Distributed Sensing and Inference

Randy Moses

Department of Electrical Engineering
The Ohio State University
randy@ece.osu.edu
http://eewww.eng.ohio-state.edu/~randy

- Who am I?

- Why am I here?

- Now that I'm here, what should I do?

My Research Interests

Statistical Signal Processing

    modeling, parameter estimation, hypothesis testing

- Radar imaging
  - Tomography for radar
  - Multistatic: multiple transmitters and receivers
  - Physics-based modeling for low-dimensional feature sets
    - Discovery, estimation, evaluation
  - Automatic Target Recognition (ATR)

- Sensor Networks
  - Self-calibration (location; orientation)
  - Multi-modal sensor fusion
  - Communication-constrained distributed inference

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Radar Feature Modeling and Estimation

$$E(f,\phi) = \sum_{k=1}^{n} A_k \underbrace{\left(j\frac{f}{f_c} \right)^{\alpha_k}}_{\substack{\text{Frequency}\\\text{Dependence}}} \underbrace{e^{-2\pi f \gamma_k \sin\phi} \operatorname{sinc}\left(\frac{2\pi f}{c} L_k \sin(\phi - \phi_k) \right)}_{\substack{\text{Aspect}\\\text{Dependence}}} \underbrace{\exp\left(-j\frac{4\pi f}{c}[x_k \cos\phi + y_k \sin\phi] \right)}_{\substack{\text{Location}\\\text{Dependence}}}$$
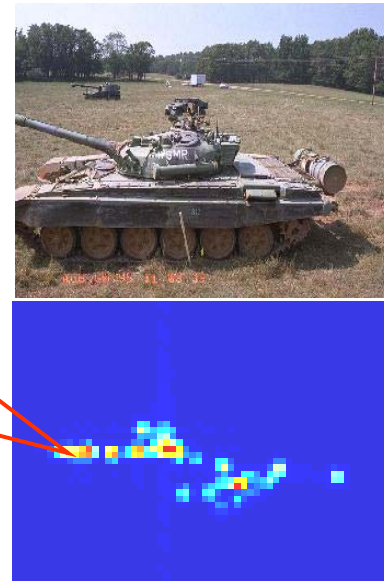
Scattering Attributes

A_k	=	amplitude **[H, V, X]**
x_k , y_k	=	location
$_k$	=	frequency type
L_k	=	length
$_k$	=	pose angle
$_k$	=	angle response

T72-sn132
AZ=249.79, EL=17.18

Extract

x=35.2 m
y=46.3 m
A=9.43 dB
     = 0.5
L=1.33 m

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Backhoe Data Dome

XpatchF synthetic backscatter data

- Publicly released
- 7-13 GHz frequency band
- 0-360° az, 0-90° elev
- 0.07° angle spacing
- 1" x 1" x 1" resolution
- Full polarization
- ~300 Gbytes of data

'Data Dome' Representation in k-space
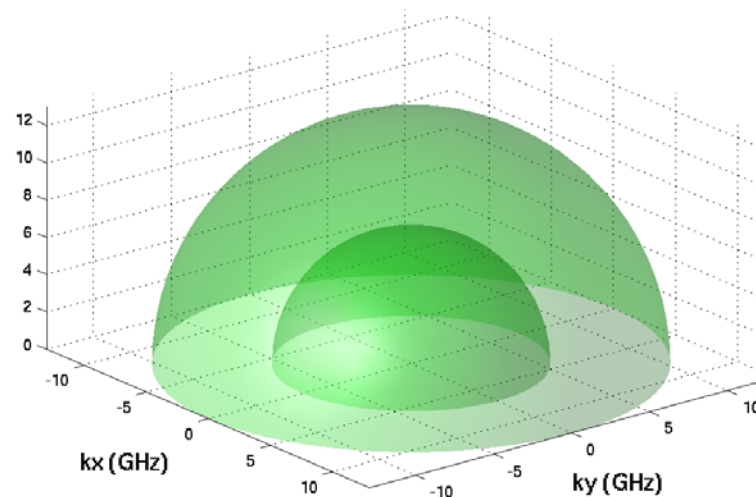
# 3D Radar Tomography Example
Is there more to signal processing than pretty pictures?


