Introduction to Spatial Audio

Course goals

- Sound is an extremely important part of life for humans
  - Communication
  - Sense-making and sensing
  - Geometric perception
  - Pleasure
  - Survival
- As computing, sound sensors, loudspeakers become ubiquitous, significant opportunities for computer science/engineering/audio-folks

Audio and Computer Science

- Speech processing is a significant area of research.
  - Goal to talk to your computer (Star Trek, 2001 Space Odyssey, etc.)
  - Well represented in CS departments
  - Process of speech recognition is
  - Sound -> Features -> recognition
  - We will very briefly touch on this

Digital Signal Processing

- Core course in EE departments, and increasingly in other areas
- Representation and manipulation of signals using families of functions
  - Fourier series, wavelets, and others
  - Fast algorithms

Auditory Psychophysics

- How does the human system
  - Capture
  - Analyze
  - Process

Audio

- What are its capabilities and limitations
- How can one exploit these capabilities in designing audio systems

Spatial Audio

- Sound is usually created by relatively compact sources that occupy a small region
- It scatters off various objects in the world and is perceived/recognized after human/computer auditory processing
- Humans draw various percepts from the processed sound
  - Labels applied after processing
    - Direction, location, ambience, quality, near, far, …
- Computers can also process sound and determine
  - Direction, location, signal-to-noise ratios, …

Source Localization

- Obtain sound source location
- Obtain direction of the source

Course Administrative Details

- Prerequisites: The course will be somewhat mathematical, and you should be comfortable or willing to work with some differential equations and do some Matlab programming.
- Exams: There will be a mid-term and a final exam. In addition there will be homework that either involves short problem sets, or require reading of research papers.
- Credit: For computer science students, the class will count as a PhD qualifying course, and a MS qualifying course in Visual and Geometric Computing. The MS comp grades will be based on the mid-term and final exam.

Outline

A survey of the field and applications

Some basic principles of physical acoustics;

Notions of frequency, the Fourier transform, and representations for analysis;

An introduction to the human auditory system

Review of basic signal processing

Source localization and beamforming with arrays of microphones.

Human spatial hearing: The physical and psychoacoustical basis of sound localization and space perception.

Room acoustics: sound propagation in rooms. Modeling. The influence of short and long term reverberation.

Head related transfer functions

Modeling Room impulse responses and head related impulse responses.

An introduction to commercial systems for surround sound and spatial audio.

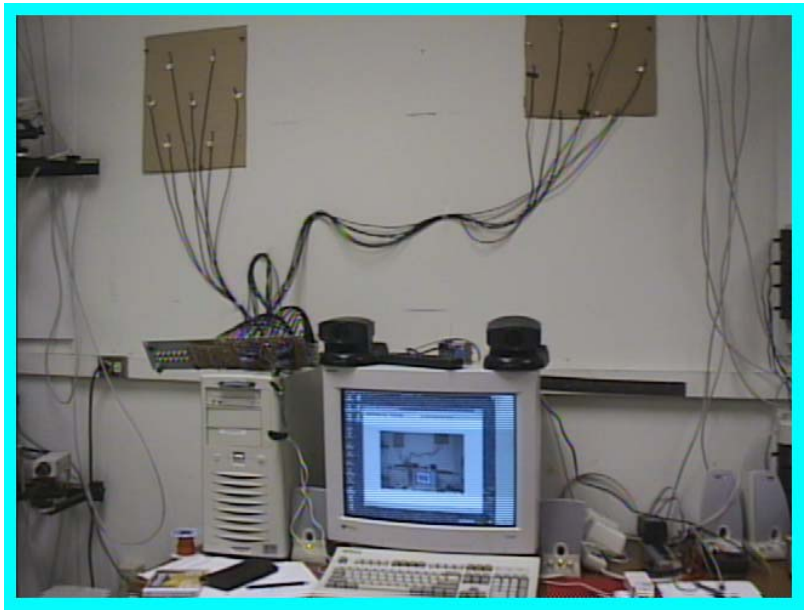
Emerging Spatial Audio Playback systems: Wave Field Synthesis. Ambisonics.

