

On the Structure of Data Sets Observed by Physically Embedded Networks

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(Joint work with G. N. Lilis and M. Zhao.)

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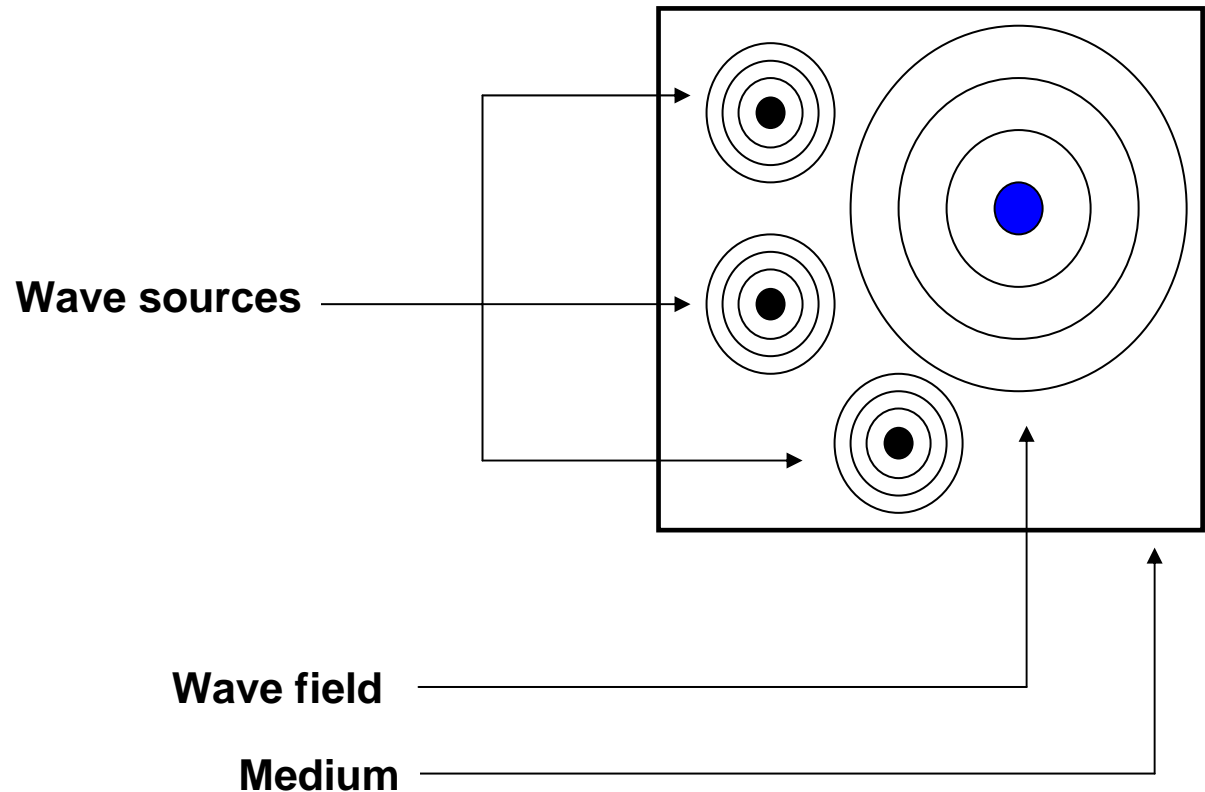
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Outline

- The Problem of Wave Field Synthesis
What it is
Where it comes up
- Problem Formulation and Technical Challenges
A Distributed Feedback Control Loop
Discrete Representations of Spatial Signals
Impact on Network Operations
- Numerical Simulations and Experimental Work (in progress)
- Summary and Conclusions

The Problem of Wave Field Synthesis

- A point source generates a wave field in space.
- An array of point sources at other locations try to create the same field.

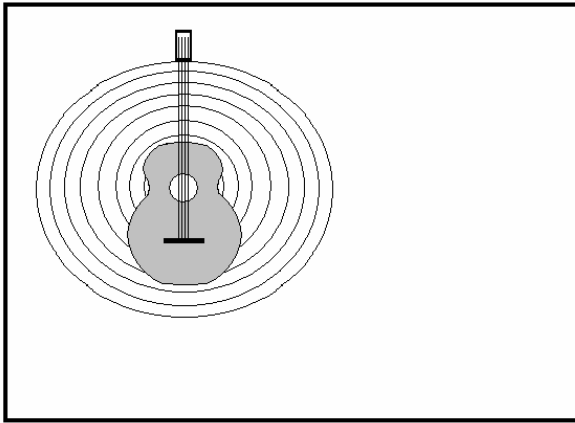


Why? A good context in which to study problems of large-scale actuation...

