Graduate Information Day

Signal Processing Graduate Program at the University of Michigan

October 19, 2002

SP: a subarea of Systems Engineering

- High level view: approach tends to be generic, applicable to many different technologies, and independent of implementation details
- Design algorithms that will be implemented in hardware
- Interesting and applicable mathematics!!!
- Lots of Matlab!!!
- Used every day in industry!!!

Faculty in EE:Systems

- A. Anastasopoulos
- **D. Anderson**
- **J. Fessler**
- J. Freudenberg
- J. Grizzle
- **A. Hero**
- D. Koditschek
- S. Lafortune
- M. Liu
- S. Meerkov
- D. Neuhoff
- S. Pradhan
- W. Stark
- D. Teneketzis
- **G. Wakefield**
- K. Winick
- **A. Yagle**
- **D. Kipke**

Graduate Courses

- **EECS 501, Probablity and Random Processes**
- **EECS 502, Stochastic Processes**
- **EECS 551, Wavelets and Time Frequency Distribution**
- EECS 554, Digital Communication and Coding
- EECS 555, Digital Communications
- **EECS 556, Image Processing**
- EECS 557, Communication Networks
- EECS 558, Stochastic Control
- **EECS 559, Advanced Signal Processing**
- EECS 560, Linear System Theory
- EECS 561, Design of Digital Control Systems
- EECS 562, Nonlinear Systems
- **EECS 564, Detection, Estimation, and Filtering**
- EECS 565, Linear Feedback Systems
- EECS 567, Robotics
- EECS 600, Function Space Methods in System Theory
- EECS 650, Channel Coding Theory
- **EECS 651, Source Coding Theory**
- **EECS 658, Fast Algorithms for Signal Processing**
- **EECS 659, Adaptive Signal Processing**
- EECS 661, Discrete Event Systems
- EECS 662, Advanced Nonlinear Control

Research Areas in Signal Processing

- Signal and Image Compression
  - Audio compression (MP3)
  - Image/video compression (JPEG, MPEG)
- Imaging and Image Reconstruction
  - Medical Imaging
  - Radar Imaging and Remote Sensing
  - DNA Microarrays, Microscopy
- Signal Analysis and Pattern Discovery
  - Audio (music, speech and song, spectral analysis)
  - Array processing (neurological, ERP, EKG)
  - Communications (Internet traffic, sensor nets, space-time)

Where have we placed our graduates in last 5 years?

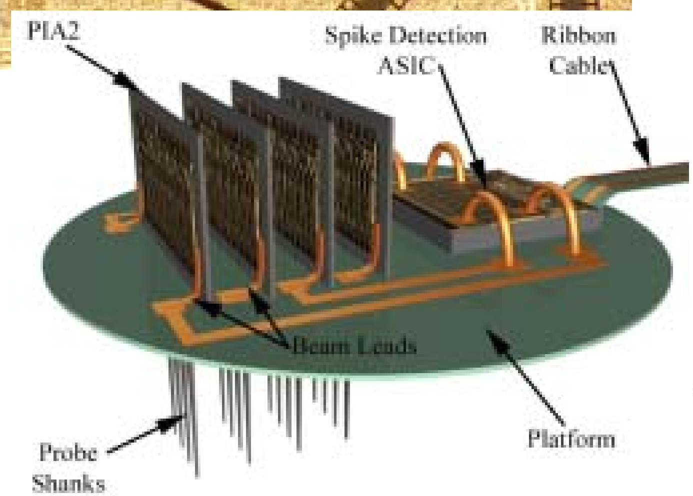
Industry: Veridian, Ford, GM, Xerox, Rockwell, Motorola, Harris, TRW, BroadCom, GE, ADAC, Qualcomm, Lucent, Whirlpool, Lattice Semiconductor, Rand Corp., Altra-Broadband, other startups

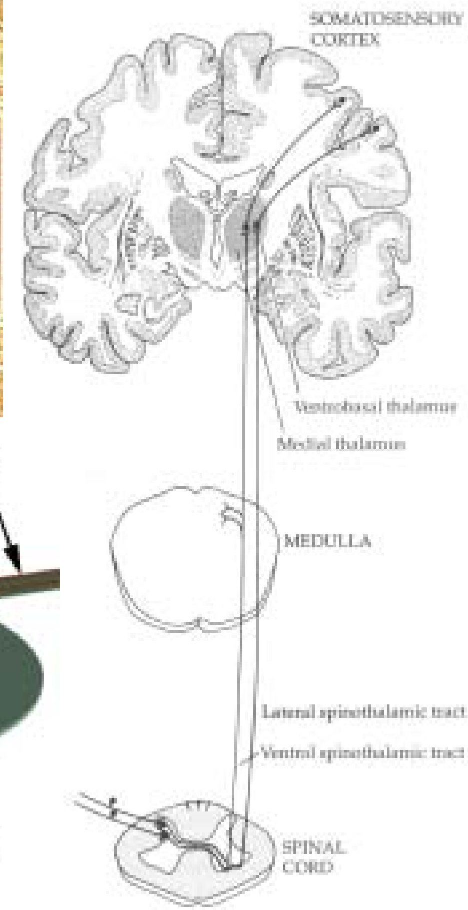
National Labs: MIT Lincoln Labs, Air Force Research Labs, Army Research Labs, Los Alamos

Universities: Wisconsin, Berkeley, UC San Diego, Georgia Tech, Virginia Tech, UPenn, Washington Univ., Oakland U, SUNY Stony Brook, UC Riverside, U of Michigan, U of Iowa, Naval Postgrad School

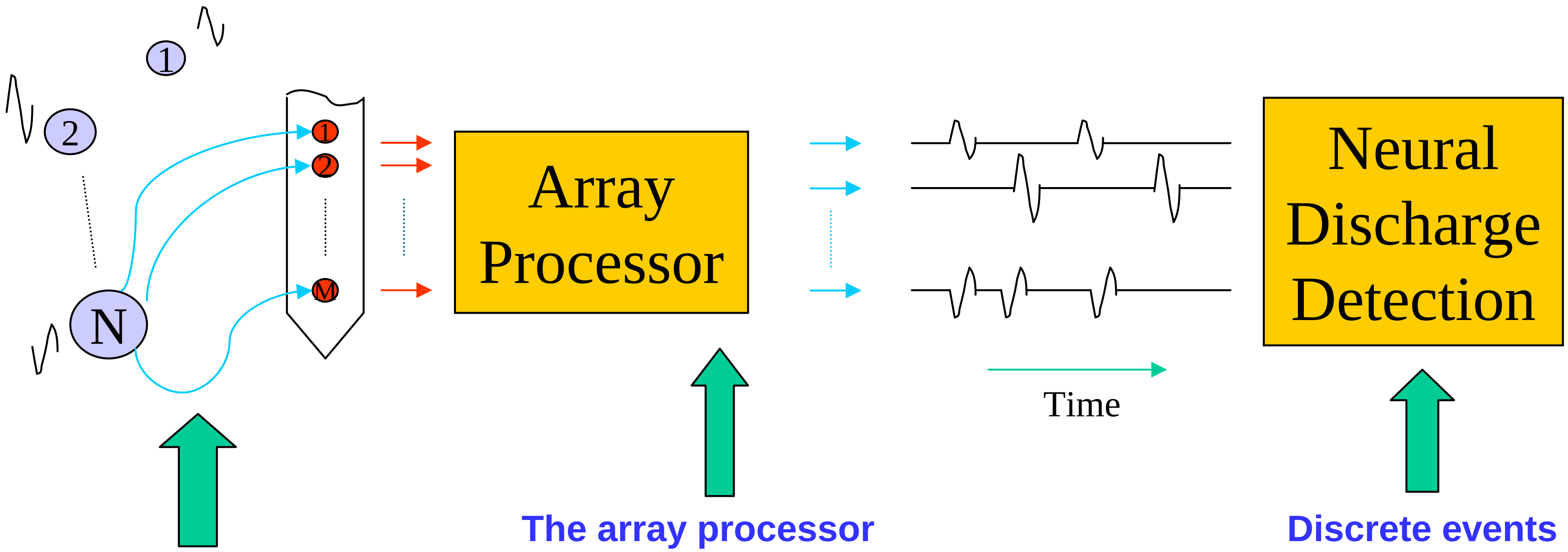
I. SP for Neural Systems (Anderson)

- Neural Engineering is a major thrust Area of the College
- We have created devices that can be implanted in most volumes of the brain
- The devices are shaped to match the requirements of the site of implantation
- The technology exists to process signals on the devices and nearby on platforms.





