Introduction and Sales Pitch

ECE 6279: Spatial Array Processing
Fall 2013
Lecture 1

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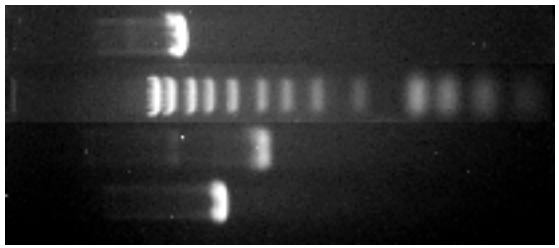
References

- **This class will draw material from many sources**
  - Required: J&D, D.H. Johnson and D.E. Dudgeon, *Array Signal Processing: Concepts and Techniques*, Prentice Hall, 1993
  - VT-IV, H.L. Van Trees, *Optimum Array Processing* (Part IV of Detection, Estimation, and Modulation Theory), Wiley, 2002 (not required!)
  - Assorted journal papers, some to be electronically distributed
- **For lectures, I will try to change the notation of all sources used to match that used in J&D**
  - I will try to give "conversion guides"
- **Advance credit to where its due:**
  - Prof. Doug Williams taught this class many times before
    - **Kindly provided a large stack of notes and problems**
  - I took an equivalent class from Prof. Dan Fuhrmann at Washington Univ.
  - Both will be a big influence on what you will see in my version of ECE6279
- **Class website: users.ece.gatech.edu/~lanterma/ece6279**
  - See for syllabus (a living document)
  - Will try to post slides before lecture so you can print them out

Signals in 1-D

- **ECE4270: Fundamentals of DSP**
- **Speech**
  - ECE4271: Applications of DSP
  - ECE6255: Digital Processing of Speech Signals
- **Bio time sequence data (EKG, EEG)**
  - ECE4781: Biomedical Instrumentation/ECE4782: Biosystem Analysis
  - ECE6787: Quantitative Electrophysiology
- **Usually signals in time $s(t)$**
- **Sometimes do have signals in space $s(x)$**
  - 1-D cuts through DNA stains



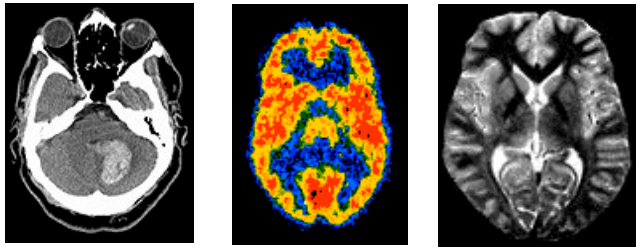
From http://www.clarechemical.com/gelstar.htm

Discovery DNA Explorer Kit ($79.95)

Signals in 2-D

- **ECE6258: Digital Image Processing**
- **Visual**
- **Biomedical (X-ray CAT, PET, MRI)**
  - ECE4783: Introduction to Medical Image Processing
  - ECE6780: Medical Image Processing

From media.skku.ac.kr/story/lena.html



From faculty.washington.edu/chudler/image.html

- **Synthetic Aperture Radar**
  - ECE8813B: Radar Imaging
- **Signals in space *s*(*x*,*y*)**
  - Sometimes formed from data in time via computational algorithms (ex: MRI and SAR)
- **More complex than 1-D signal processing since there's no obvious sense of directionality**

www.sandia.gov/RADAR/images/hangars.jpg

Signals in 3-D and 4-D

- **Signals in space: s(x,y,z)**
  - 3-D biomedical images (X-ray CAT, PET, MRI)
  - Interferometric SAR
  - Confocal microscopy
  - ECE4783/ECE6780/ECE8813B apply here too
  - 2-D theory from ECE6258 extends readily
- **Signals in space and spectra: s(x,y,λ)**
  - Hyperspectral imagery
    - **Extend R, G, B, IR, UV, to a continuum**
- **Signals in space and time: s(x,y,t)**
  - Movies
- **Signals in 3-D space and time: s(x,y,z,t)**
  - Functional PET
- **Signals in 2-D space, spectra, and time: s(x,y,λ,t)**
  - Hyperspectral movie

