Directional Multi-microphone Arrays: A Spatial-filtering Approach to Source Separation

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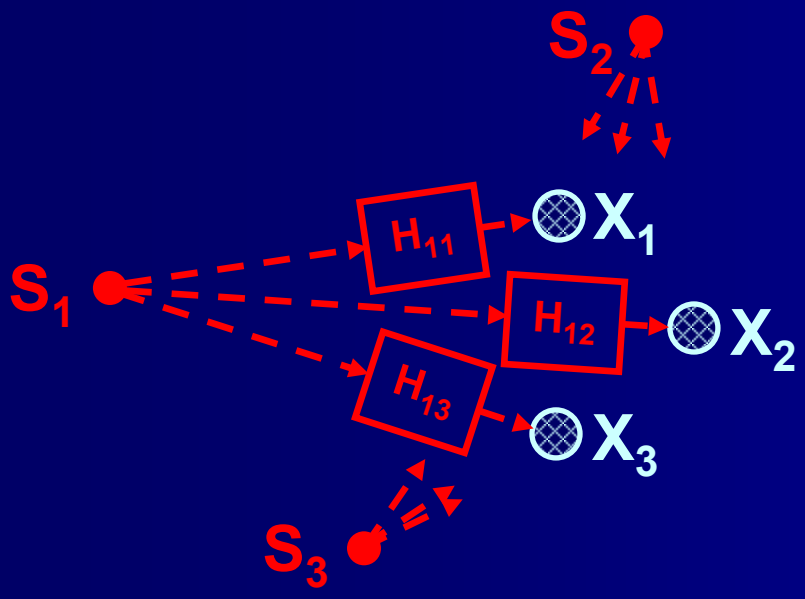
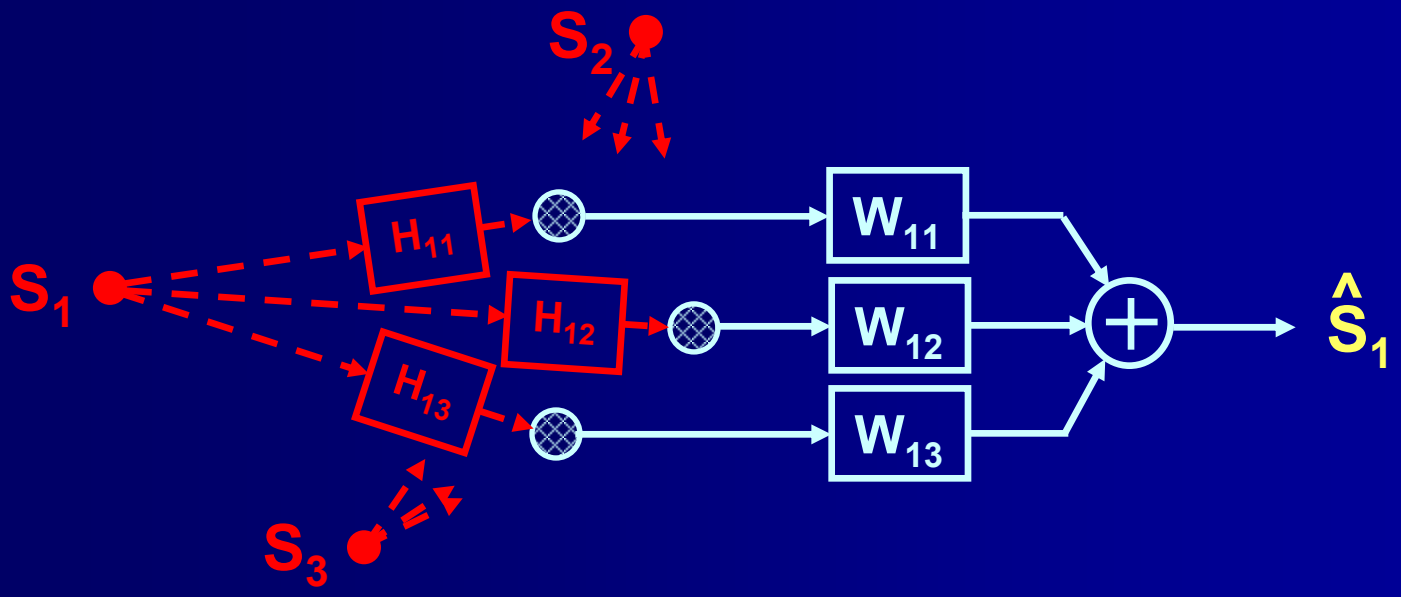
Basic Problem



- Multiple sources propagating to multiple sensors.
- Propagation paths vary with source location.