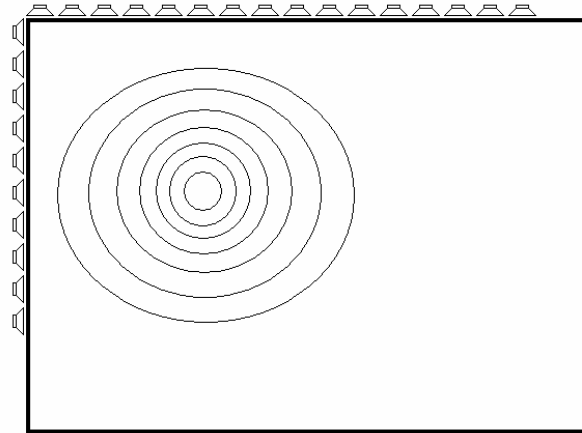
Applications – Rendering of Virtual Acoustic Sources

SOUND REPRODUCTION

- Synthesize the sound field of primary sound sources by the means of a finite number of microspeakers.



Primary sound source



Reproduced source

Challenges

- Inhomogeneities of the acoustic medium
- Temporal changes in the properties of the medium

Applications – Rendering of Virtual Acoustic Sources

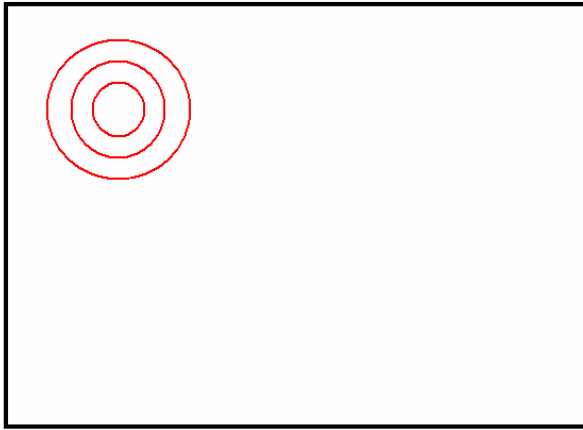
A futuristic application, but well within reach: the meeting room of the Jedi Council.



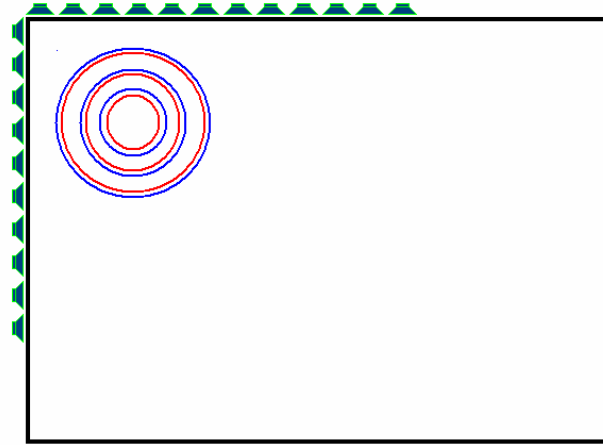
Applications – Noise Cancellation

NOISE CANCELLATION

- Synthesize sound fields that will eliminate existing noisy sound patterns.



Noisy sound pattern



Cancellation of the noisy pattern

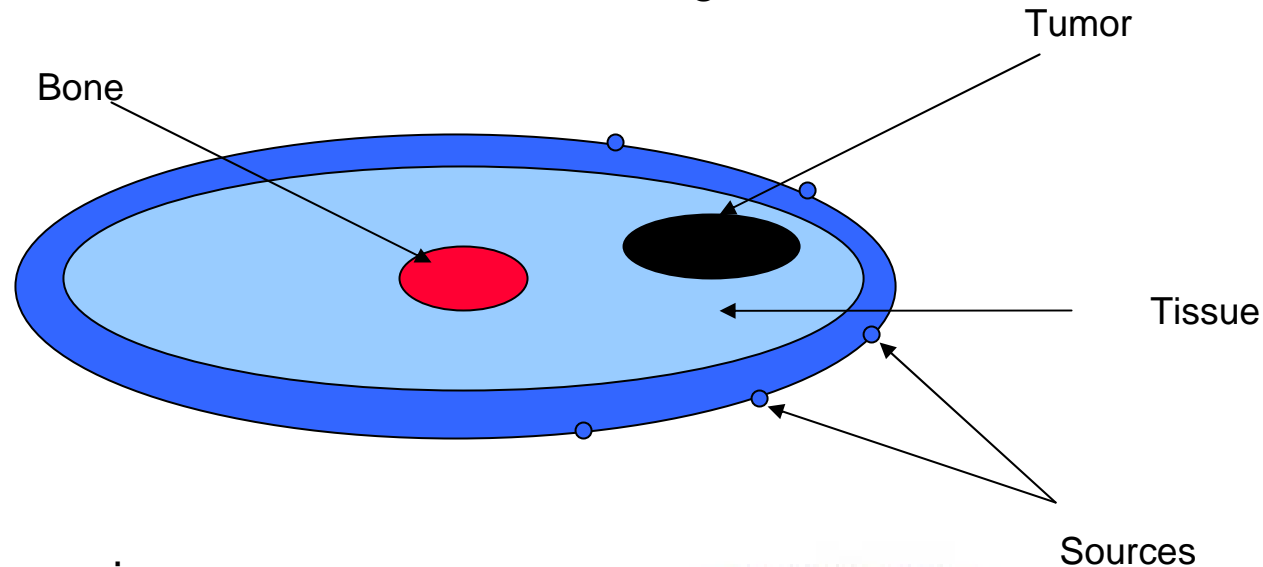
Challenges

- Difficulty in detection of the noisy pattern.
- Efficient estimation of the noisy source characteristics.