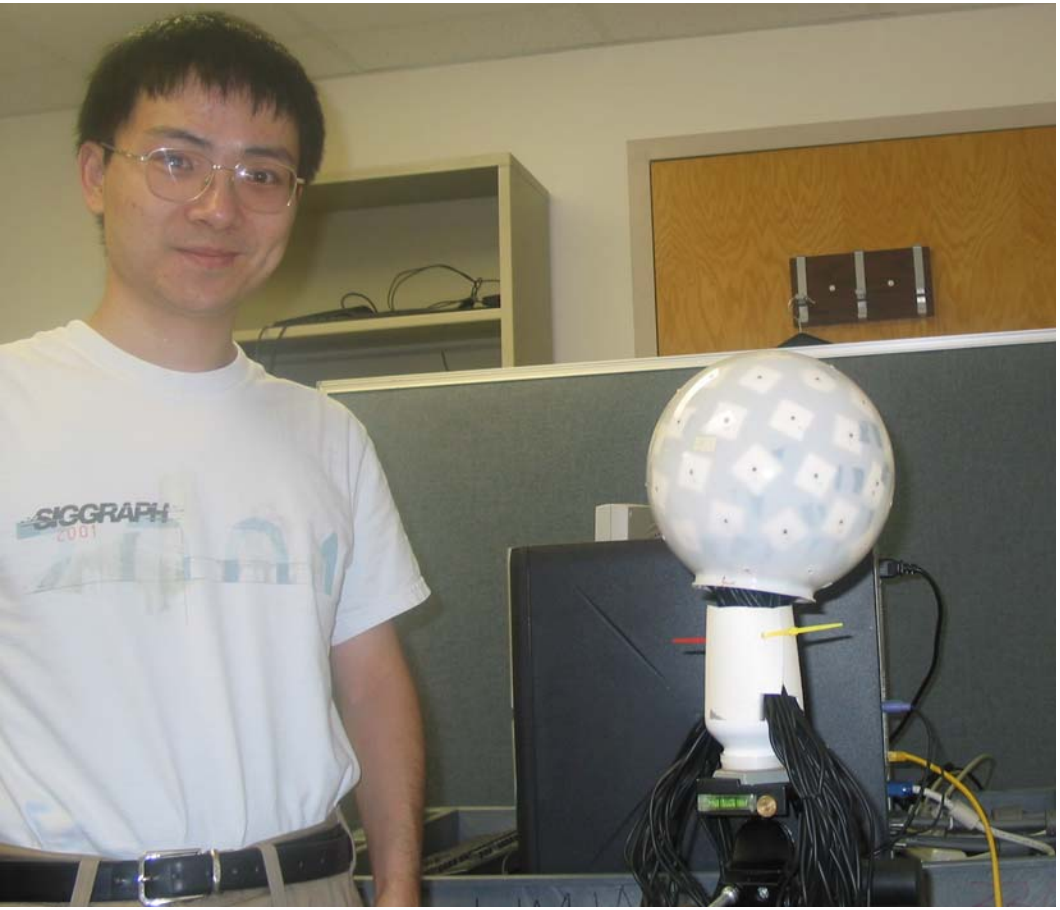
Research systems being developed at the University of Maryland.