One of the Important Problems in Neural Signal Processing Is the Extraction of Individual Cell Signals from a Mix of Signals on an Array



Several Nerve cells surrounding the electrode send signals in overlapping patterns to the sensors on the recording electrode

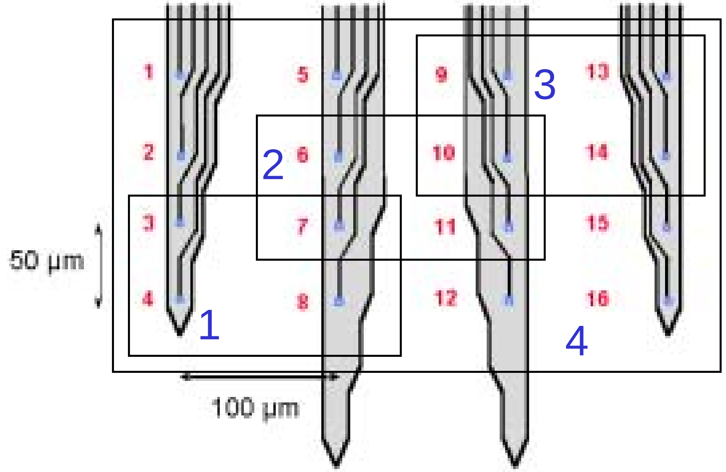
The array processor unmixes the sensor channels into neural signals

Spatial location information is inferred from the weighting of signals

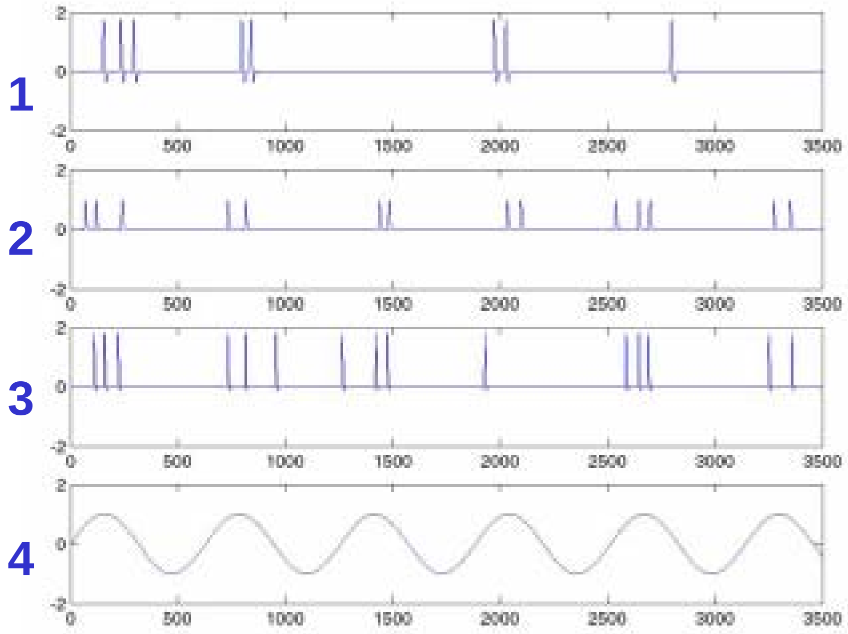
Discrete events are derived from the neural waveforms