Signals in 3-D and 4-D

- **In time, have the idea of causality**
  - A system is causal if it only uses inputs from "past" times
  - Cannot look into the future
  - Necessary for real-time implementation!
  - Causality not necessary if willing to collect data and process later off-line

- **In space, no notion of causality**

- **Taking more data in time is usually cheap**
  - Just wait a little longer…

- **Taking more data in space is more expensive**
  - Requires hardware
    - **Ex: more pixels on the CCD camera**

We'll Be in 4-D

- **Space-time signals; signals in 3-D space and time**

$$s(x,y,z,t) \text{ or more compactly } s(\vec{x},t)$$

- **Like in those other classes, we'll be dealing with sampled data**
- **Sampling in time will be cheap**
- **Big change here: sampling in space will be expensive**

Very Large Array
New Mexico

Each antenna weighs 230 tons!

From www.nrao.edu/pr/2000/vla20/background/vlafacts

Total cost: $78.6 million (in 1972)

ASR-9 Air Traffic Control Radar

- **"Mechanically scanned" in azimuth**

From www.its.bldrdoc.gov/home/programs/rsms/photo/asr-9.html

- **Problems:**
  - Moving parts = high maintenance costs
  - Can only look one direction at once
  - Ability to change looks rapidly determined by mechanics
- **Solution: use stationary arrays and "steer" the beam electronically (i.e., with signal processing)**

Aegis Combat System

- **AN/SPY-1 phased-array radar system**
- **"3D radar" - meaning it can beamform (look) in both azimuth and elevation**
- **Four arrays, one mounted on each side of the ship for full 360 degree coverage**

From www.navysite.de/weapons/aegis.htm

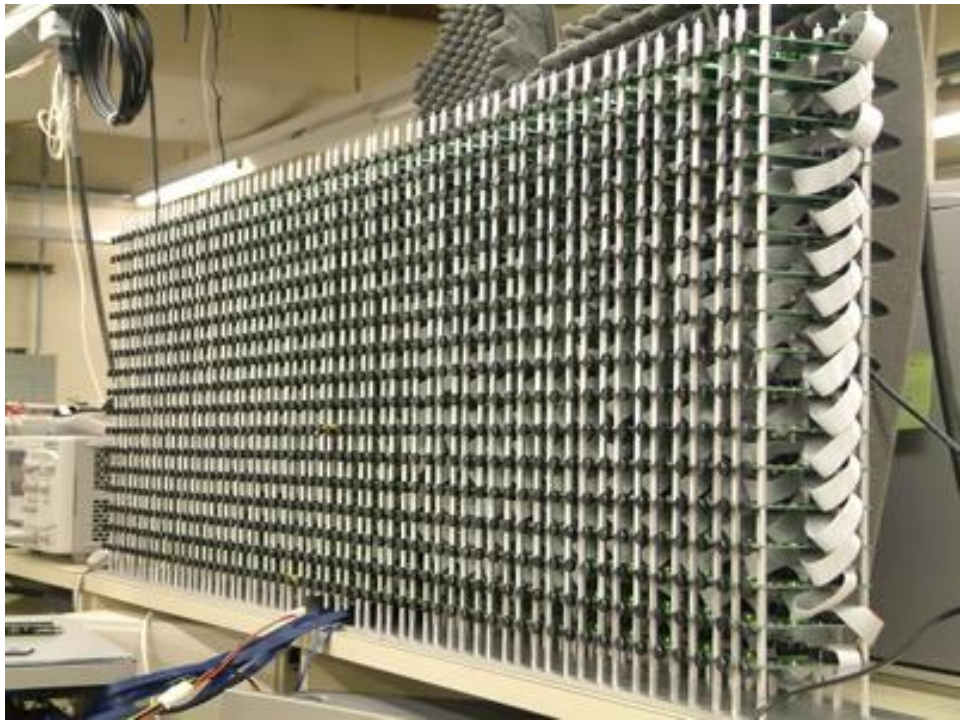
VoiceTracker

- **Commercial product by Acoustic Magic**
  - Info/images from www.acousticmagic.com
- **8 element, 18 inch long array**