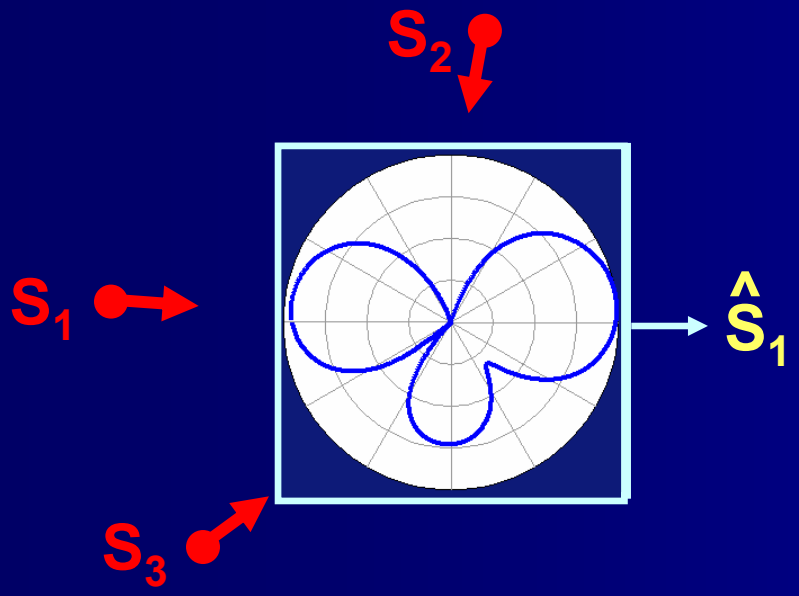
What is Spatial Filtering?



- Filter-and-Sum to estimate *each* source.
- M-mics can filter a target from a field of M-1 interferers
- For known target location, filters chosen by:
  - Explicit Nulling
  - Fixed Beamforming
  - Adaptive Beamforming

Explicit Nulling (EN)

Weights are designed to explicitly null interference locations while preserving the target location.



Can yield substantial improvements in SNR if source locations are well-known and if there is no reverberation.

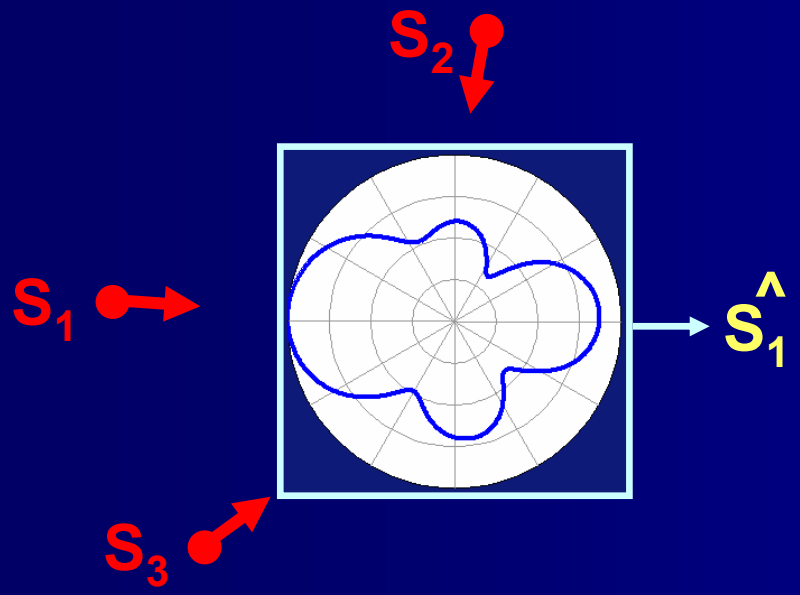
Performance deteriorates when locations unrelialbe and in reverberation.

Fixed Beamforming (FBF)
Assuming known target location

Filters maximize:

$$\text{Directivity Index (DI)} = \frac{\text{direct-path target output power}}{\text{average output power}},$$

while preserving the direct-path target with unit gain.



More sophisticated than D-&-S

Enhances target relative to any potential interference.

For head-sized arrays, 4-10 dB* of SRT improvement is representative in mild reverberation.