Example

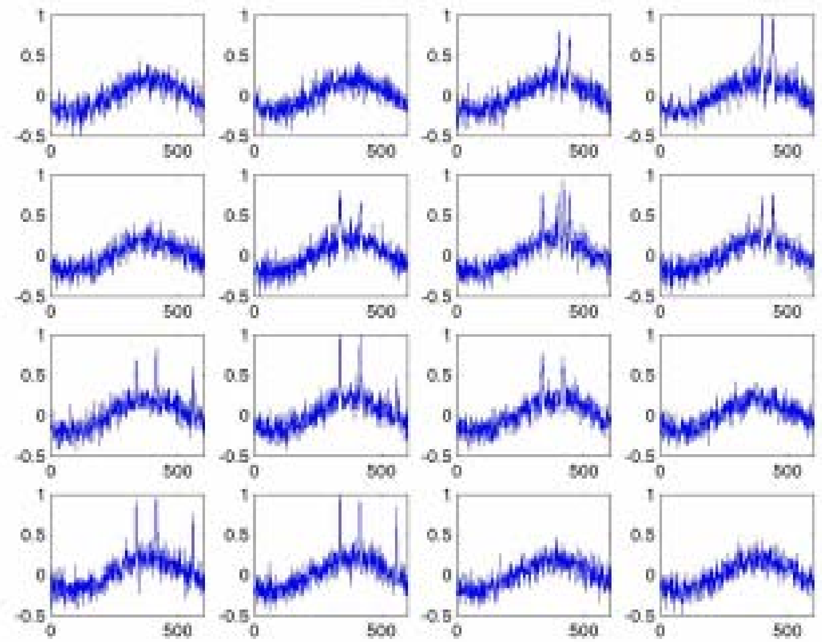
Signal Mixing on a 4x4 Neural Array



Raw Signals

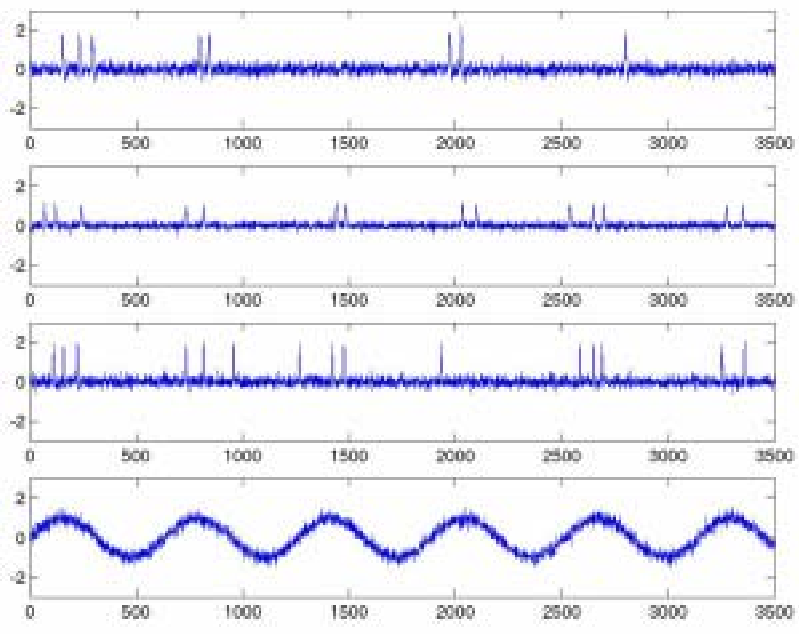


Mixed over channels with added white noise

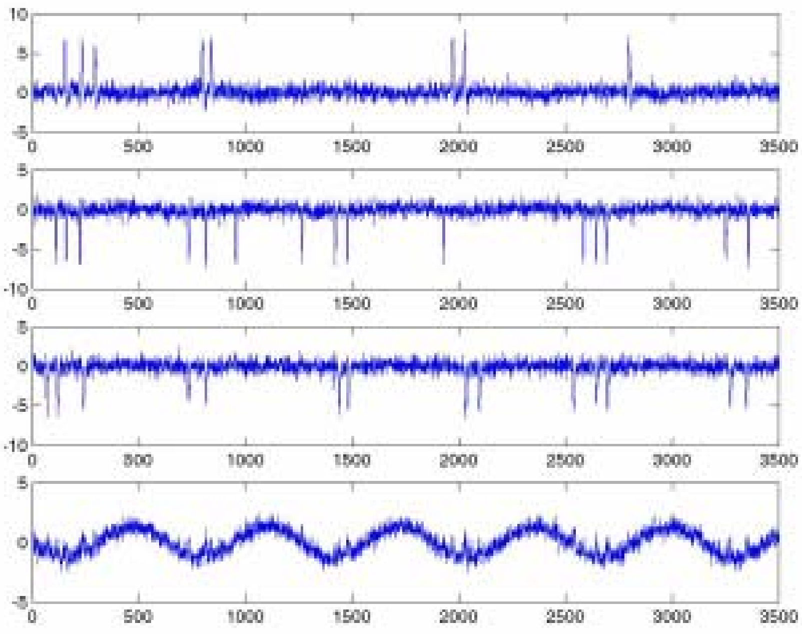


Estimates of the original data records have been recovered by two methods

Pseudo Inverse using full knowledge of the Mixing Matrix and the covariance matrix



Blind source identification using Independent Component Analysis

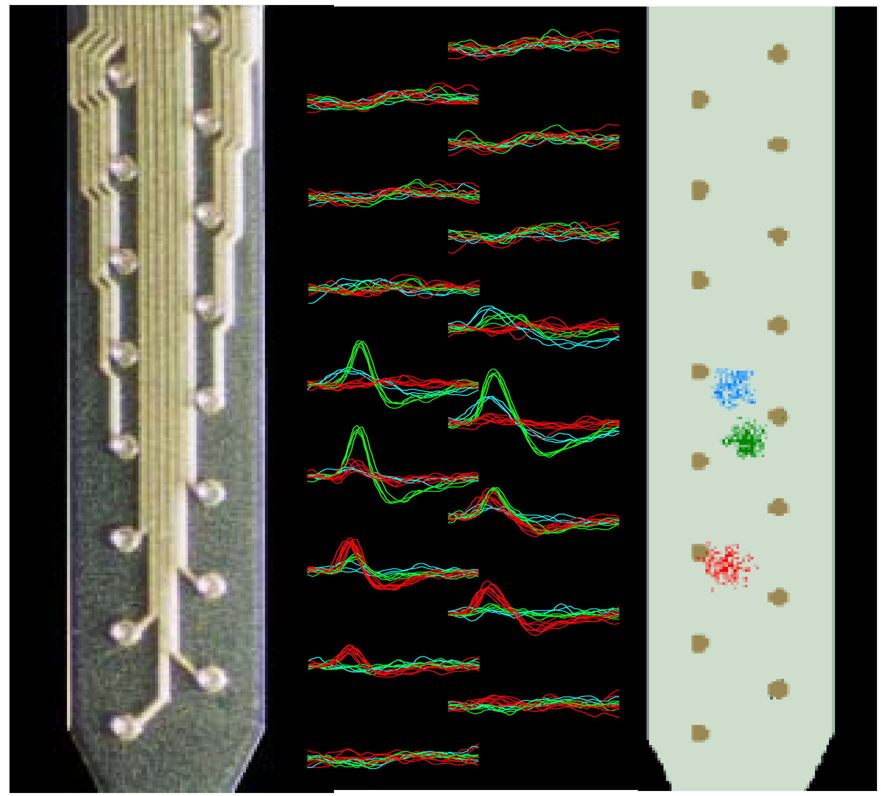


MichiganEngineering

NCRR Center for Neural Communication Technology

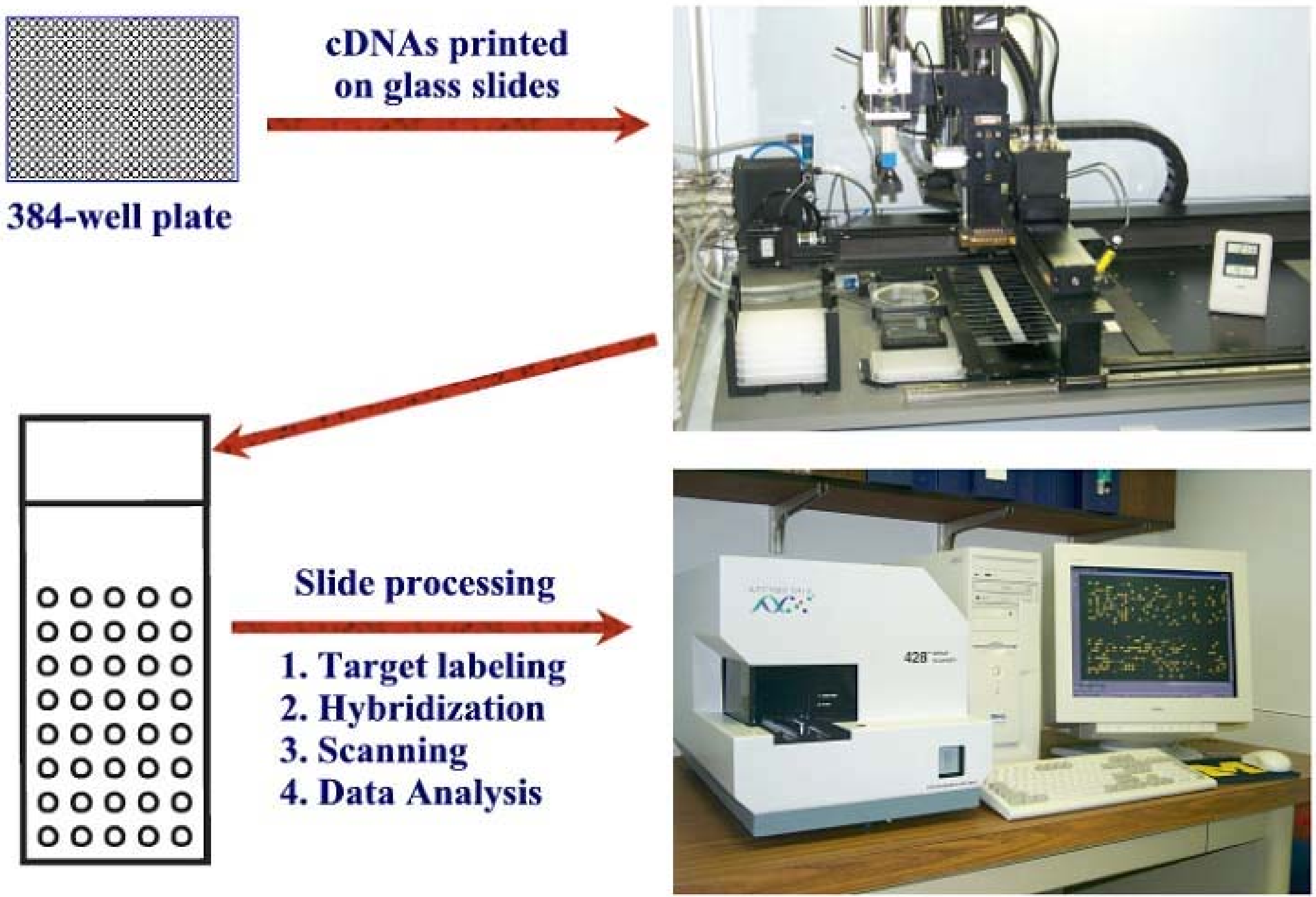
Source Location of Neural Signals over a multisite electrode

- When there is significant distribution of neural signals over the field of recoding site sensors estimates of neuron position can be obtained.
- Four sites are required to determine 3-D location when the signal is of unknown magnitude.