- **Locate and focus on main speaker**
- **Adaptively remove interference**

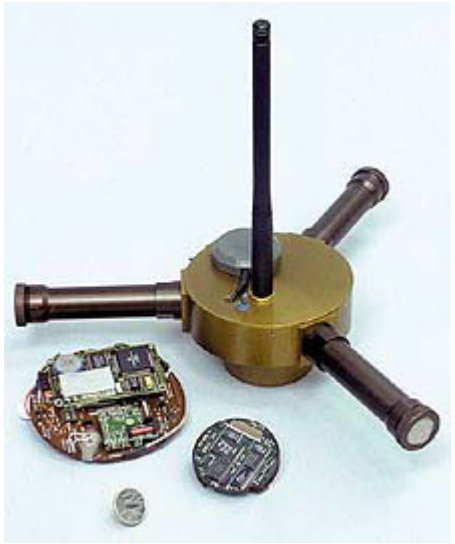
LOUD

- Large acOUstic Data Array Project
- 1020 nodes!!!
- See cag.csail.mit.edu/mic-array



Unattended Ground Sensors

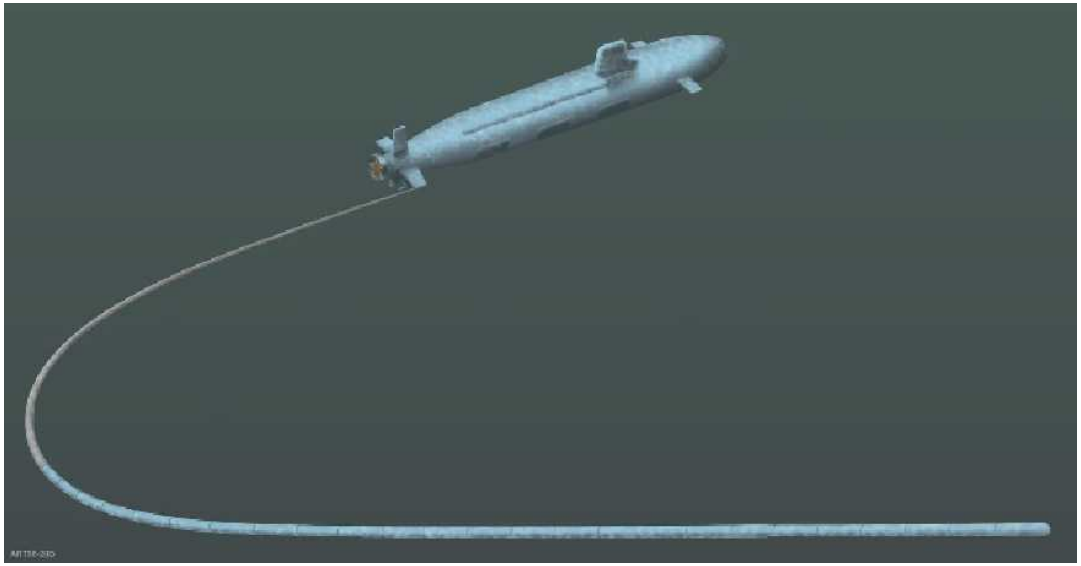
- **Deployed by hand or dropped from the air**
- **Communicate and collaborate with other UGS nodes**
- **Big Army interest: track vehicles, people**
- **Battery usage is a big issue with these devices**
- **A 12-inch array by Northrop Grumman:**
  - GPS
  - Electronic compass
  - DSP chips



From www.dsd.es.northropgrumman.com/ate/UGS.html

Underwater Sonar Arrays

- **Either inside or towed by a submarine or a ship**
- **Towed arrays flop around, makes things trickier**
- **Some of the assumptions we will make in this class break down in the sonar case**
  - ECE6279 won't focus on the sonar case