Color encodes radar look angle.

Sensor Network Self-Localization

- Location estimation for nodes in a large ad-hoc network.

- Measurements:
  - Distance
  - Signal time (difference) of arrival
  - Received signal strength
  - Direction of arrival

- Investigate location error as a function of:
  - Node density
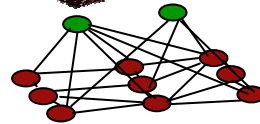 - Number of beacons
  - Network size
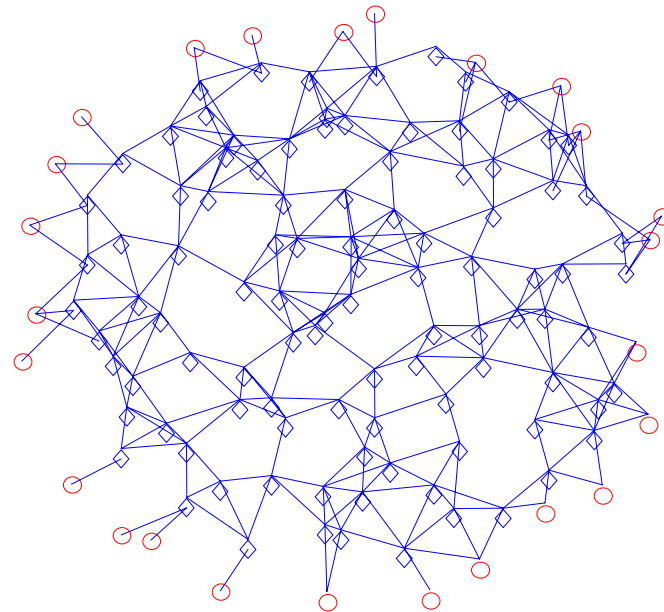
Red: beacon nodes
Blue: nodes w/unknown location
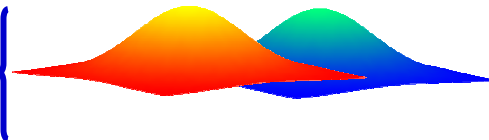
Distributed Inference for Sensor Networks

Targets of Interest

Sensed Phenomena

Measurements dependent across time and space
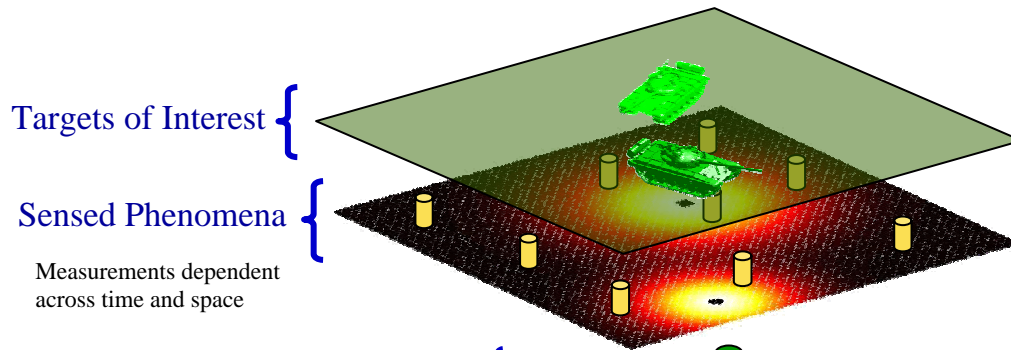
Statistical Model for Sensed Variables and Information Fusion

Graphical Model for Ad-hoc Communication

Event Likelihoods for Human Decision-Making

Collaboration in

Sensing

Communications

Decision-Making by People

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- Identifiability of models
- Inference quality vs. measurements
  - What measurements do we take to produce 'best' estimates or inferences?
- Robust parametric/nonparametric inference
  - Use models where you can
  - Use nonparametric statistical methods on 'residual' for robustness
- Automatic inference to support human decisions
  - Explore human   machine inference interface
  - SP must generate outputs with higher information rate

Now that I'm here, what should I do?