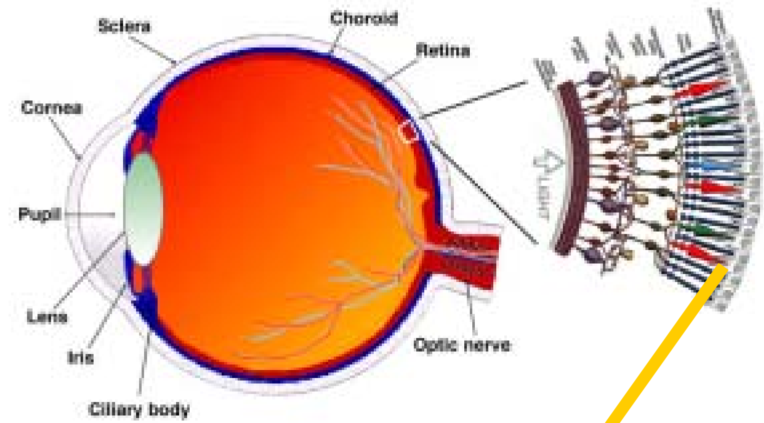
PT16B Single Unit Data 3D Location

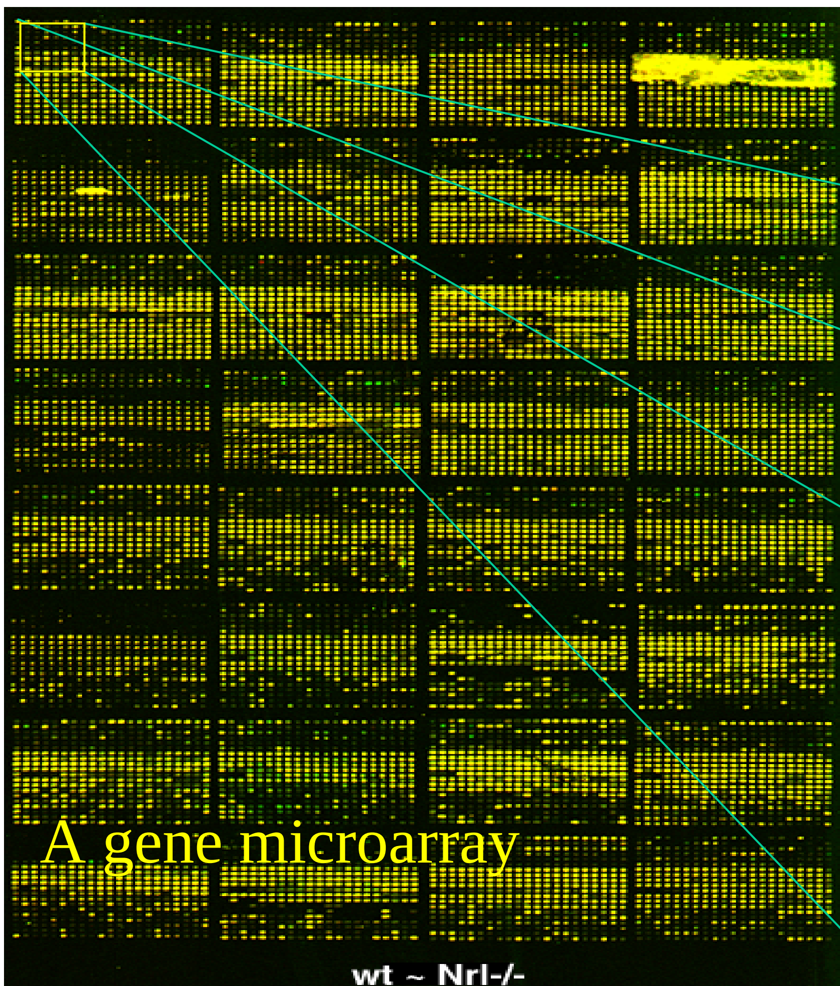
II. Gene Microarray Analysis (Hero)



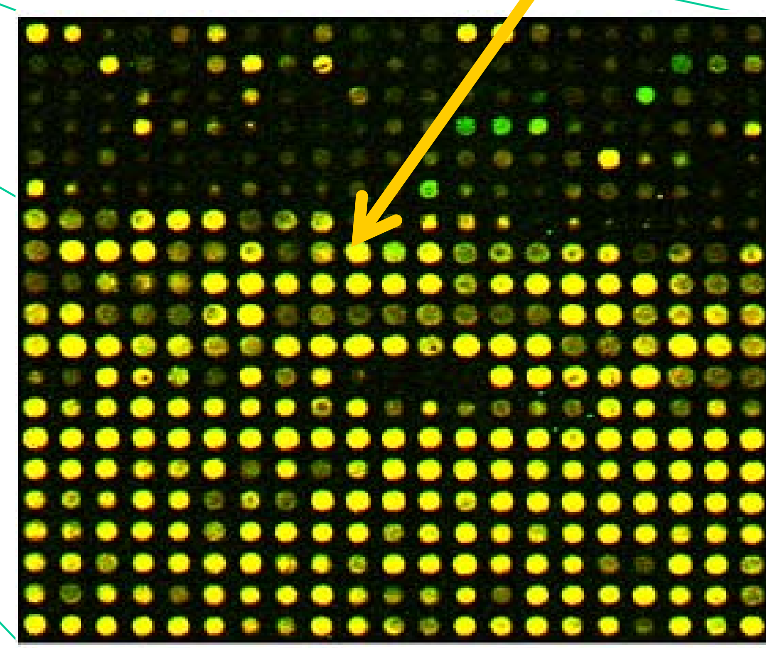
Eye-gene microarray: gene discovery

Objective: dicover genes which regulate development, aging, and disease in the retina.