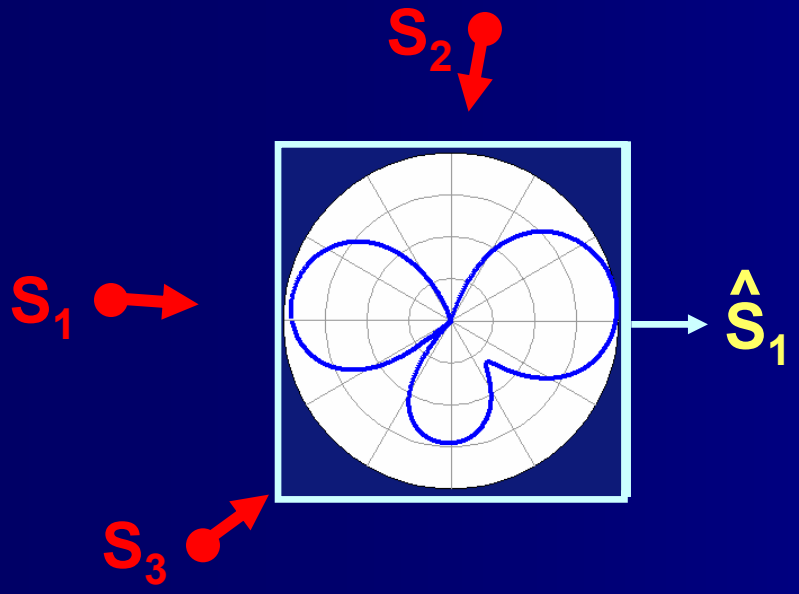
* Luts, et al. (2004).

Adaptive Beamforming (ABF)
Assuming known target location

Weights satisfy:

$$W_{opt} = \text{argmin}_{W_{i,j}} \; E[\text{output power}],$$
$$\text{such that direct-path target preserved}$$

Various approaches: e.g., Griffiths-Jim, Frost, FMV.



Actively steers nulls towards interference.

For head-sized arrays, 11-16 dB* of SRT improvement is representative with low reverberation.

* Greenberg, et al. (2003).

Trade-offs

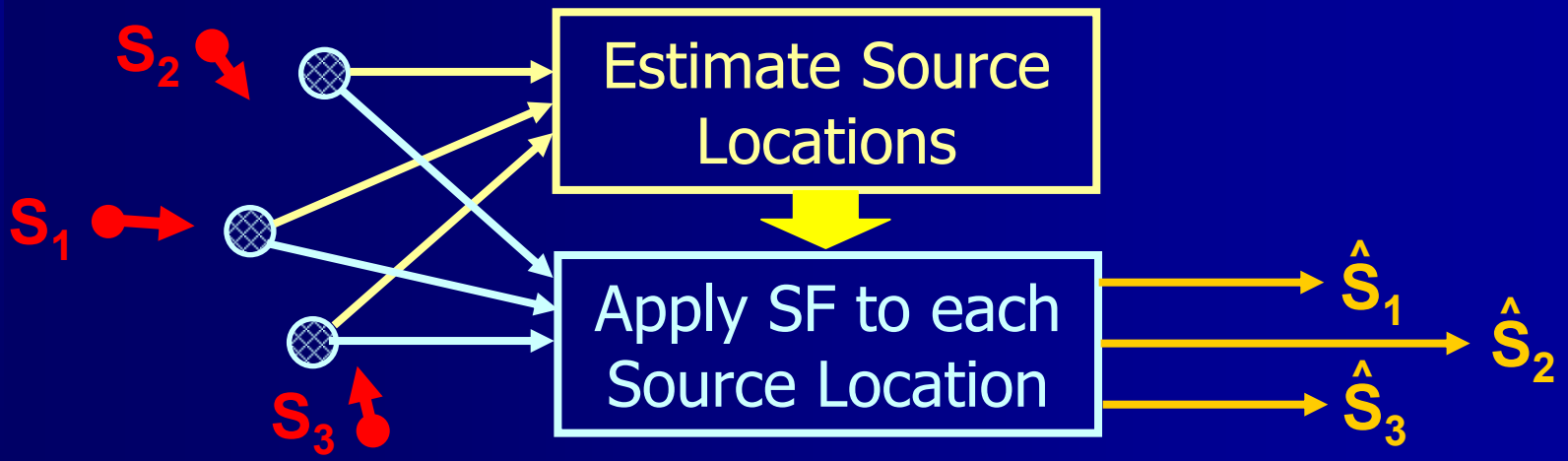
- EN: simple to implement with known source locations **but** requires lots of a priori knowledge and low reverb.
- FBF: simple and robust directionality **but** directional advantage is limited.
- ABF: can attain higher SNR improvement **but** performance is complicated and deteriorates with reverb and too many sources.