Applications - Cancer Treatment

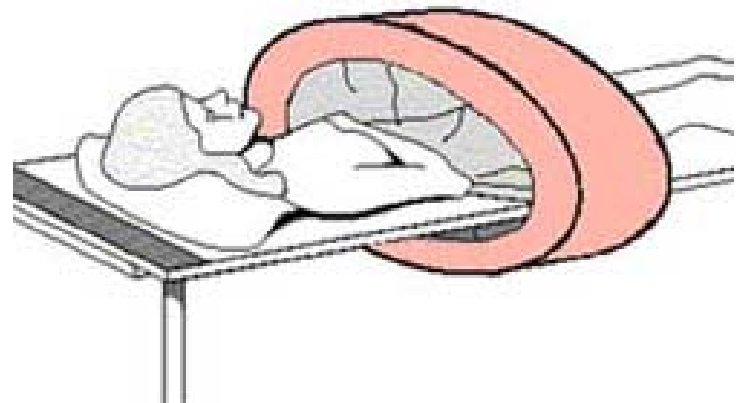
CANCER TREATMENT

- Specify **distributed micro-wave sources** on the **boundaries** of a region, that surrounds **a tissue**, that will result in the creation of a desired wave field pattern concentrated in the tumor region.



CHALLENGES

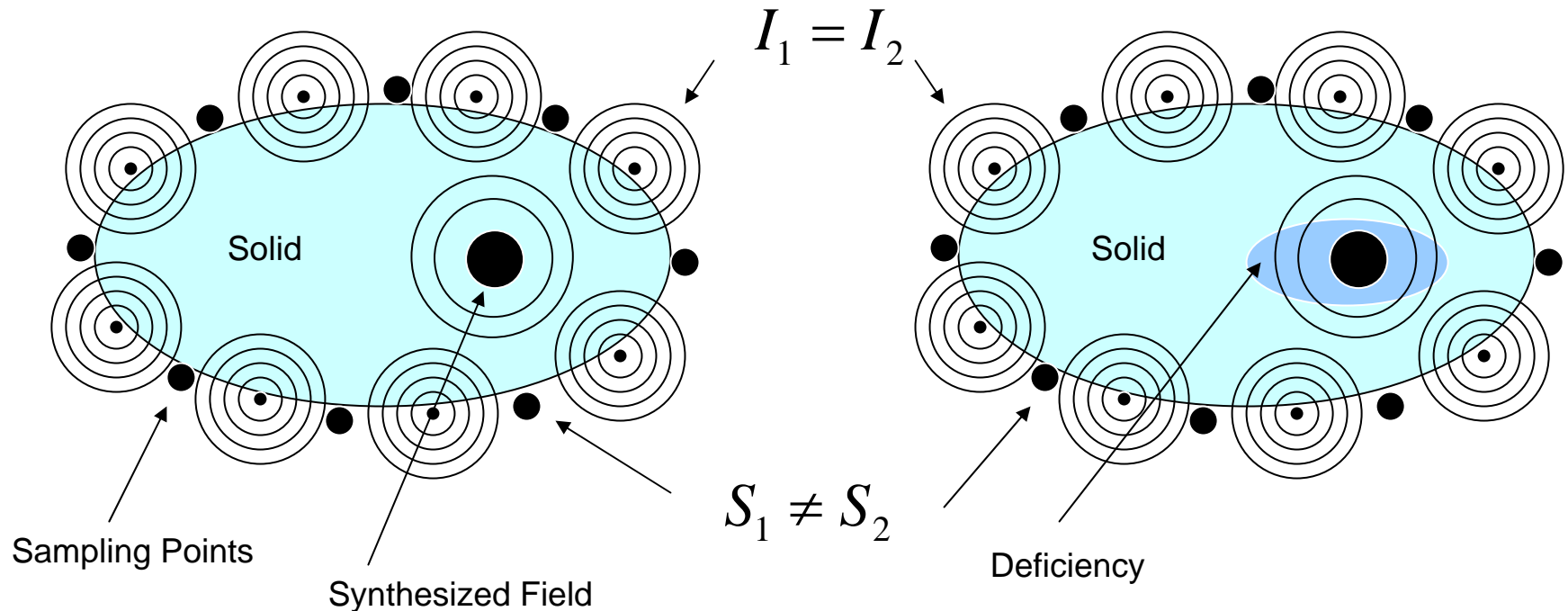
- Inhomogeneous tissue region
- Different penetration depths of the waves
- Sensitivity of the surrounding tissue



Applications – Solid State

SOLID STATE

- Identify the properties of solid media and locate deficiencies, by synthesizing wave fields inside them and measuring the responses externally.