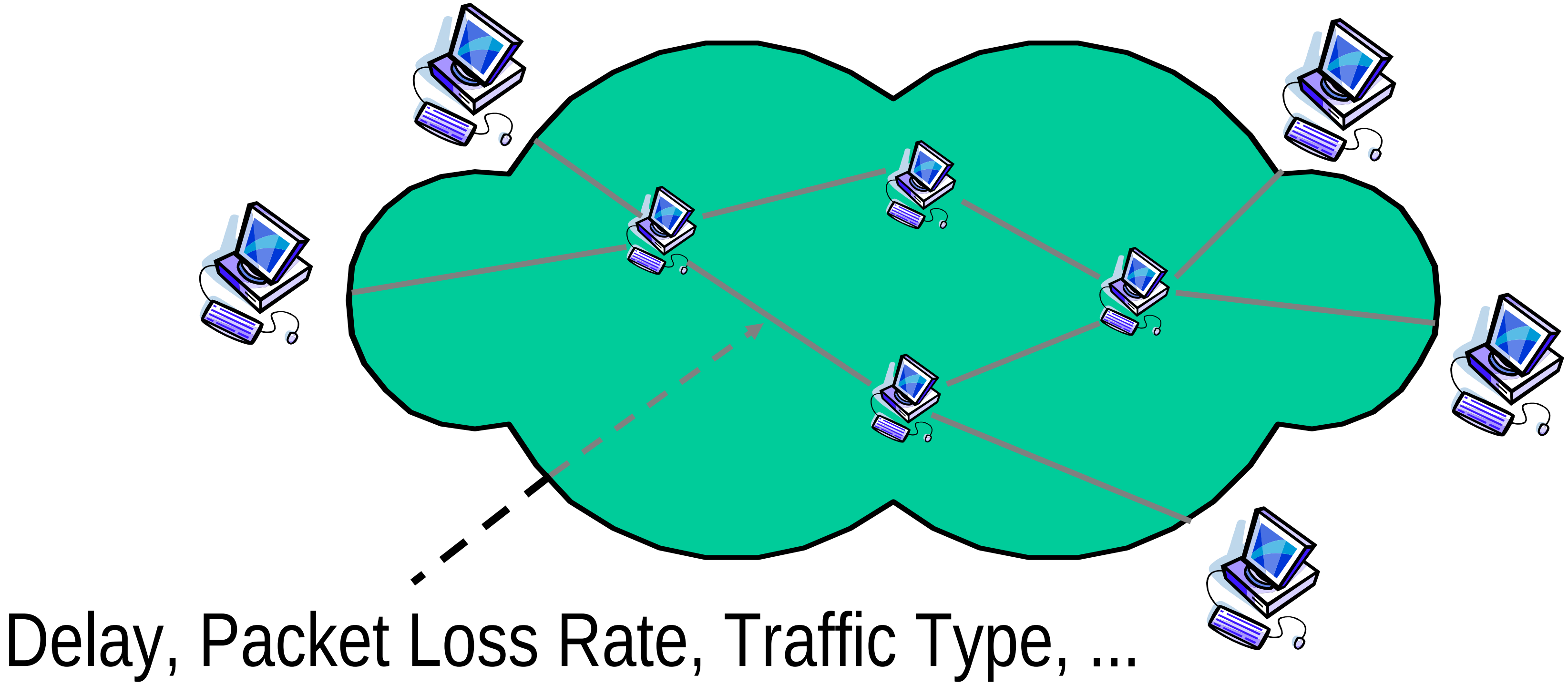




Is this gene probe a rod development gene?



III. Signal Processing for Networks (Hero)

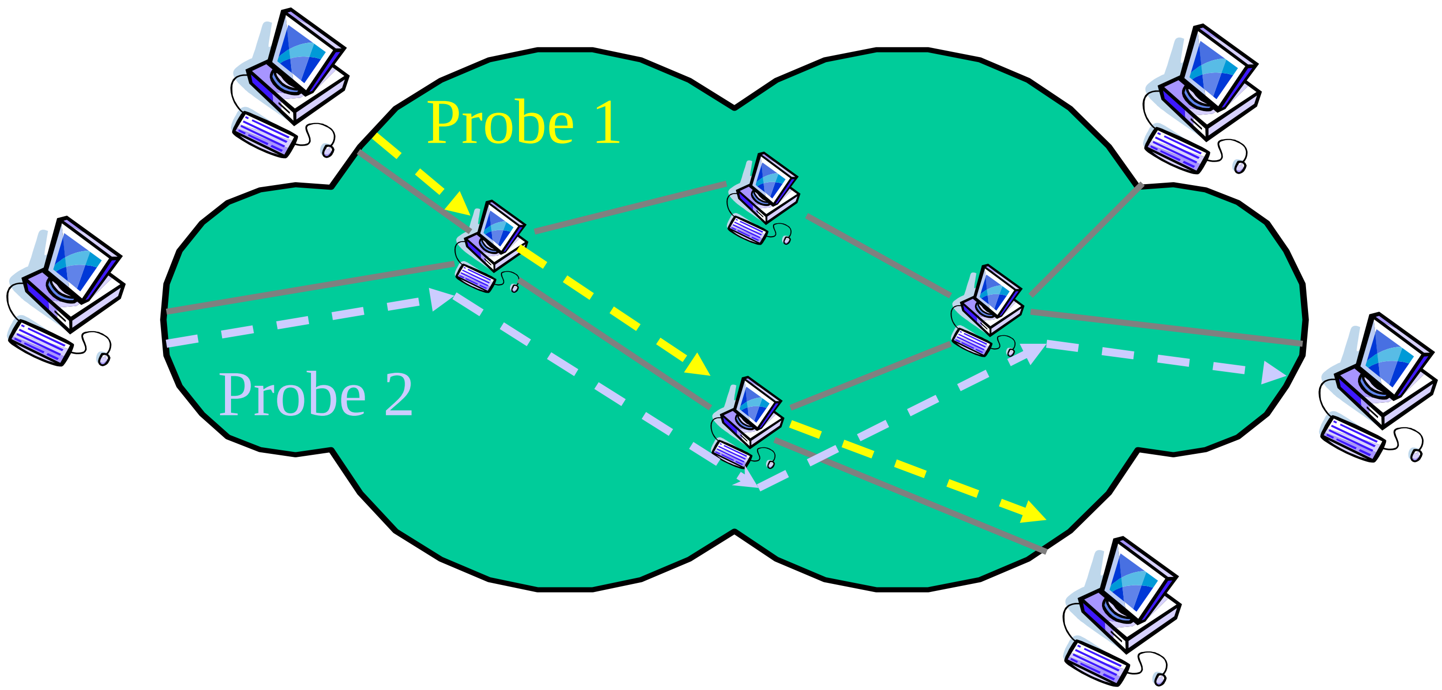


Problems with direct measurement (rmon):

- Diagnosis unavailable or disabled at internal nodes.
- Non-cooperative internal nodes.
- All internal nodes must be synchronized