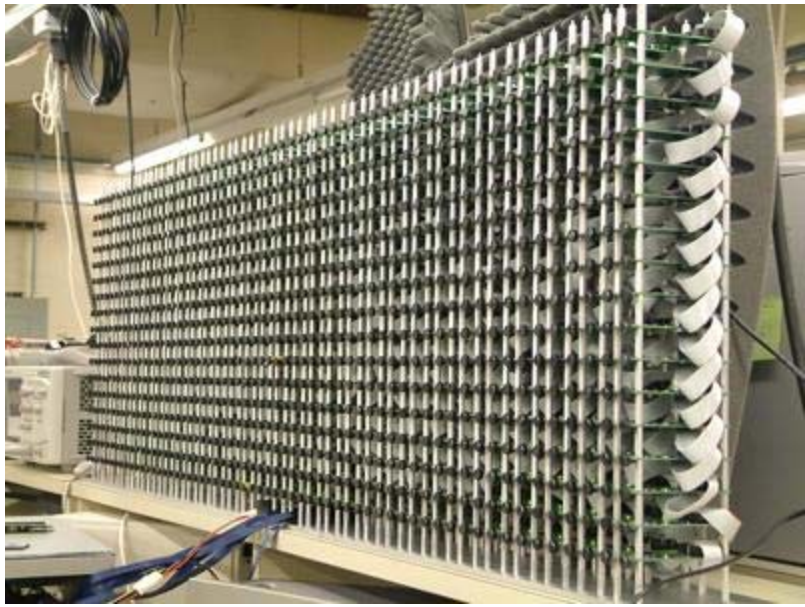
Selected Research topics

Array signal processing

- Use an array of microphones/hydrophones to localize and recognize sound sources
  - Sonar arrays during the cold war
  - Hunt for Red October (Tom Clancy)
- Array signal processing important in many areas, including for sound capture by PCs and speakerphones, antenna design for cell-phones, bluetooth etc.




SIGGRAPH
2001

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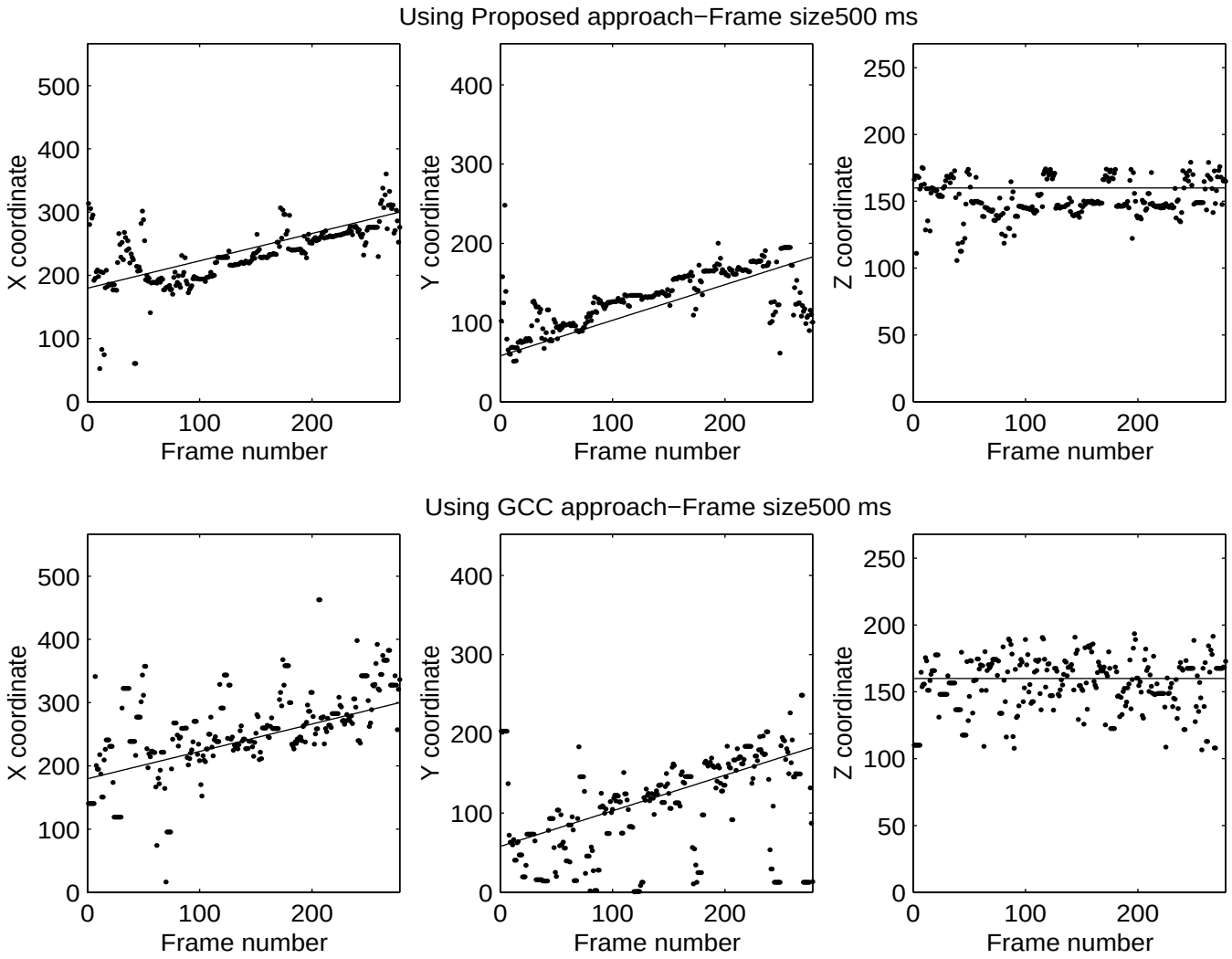
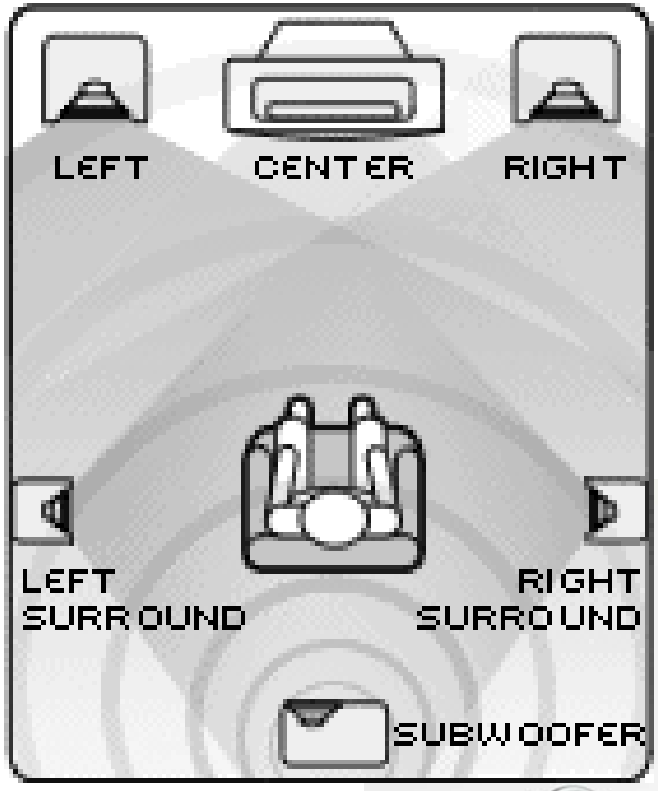
Localization and tracking