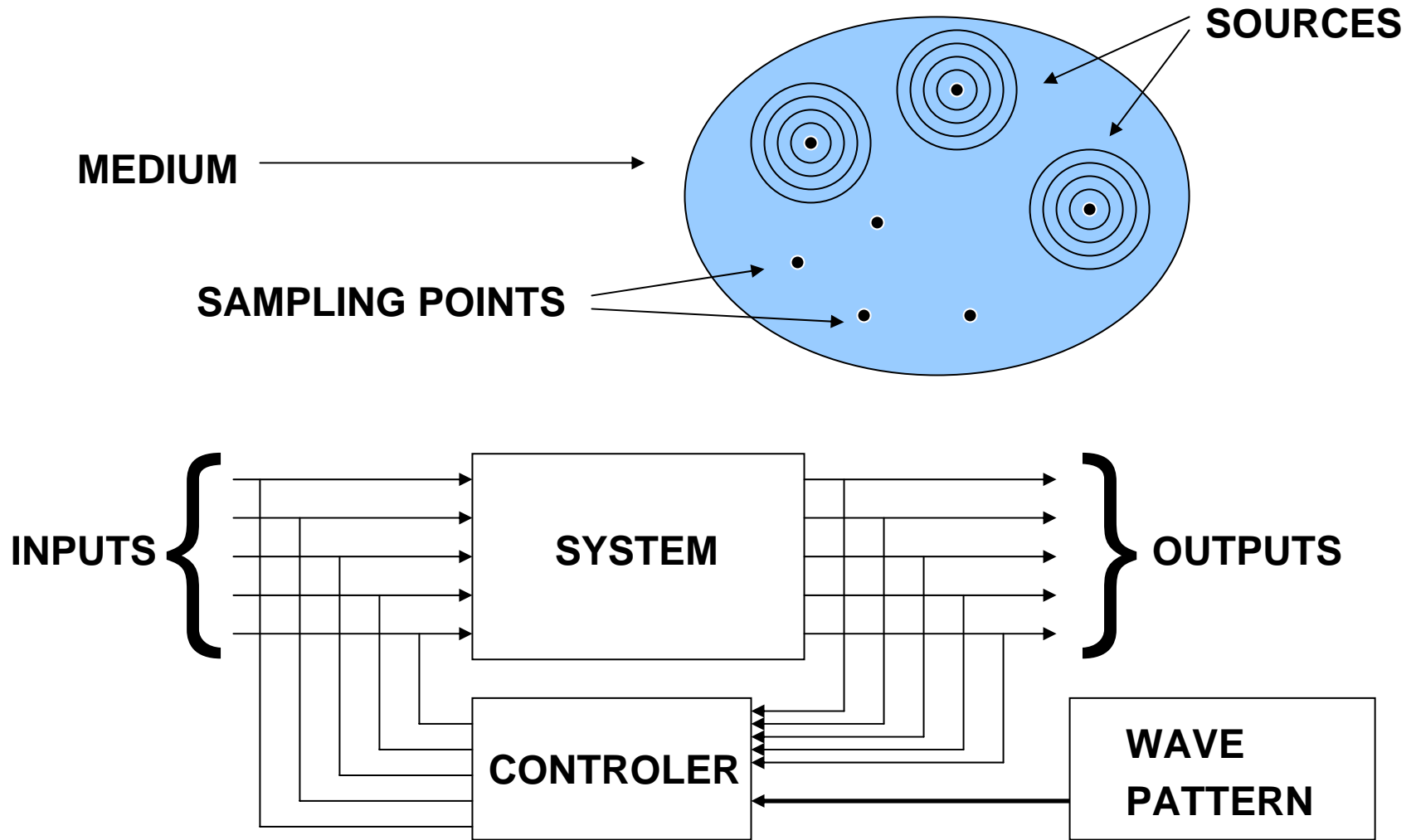
CHALLENGES

- Noise in observation
- Aliasing problems

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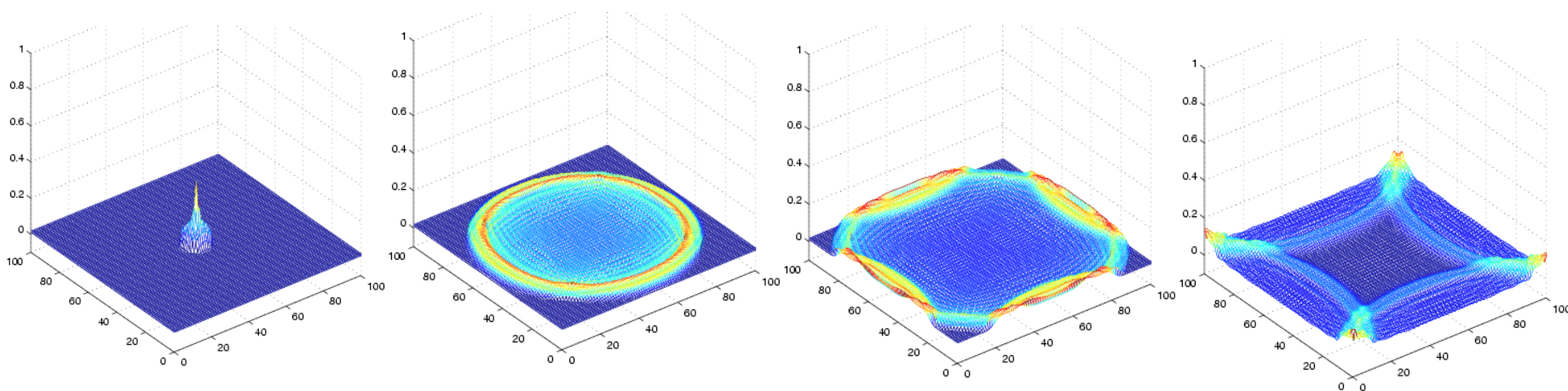
A Distributed Feedback Control Loop



Main challenge: sensing/actuation performed by a network – how do we do DSP on this data?

Discrete Representations of Spatial Signal Fields

Sampling/interpolation: the front-end for any DSP algorithm...



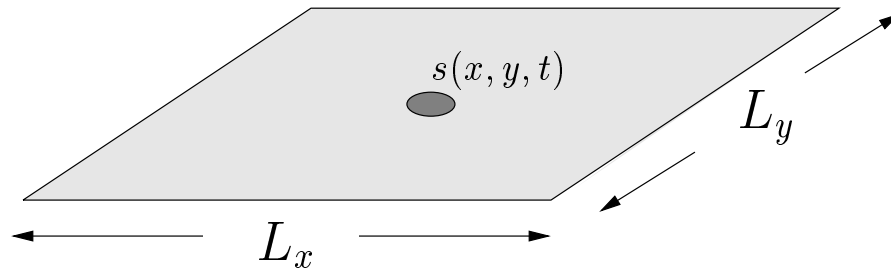
- Waves are confined to a finite region → not bandlimited in the classical sense.
- Sensor network cannot implement antialiasing filters → cannot do classical sampling.