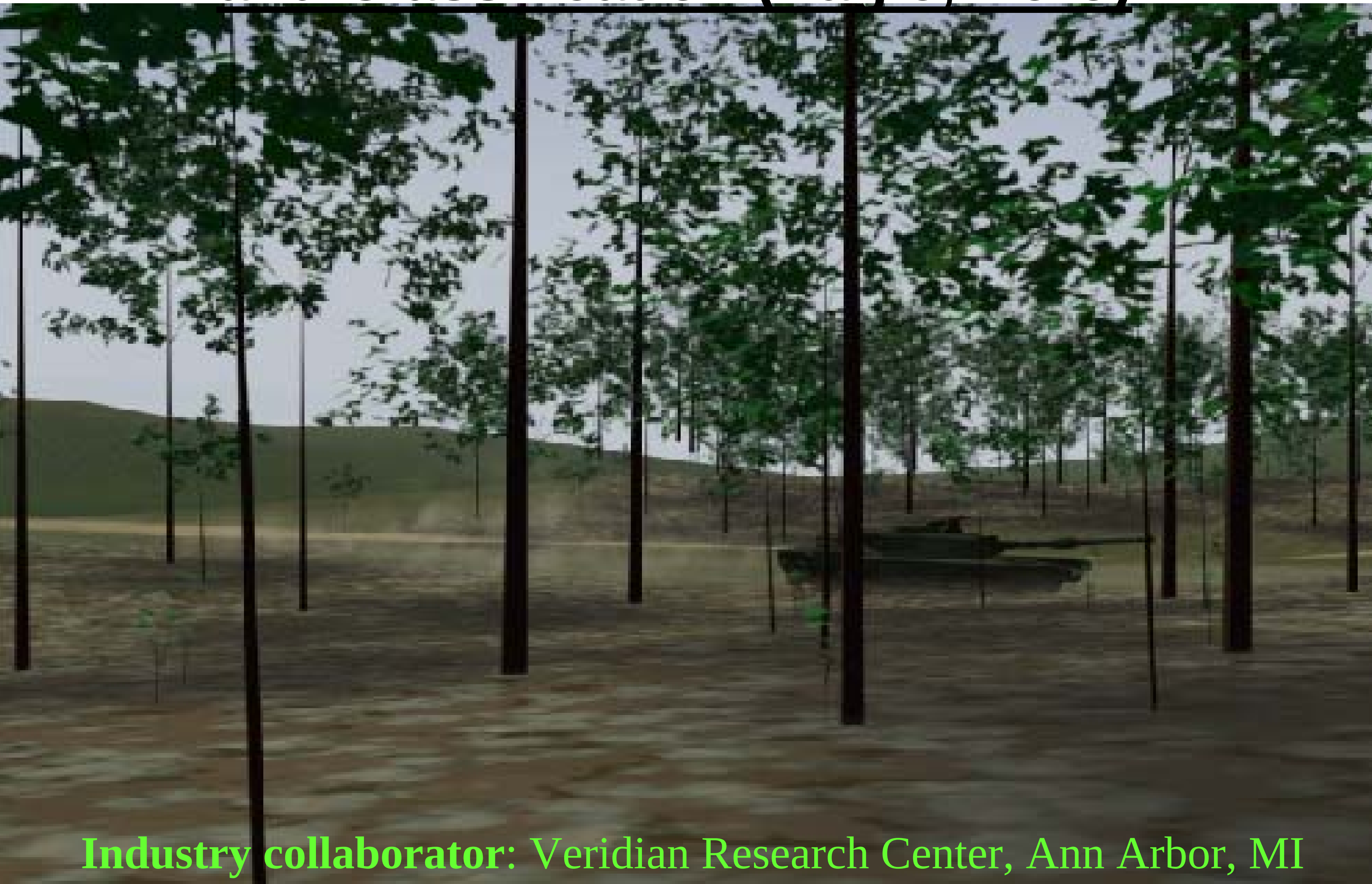
Network Tomography Problem

- End-to-End Measurements



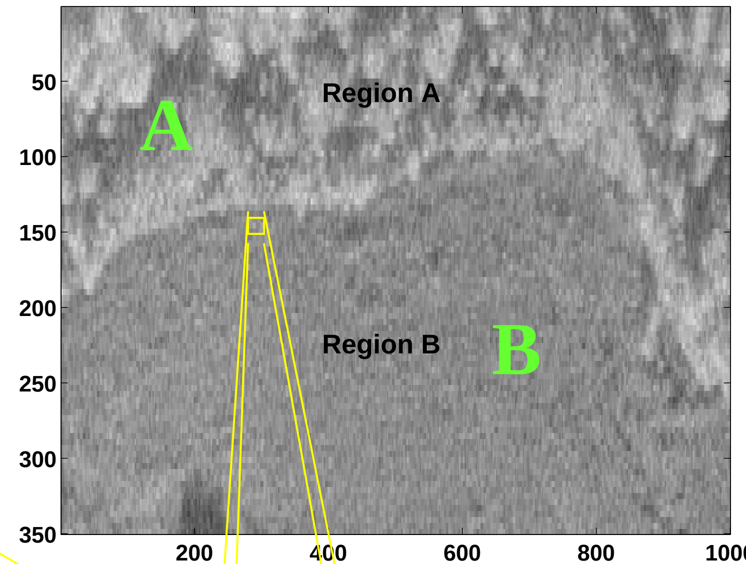
- Multiple probes sent from edge of network
  - Extract info on internal traffic rates, delays
  - Apply principles of tomographic imaging

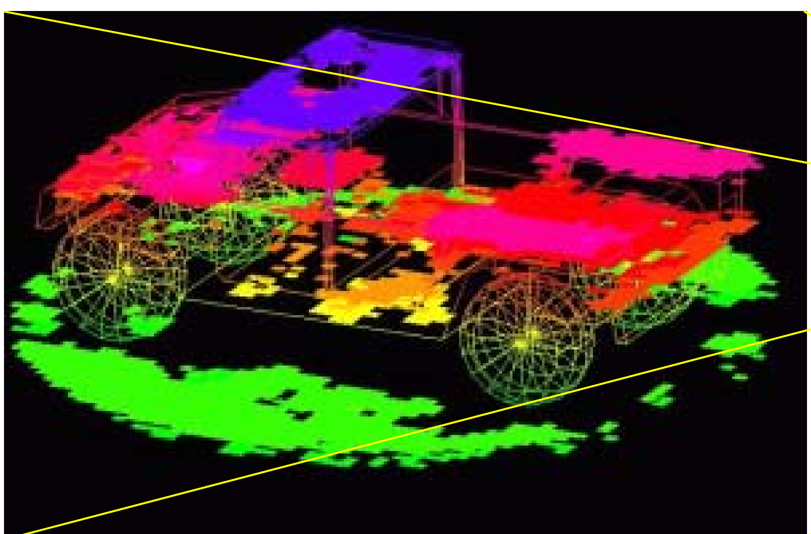
IV. Sequential Adaptive Target Detection and Classification (Yagle, Hero)

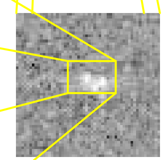


Industry collaborator: Veridian Research Center, Ann Arbor, MI

Typical target signatures are weak



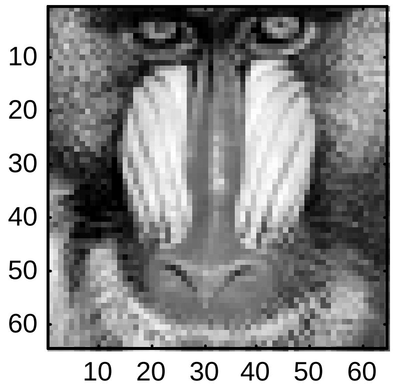




SAR Target
Chip on boundary

V. Statistical Image Restoration and Reconstruction (Fessler, Hero)

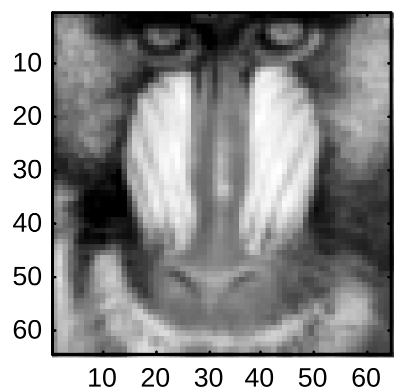
64x64 pixel image



Noise and blur degraded measurement with IID additive Gaussian Noise

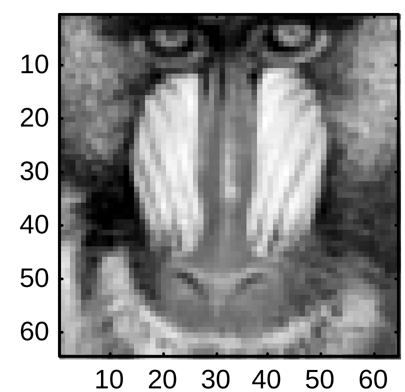
$$\underline{y} = A\underline{x} + \underline{n}$$