Sniper detection


LEFT
CENTER
RIGHT
LEFT
SURROUND
RIGHT
SURROUND
SUBWOOFER


Klipsch

Speaker Arrays

- Design speakers to create virtual reality
- Design speakers to create sound directed at points
- 5.1, 7.1. 42.x systems

Simulating speaker arrays on headphones

- Lots of content is created for multi-speaker systems (x.y)
- How to play these back on headphones?

Games and Virtual Reality

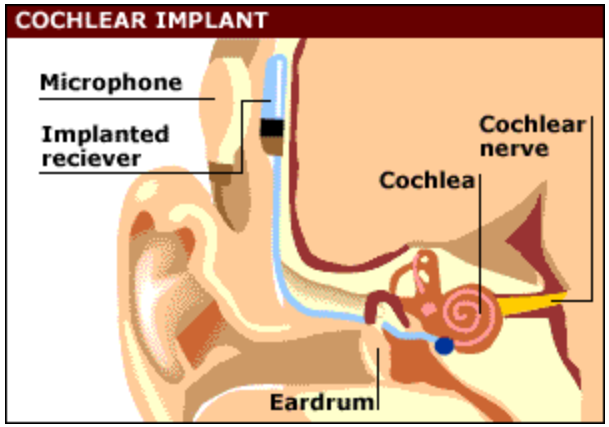
- Create spatially distributed sounds
- Artificial environments
- Capture spatial sound for analysis and later playback

Human Computer Interaction

- Sounds to signify events
- Spatial presentation of data
- Hands free speech capture
- Speaker localization