*Yet these signals “look” highly structured... they are constrained by a PDE!
From the wave equation, we can derive an alternative interpolation kernel – front-end ok! (What does this enable?)*

Impact on Network Operations

A toy but representative setup:

- Rectangular homogeneous membrane, no friction, perfect reflections.
- Point source acting at a fixed location.



Main result:

Pressure at location (x', y') = source at location (x, y) , convolved with a linear filter.

Main consequence:

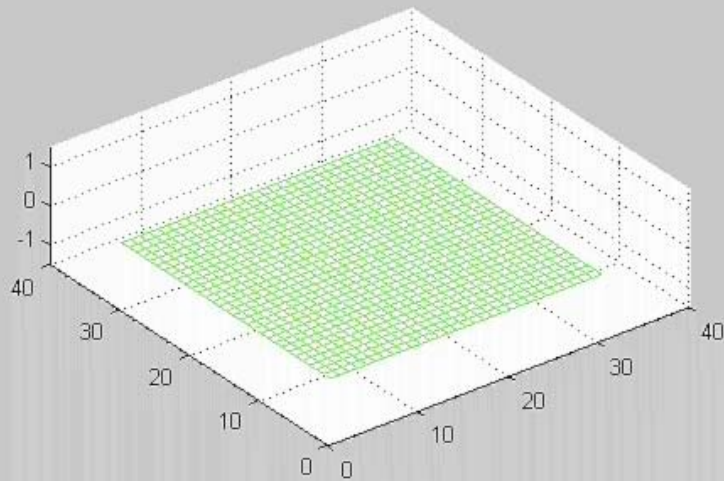
Pressures at a single location are (almost) enough to recover pressures everywhere.