How do we build SP   network 'bipartite graphs'

Epistemology

- [Craig Q2] What can SP tell us about the network?
- [Craig Q3] What should the input signals be?
  - What do we want to know?
  - What can we measure, and why do we think those measurements will be useful?

Jointly define/hypothesize/test a model

model   measurements   inferences

What are the research questions?

- What can SP tell us about the network?

- What's happening in my network?

- How do I detect/identify/quantify (unusual) activity
  - DoS; equipment failures; routing changes

- What can I infer from xxx measurements?

- What other measurements would make the inference task (much) easier?

- How do I present inference outputs to decision-makers?

- How do I automate the inference/decision/response process?

Data Thoughts

- Some high-fidelity data is useful, even if it is synthetic
  - Model development; model robustness; new insights
- Range of data sets: controlled   realistic
  - Identify questions that can/cannot be answered with each set
- Choose measured data sets carefully
  - Goal-oriented
  - Minimize 'noise' that detracts from research
- Staged data collections with refinement
- Challenge problems:
  - "If you measure something, it will improve."

ATR: MSTAR Data Set

T-72

BMP-2
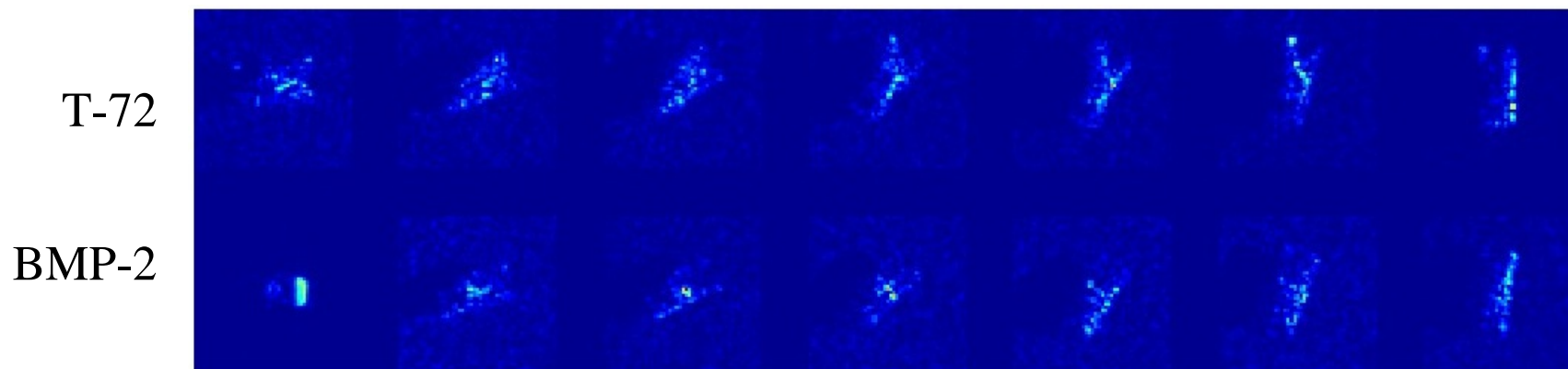
MSTAR Public Targets:

   10 targets x ~275 aspects = 2747 image chips

SP ↔ network 'bipartite graphs'

- Problems before tools

- A signal processing 'resource bank'?
  - Triage of research questions?

If you were to design the next internet, what measurements would you build in?

The answer guides:

- the compelling research questions

- the initial data needs

- a scientific framework for collaboration at the next level