Applying Spatial Filtering to Blind Source Separation

- Spatial filtering assumes:
  1. There is a single target.
  2. The target (and possibly jammer) location is known.
- In blind source separation, there are many targets at unknown locations.
- How does this work with BSS?

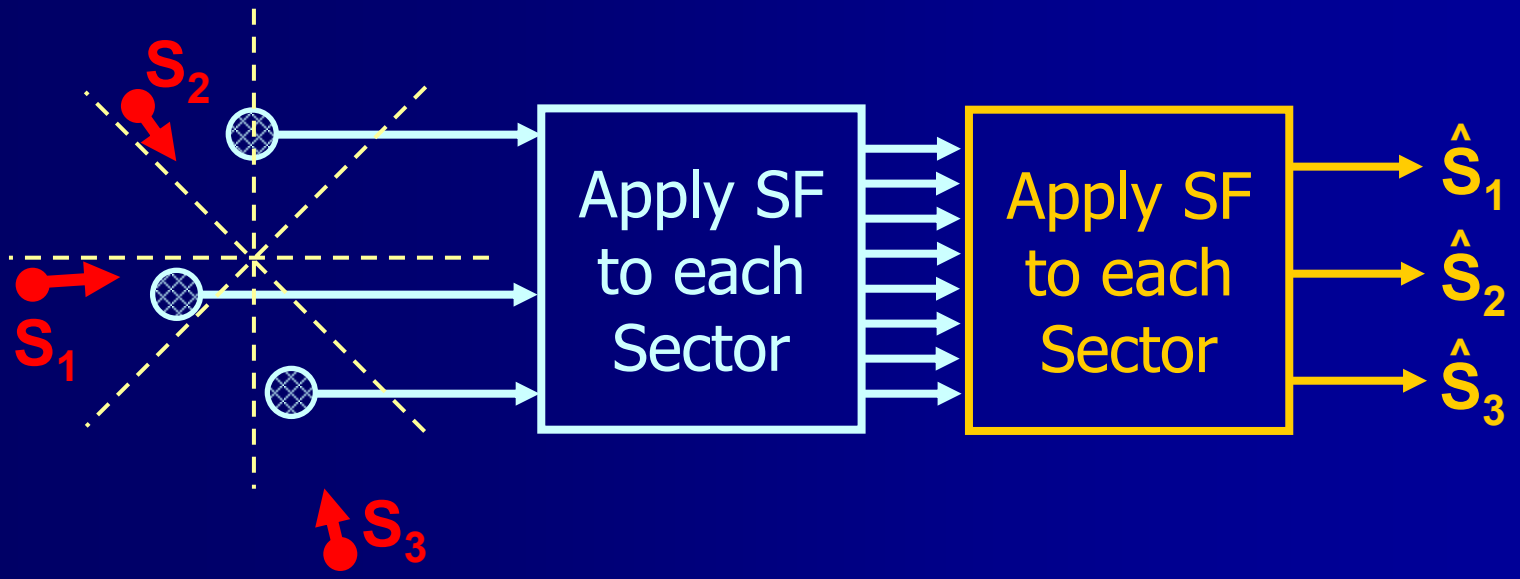
Approach I: Estimate Source Locations

- Use input signals to estimate the locations of the components sources in the environment.
  1. Narrowband techniques (MUSIC or ESPRIT).
  2. Inter-mic time-delay methods (TDOA)
     RMS loc errors < 10 deg.
- Create a separate spatial filter towards each target.



Approach II: Use Spatial Sectors

- Divide space into sectors.
- Create a spatial filter towards each sector
- Evaluate each sector output to determine if a source is present.



Approach II: Already Seen It?

Teleconferencing:

- 3 cardioid mics determine dominant talker location.
- Fixed or adaptive beamforming extracts target signal.

(Polycom Soundpoint)

Outstanding Issues

- Reverberation
  - Affects the reliability of target location estimates.
  - Affects ability of spatial filter (both fixed and adaptive) to enhance the SNR of the specific target signal.
  - More to come tomorrow!!
- Non-Stationarity
  - Locations / spatial filters are hard to design.

Why Spatial Filtering is Still Worthwhile

- SF may be regarded as ‘classical’ or ‘old’ **BUT:**
  - It is implemented and in use right now.
  - Can be made quite robust to reverberation or numerous sources so that the performance degrades gracefully.
  - There is still room for improvement.