Subject Variabilities on Human Inspiratory Flow
Choi, **Lin**, Tawhai, and Hoffman

•Patterns of Mixing in the Alveolar Region of the Human Lungs
Kumar, **Lin**, Tawhai, McLennan, and Hoffman

Technical Expertise needed in SIG

- Installation, Maintenance, and Operation
- Training of New Users
- Organizational & Management Plan
  - Utilization Plan – user account & allocation
  - System Security
  - Additional Measures to Recruit New Users
  - **Internal Advisory Committee**
  - Software and Data Sharing
  - Financial Plan
- Institutional Commitment

Internal Advisory Committee

Name	Title	Department, Center or Institute
Geoffrey McLennan	Professor, Director of Interventional Bronchoscopy and IIBI Director	Internal Medicine, College of Medicine; Iowa Institute for Biomedical Imaging Institute (**IIBI**)
Peter Thorne	Professor and EHSRC Director	Occupational & Environmental Health, College of Public Health; Toxicology, College of Medicine; Environmental Health Sciences Research Center (**EHSRC**)
Thomas L. Casavant	Roy J. Carver, Jr. Chair Professor and CBCB Director	Biomedical Engineering and Electrical and Computer Engineering, Center for Bioinformatics and Computational Biology (**CBCB**)
Larry Weber	Donald E. Bently Faculty Fellow of Engineering, Professor and IIHR Director	Civil and Environmental Engineering, IIHR-Hydroscience & Engineering (Iowa Institute of Hydraulic Research, **IIHR**)
Mark Wilson	Data Systems Coordinator	IIHR-Hydroscience & Engineering
Boyd Knosp	Director	University Information Technology Research Services

Broader Impact

MSM

I-CLIC

IIBI

EHSRC

IIHR

NZ Bioeng. Inst.

NBCR-UCSD

AMCS

BRP Partners

SIG-cluster

SIG-vertical MRI

High-End-SIG
Gas Polarizer

NIEHS-EHSRC

- Data storage
- Computation
- Visualization

- Medical Imaging
- Health Sciences
- Engineering
- Mathematics
- Biostatistics
- Computer Sciences

Thank You!