Auditory Prostheses

- Hearing aids
- Cochlear implants
- Auditory Displays



Mathematical Tools

- Signal processing for analyzing sound and extracting features from it
- Mathematical acoustics to understand the interaction of sound with scattering objects
- Some notions of learning, and statistics

Biological tools

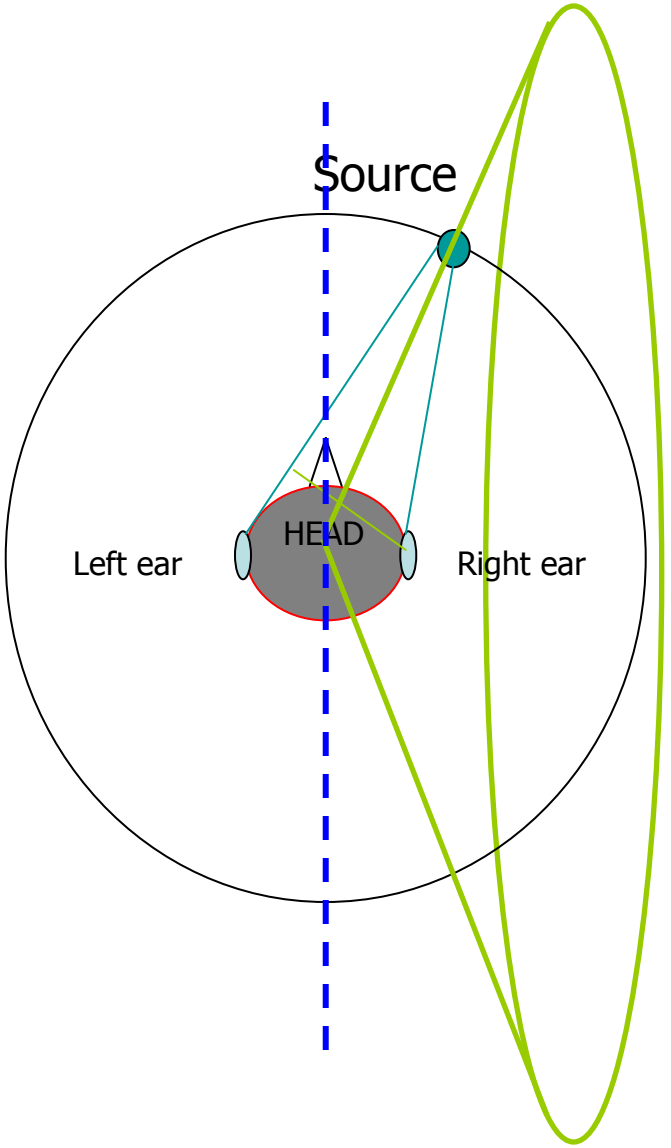
- Many problems appear insoluble … however humans easily solve them and provide a proof of existence of solutions
- Understand how human system does things
- Cochlear signal processing, head related transfer functions,
- Psychophysics: Capability of the human system, Just noticeable differences, …

Head Related Transfer Functions

- Scattering of sound off humans
- Research area I am involved in, and will be somewhat over-represented in this course.

How do we perceive sound location?

- Initial idea: Measure attributes of received sound at the two ears
- Compare sound received at two ears
  - Interaural Level Differences (ILD)
  - Interaural Time Differences (ITD)
- Surfaces of constant Time Delay:
  $| x\text{-}x_L | - | x\text{-}x_R | = c\ \delta t$
  - hyperboloids of revolution
  - Delays same for on cone-of-confusion
- Level differences vanishingly small
- Other mechanisms necessary to explain
  - Scattering of sound
    - Off our bodies
    - Off the environment
  - Purposive Motion



HRTFs are very individual

- Humans have different sizes/shapes
  - Ear shapes are very individual as well
  - Properties of scattered wave are different
  - HRTFs will be very individual
- Need individual HRTFs for creating virtual audio
- Typically individual HRTFs are measured in a tedious process
  - Play sound from a known location
  - Capture it with a in-ear microphone
  - Repeat from different location