$$E[\underline{n}\,\underline{n}] = K = \sigma I$$



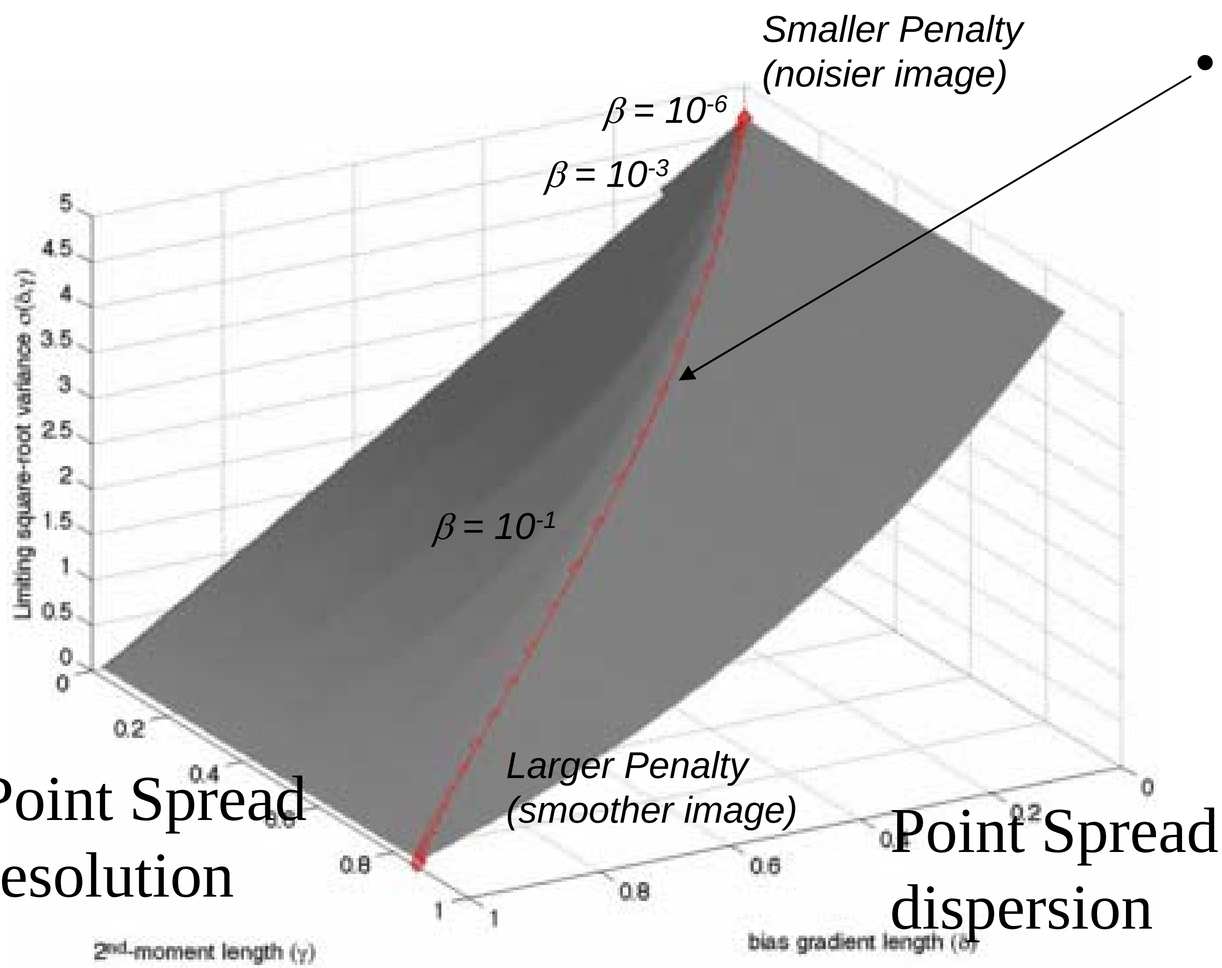
Penalized Weighted Least-Squares Estimator

$$\hat{\underline{x}} = \left[A'K^{-1}A + \beta P\right]^{-1} A'K^{-1}\underline{y}$$



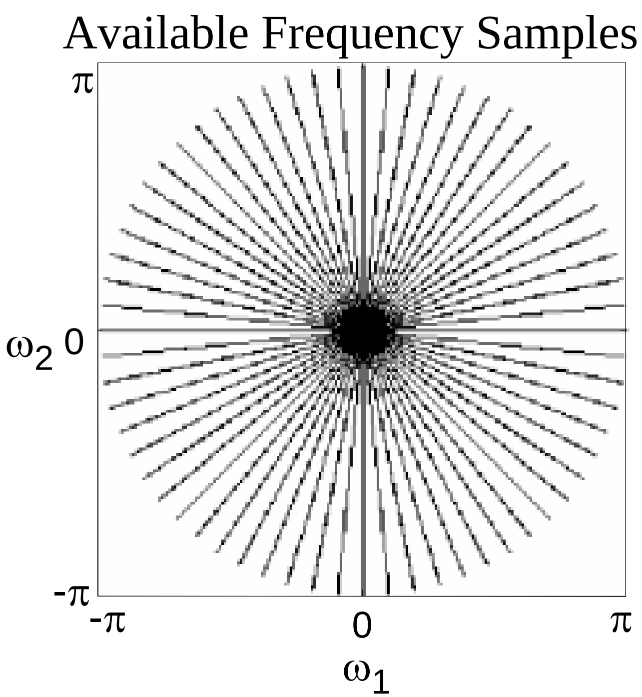
Q: Is reconstruction MSE fundamentally limited?

Uniform CR bound on Reconstruction resolution and variance



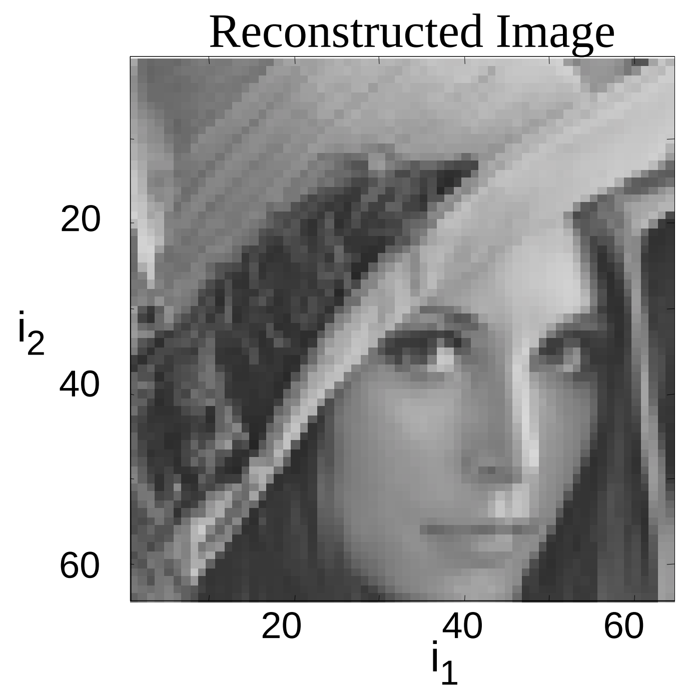
- Penalized Weighted Least-Squares reconstruction is optimal since it achieves the lower bound!

VI. Image reconstruction from Irregular Samples (Yagle)



Solve the system of linear equations

Ax=b



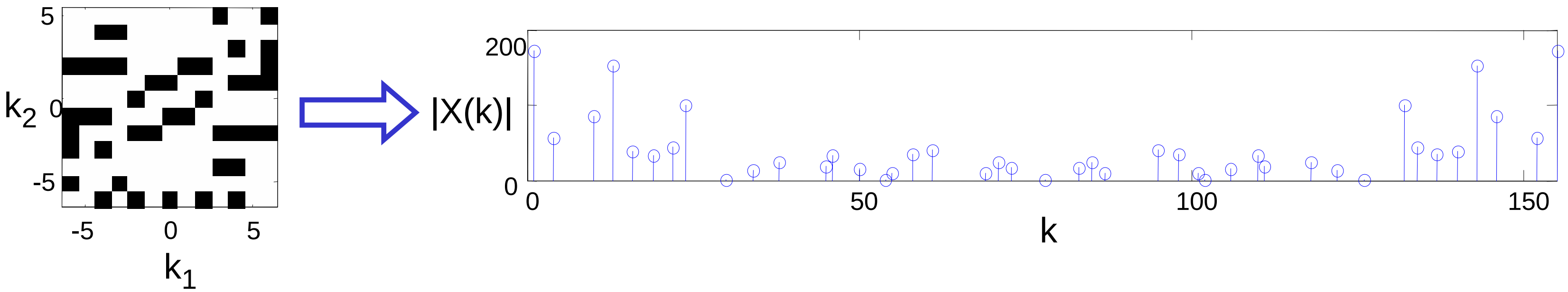
Problem: Reconstruct an image, x, from some samples, b, of its 2D Discrete-Time Fourier Transform.