From http://www.navlog.org/TB29.html

Some Objectives of Sensor Arrays

- **Quoted from J&D, p. 3:**
  - Enhance SNR ratio beyond that of a single sensor's output
  - Characterize the field by determining the number of sources of propagating energy, the locations of these sources, and the waveforms they are emitting
  - Track the energy sources as they move in space
- **Achieve high resolution with a sampled aperture if a filled aperture is too costly to build**
- **Achieve flexibility mechanically scanned systems do not allow (especially in rejecting interference)**
- **Dual problem: direct transmitted energy in a particular direction**

Two Classes of Scenarios

- **Communications**
  - A cell base station tracks you talking on your cell phone while you're in your car
  - Your future advanced wireless internet hub tries to notch out interference from your microwave oven
- **Situation awareness**
  - Send out and receive radar or sonar pulses
  - Passively pick up its transmissions
    - **Track aircraft via their communications (e.g., Link-16)**
    - **Track aircraft via their own radar outputs**
    - **Track submarines via the sound their engines put out**

The Unknown Medium Problem

- **Previous discussions assumed we know the propagating medium, and want to find out about sources**
  - J&D and VT-IV, and ECE6279, will focus on this case
- **Sometimes, you know the source, but want to find out about the medium**
  - Ultrasound
    - **Medical**
    - **Industrial (non-destructive evaluation)**
  - Seismology
- **Sometimes, like in sonar, you must find out about sources and the medium simultaneously**
  - Really tricky

Main Themes of the Class

- **What makes our space-time signals special?**
- **They propagate in space according to a wave equation**
  - Puts a lot of structure on our signals
  - Allows us to infer a lot from limited data

- **Linear system theory is still your friend**
  - Describes how the data is generated
  - Basic techniques for doing inference

- **Power of statistical models**
  - Low-rank models

- **Power of nonlinear processing in doing inference**
  - Subspace methods (can be applied in other areas)
  - Maximum-likelihood methods (will do mini-version of ECE7251)

Programming

- **We'll do a lot of playing in MATLAB**
  - Nothing fancy
- **You could also probably use S-PLUS, R, Scilab, MATRIXx, ScientificPython**
- **If you haven't programmed in MATLAB before, you can probably learn MATLAB and do the problem in the time it would take you to do the problem in a language you already know**
- **Student version of MATLAB isn't too expensive in bookstore**
- **Open-source MATLAB rewrites:**
  - Octave: www.octave.org
  - Freemat: freemat.sourceforge.net

Prerequisites

- **Signal processing at the level of ECE4270 (actually, ECE2025 or ECE2026+3084 is sufficient)**
  - Familiar with convolution, Fourier transforms, etc.
- **Probability at the level of ECE3075 or ISyE/ECE3770**
  - Multivariate Gaussian distribution must be an old friend
  - Know how to manipulate conditional probabilities (Bayes' rule)
- **Basic linear algebra**
  - Know what eigenvectors and eigenvalues are
- **I want this course to be accessible to students with a wide variety of backgrounds**
  - At any point, if I assume some background knowledge you don't have, let me know right away!
  - I'm willing to do a lot of review
  - Want it to be accessible to both graduate and undergraduate students

Courses that Might Provide Context

- **These are not prerequisites, just suggestions for future classes!**
- **ECE6601: Random Processes**
- **ECE7251: Signal Detection and Estimation**
  - I will present a Reader's Digest version of some ECE7251 topics
  - No proofs; just the results you need
- **ECE6254: Statistical Digital Signal Processing and Modeling**
  - Spectrum estimation
- **ECE6272: Fundamentals of Radar Signal Processing**
- **ECE8813B: Radar Imaging**

Survey

- **Before the start of next week, e-mail lanterma@ece.gatech.edu with Subject: "6279 survey"**
- **Tell me:**
  - What courses have you taken or are taking now (at GaTech or elsewhere) in
    - **Linear algebra**
    - **Probability**
    - **DSP**
    - **Detection & estimation theory**
  - Who is your advisor (or where do you work)?
  - What are your research interests?
  - Any particular topics would you like to see covered?
  - When are your exams/project deadlines in your other classes?