Outline

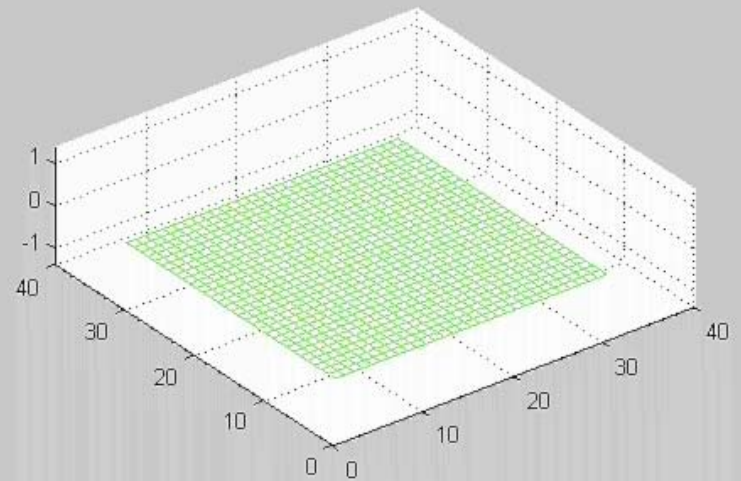
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Numerical Simulation of *Constrained* Solutions to the Wave Equation

Problem: Specify source function generating a sampled field in a **Homogeneous** cylindrical domain



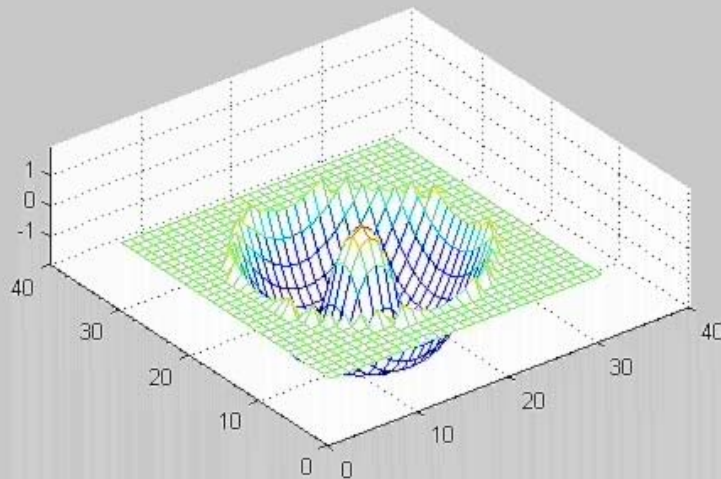
Sampled wave field from FD



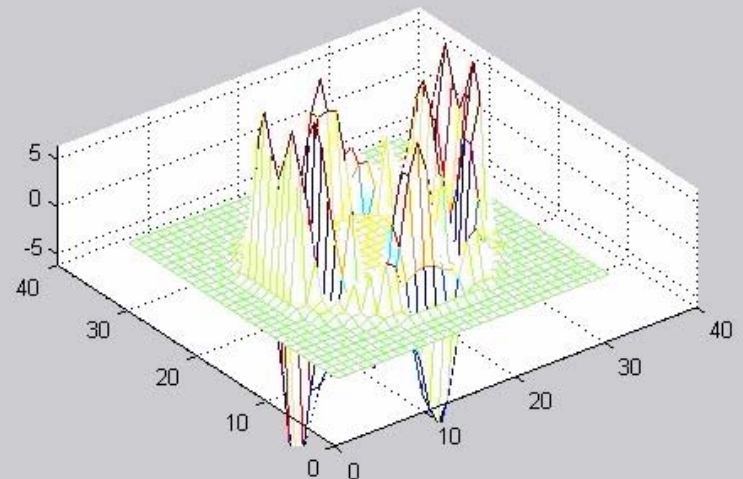
Calculated source distribution

Numerical Simulation of *Constrained* Solutions of the Wave Equation

Problem: Specify Constrained source function generating a sampled field in a **Homogeneous** cylindrical domain:

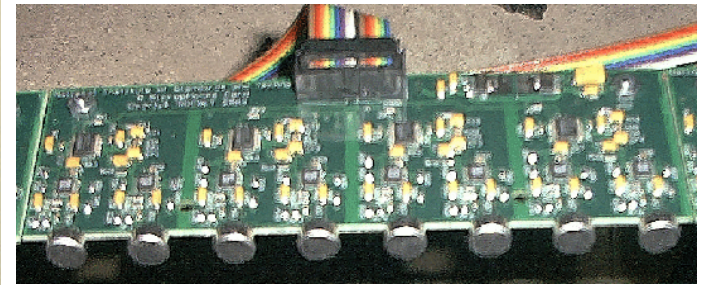
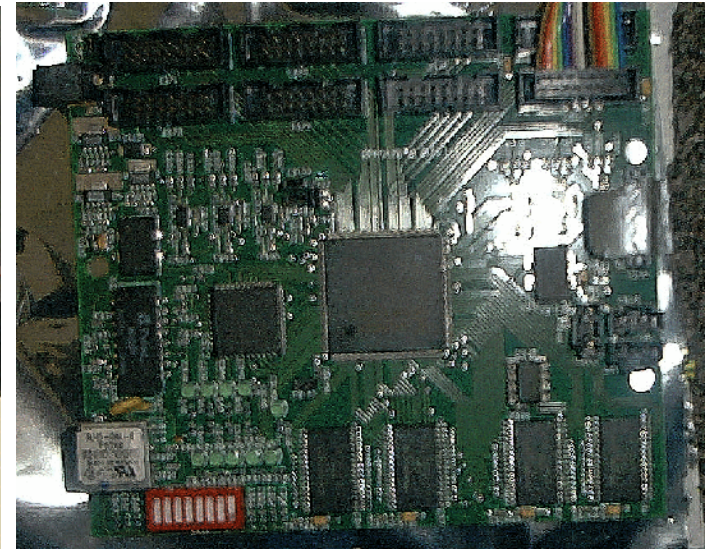
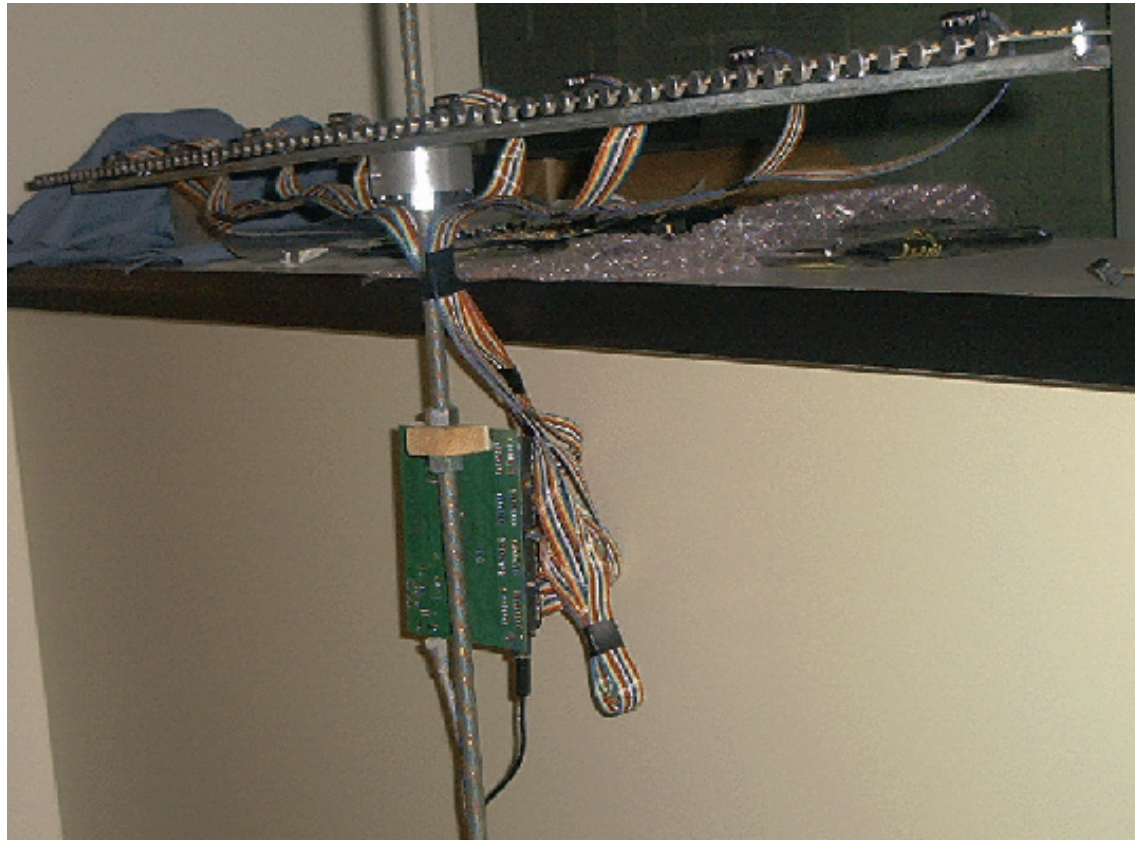