Which set of frequency samples will produce a well-conditioned system, A?

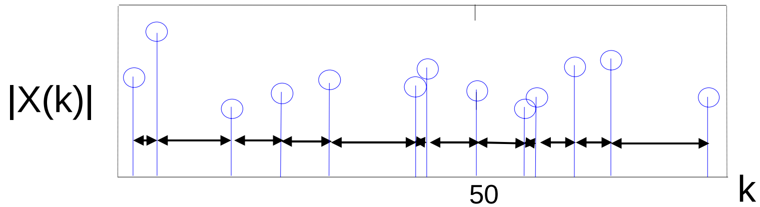
“Sensitivity of Image Reconstruction from Irregular 2D DTFT Samples”

Goal: Develop a simple procedure for evaluating the relative conditioning of various frequency configurations.

Solution: 1. Unwrap the 2D problem into 1D.



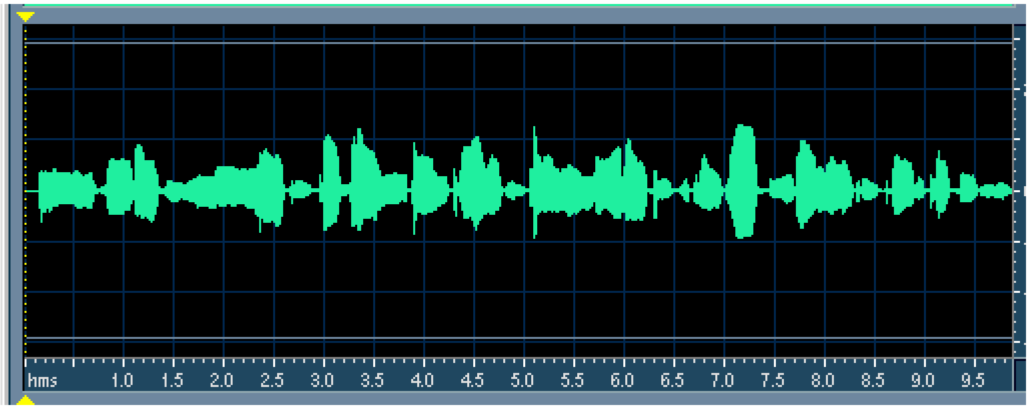
2. Use *variance of distances between adjacent frequency locations* as measure of conditioning.



$$VarianceMeasure = \frac{1}{M}\sum_{k=1}^{M}\left(\left|\omega_{k+1} - \omega_k\right| - \mu\right)^2$$

3. Solve system of linear equations using well-conditioned frequency configuration and rewrap 1D solution into 2D image.

VII. Multimedia Information Retrieval (Wakefield)

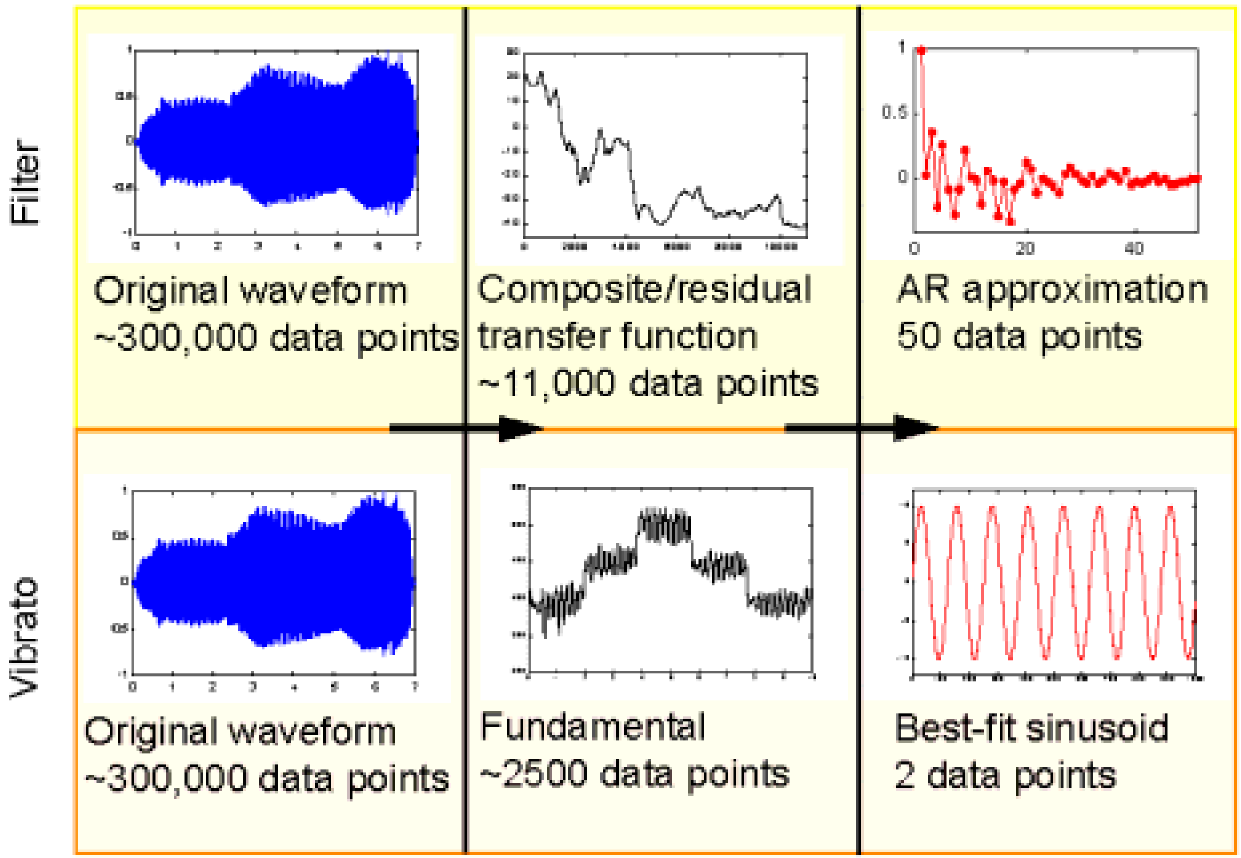


95% of all web content is non-textual in nature, yet 100% of all web search engines process text only

Approaches:

1. Develop mathematical models to extract information about melody, harmony, rhythm, instrumentation, vocalist
2. Develop database algorithms for indexing and for searching over non-textual materials
3. Develop query languages that are well matched to the user's perception AND the engineer's tools

VII. Example - Singer Abstraction



Classification systems based on very low-dimensional models of singer production are capable of matching the accuracy of human listeners in recognizing singers

Conclusion

- Many exciting signal and image processing activities take place at UM
- Funding comes from many sources including: AFOSR, ARO, DARPA, NSF, NIH
- UM’s SP graduates are placed in highly competitive positions throughout the US.
- Signal processing at UM is varied and FUN!