Propagation of Uncertainty from the Environment to the Sonar Operator

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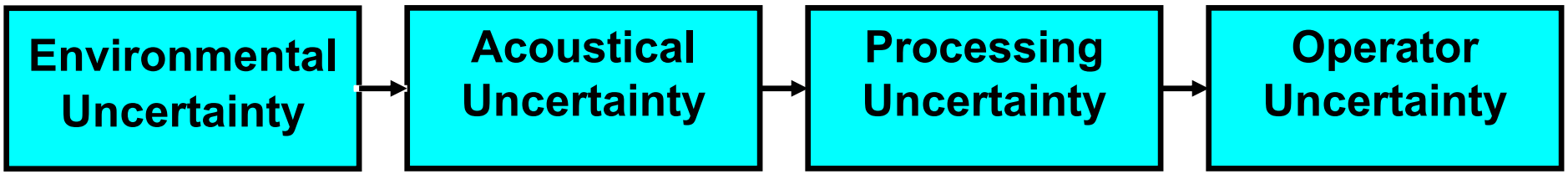
The Cascade of Uncertainty



Components

- volume
- surface
- bottom
- dynamic vs static

Components

- signal model
- noise and/or reveberation

Components

- beamformer
- spectral analysis /matched filtering
- trackers
- normalizers
- automation and displays

Components

- maneuver to avoid collision & counter detection – detect, track, localize & classify –w/ all earlier uncertainties

MIT Acoustics

Environmental Uncertainty

- **Ocean undersampled in time and space at all scales**
  - **Archival: Levitus, GDEM, BLUG, MODAS**
    - **Useful guidance if sampled adequately**
    - **Need high priority on operationally significant regions**
    - **Errors in models often not stated**
    - **Predictions and in situ measurements often disagree or lead to unacceptable errors**
- **Scales in time and space important for sonar**
  - **Temporal** $\tau_{acoustics} << \tau_{environment}$
  - **Spatial** $\lambda_{acoustics} versus\ \lambda_{environment}$
- **Volume, surface & bottom coupled, importance varies**
  - **Deep excess deep water (no bottom) vs**
  - **Littoral w/ downward refraction (volume and bottom) vs**
  - **Doppler based system (surface)**

Environmental Uncertainty (cont'd)

- **Characterizing uncertainty methods**
  - **2nd moments, EOF's, sampled covariances**
    - **Often poorly conditioned or low effective rank because of the finite number of samples (oceanographic snapshots problem)**
  - **Probability density functions**
    - **Usually 1st order, few 2nd and higher - complicated**
    - **Few multivariate => Gaussian or Poisson employed**
      - **E.g. – no N multivariate lognormal or beta pdf's**
    - **Dynamical - EKF's w/ updates => large # of states, sparse observations, linearization problems, Ricatti eqn divergence**
    - **Bayesian methods – curse of dimensionality**

Acoustic Uncertainty

- Wave equation linear wrt to solution, very nonlinear wrt to parameter dependence
- EOF's of the environment & EOF's of acoustics (ray/mode models) often not well matched, e.g.
  - Depends upon which ray/modes exploited by sonar
  - Bottom bounce vs mixed layer, bottom for RR, RSR paths
- Temporal and spatial coherence scales
  - Temporal => lower limit on bandwidth
  - Source receiver motion dominates except for fixed/fixed systems
  - Spatial => aberrations across array aperture limits before partitioning for spatial diversity
  - Vertical and multipath coherence => limits on matched field and other spatial recombination of multipaths

Acoustic Uncertainty (cont'd)

- **Acoustic prediction w/ uncertainty**
  - **Common assertion => the errors in acoustic predictions are limited by the lack of input data**
  - **Response => data for this will never be available either because of survey limits or ocean dynamics**
  - **Stochastics, or uncertainty, always will be with us=> the important issues are**
    - **Learn to incorporate it!**
    - **Understand its consequences and/or risks!**

Acoustic Uncertainty (cont'd)

- **Methods for acoustic prediction**
  - **Parabolic equation**
    - **Good narrowband solution except with high relief**
    - **Used in current TDA's (tactical decision aids)**
      - **SFMPL and PCIMAT**
    - **Narrowband vs path identification**
    - **Uncertainty not propagated (2nd moment formulation)**
  - **Coupled modes and range dependent OASIS**
    - **Range dependent extension of homogeneous codes**
    - **Moments can be propagated easily (numerically)**
  - **Computation limits at high frequency and long ranges**

Acoustic Uncertainty (cont'd)

- **Noise and reverberation**
  - **Ultimately sets limits on sonar performance**
  - **Passive systems**
    - **Structure of the noise field – high clutter (large # of discrete interferers) difficult, but presents opportunity for highest gains**
    - **Models available (DANES, ANDES, HITS) – model uncertainties unknown**
  - **Active systems**
    - **Reverberation (mosty bottom) limits performance**
    - **Very difficult to characterize accurately**
      - **Model limits – diffuse vs discrete**
      - **Little statistical characterization beyond scattering strength for extended interaction regions**

Signal Processing Uncertainty

- **Stochastic uncertainty**
  - **Obtaining a sufficient # of observations to constrains adaptive beamforming versus environmental stationarity**
- **Number of resolution cells**
  - **Modern arrays have very high resolution**
  - **Product of frequency bins X beams overwhelms an operator while searching**
- **Important to be robust at low SNR's and uncertainty vs high SNR resolution enhancements**
  - **Modern threat is at MDL (minimum detectable level) and at short range**
- **Horizontal vs vertical gain uncertainties vs array design**

Signal Processing Uncertainty (cont'd)

- Normalizers (contrast enhancement for an operator) very nonlinear with uncertain performance
- Trackers (tracks of all detectable shipping) have very uncertain performance due to multipath, signal fading and clutter
- Automation and pattern recognition at MDL mostly ad hoc
- Noise and clutter rejection algorithms

- Sonar signal processor objectives are to provide reliable detections in spite of environmental uncertainties

Operator Uncertainty

- **Operator experience – uncertainty at the sonar display often difficult to quantify**
  - **Prediction TDA's often not used**
    - **Complexity of use vs skills of operator (w/ training)**
    - **Reliability track record**
- **CO's concerns**
  - **Trade off risks vs ship safety, counter detection, self defense, tactical advantage and mission objectives in terms of speed, depth, environment**
  - **What are the consequences of using the predictions (environmental, acoustic and sonar) vs the risks**
  - **Is a maneuver coupled to a very sensitive parameter? or is** $\frac{\partial\, Performance}{\partial\, Environmental\ Model}$ **very large**

Summary
Capturing Uncertainty for Sonars

- **Uncertainty propagates through the complete chain for sonar performance!**
  - **Characterizing only one component not appropriate**
- **Currently, the S&T efforts are concentrated at one component of uncertainty, whereas we need:**
  - **Closer coupling of oceanography, acoustics and sonar signal processing**
  - **Awareness of needs of the end user**
- **Capturing uncertainty robustly and simply remains an unsolved and difficult problem!**
  - **Crosses several communities, e.g. –dB budget, operational investment decisions, OPNAV projects**
  - **Fundamental research needed on all aspects, it is not just the environment**