Sampled wave field from FD
18 Frames



Calculated CONSTRAINED
source distribution

Our Experimental Testbed – A Large Acoustic Array

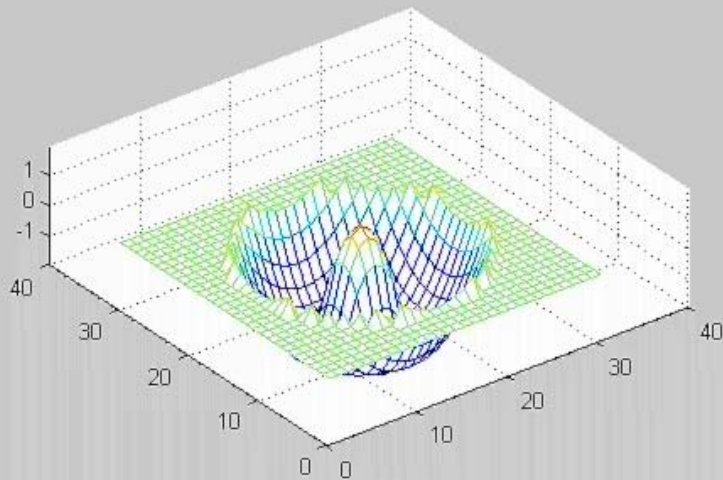


Outline

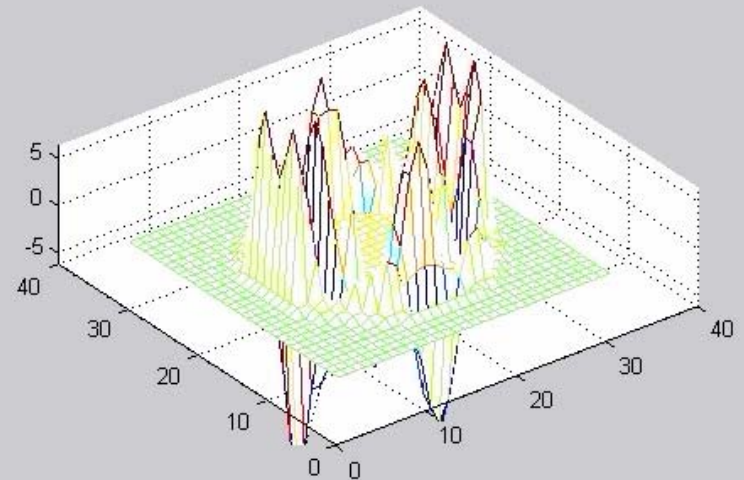
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Possible Defense Application I: Electronic Warfare

Creation of fake EM signatures, to fool a surveillance system.



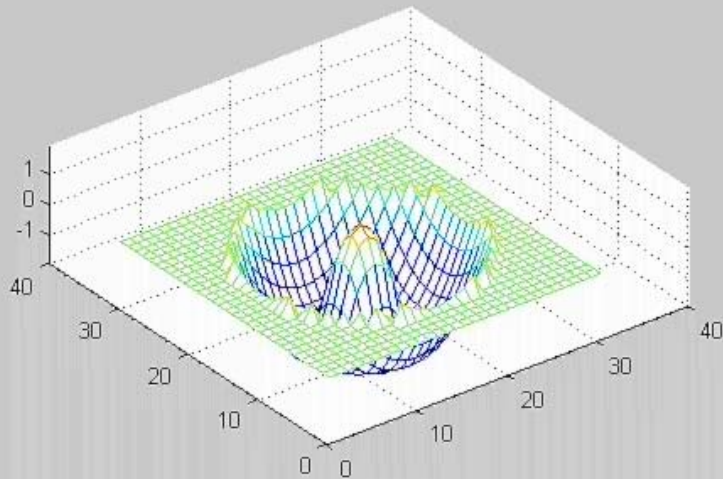
Fake signature created by ...



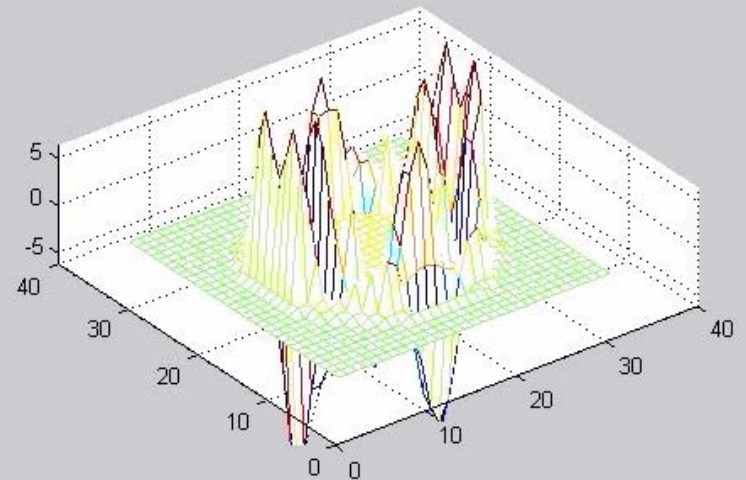
... a network of far transmitters!

Possible Defense Application II: Distributed Weapons

A directed energy weapon, out of many small undirected ones.



Pressure waves created by ...



... a network of small explosions!

Main Things (I would like you) to Remember

- About the WFS problem formulation:
 - ✓ A feedback control loop, where observer/controller devices are networks.
 - ✓ A good problem to explore large-scale embedded actuation.
 - ✓ A problem in which increasing resolution is both interesting and useful.

- Classical pure networking questions are very heavily dependent on the structure of the signals observed/controlled by this network.

(“On the Structure of Data Sets Observed by Physically Embedded Networks”)

- A very general abstraction, whose solution applies to a wide range of civilian applications (acoustics, health care, civil engineering) – and hopefully, to problems of interest to you as well.

Main Conclusion



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