Sonar Processing Framework based on the SCAT Model of Bat Biosonar

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Motivation

Bat biosonar is both fast and robust, which makes it valuable for developing real-time, biologically inspired, guidance control systems for improving man-made systems, especially for naval purposes. Our long term goal is to create a biologically inspired autonomous guidance control system that can identify targets, steer flight, and control the emission of successive broadcasts, all while avoiding interference from surrounding clutter.

Proof of Concept Goals

Develop the computational framework of the Spectrogram Correlation And Transformation (SCAT) bat echolocation model that utilizes coincidence detectors as its core mode of processing.

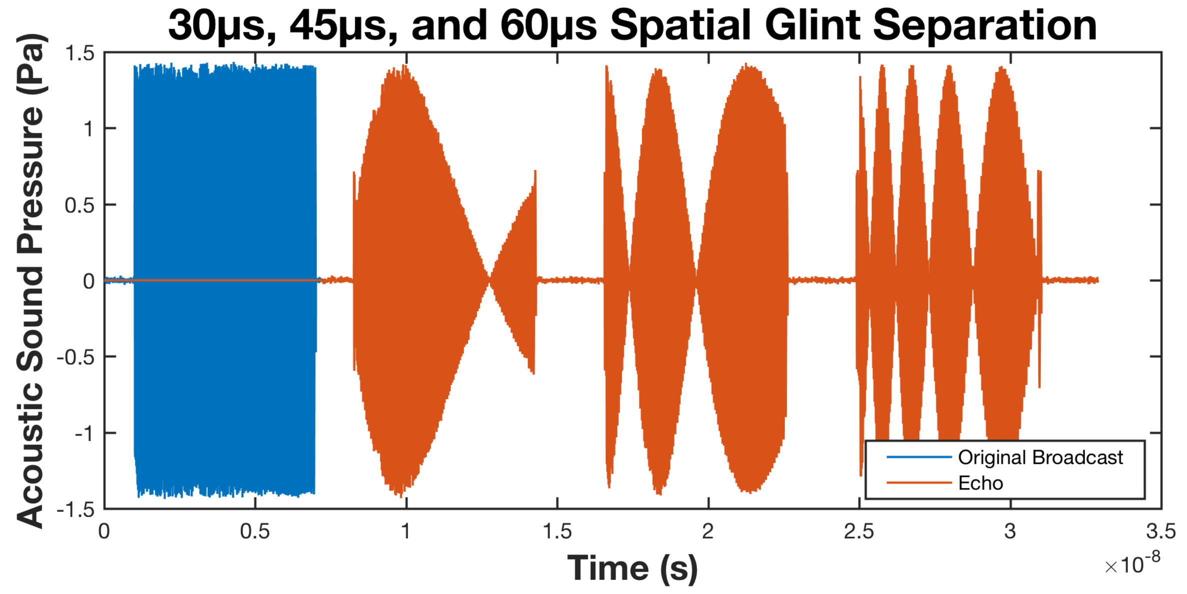
Echolocation Mechanics

- Bats broadcast FM sweep and listen for echoes
- Echoes further away result in longer delay
- Object glint separation characteristics are encapsulated in interference null patterns

Data Set

Simulated HFM (Hyperbolic FM) down sweep signals

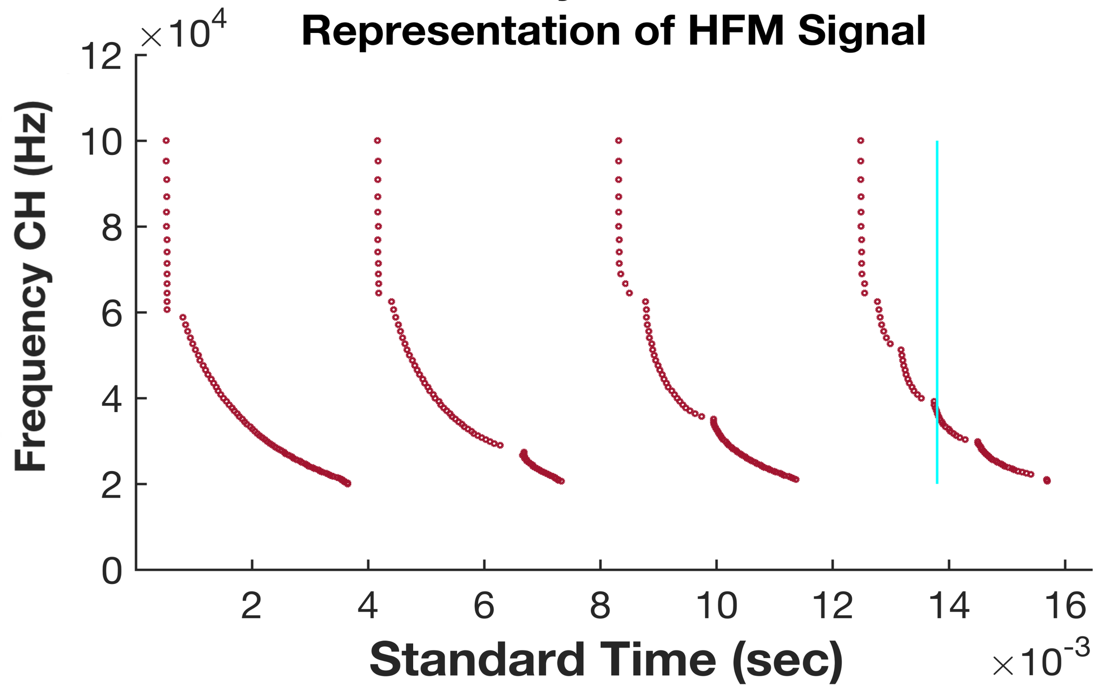
40dB HFM Simulated Acoustic Signal with 30μs, 45μs, and 60μs Spatial Glint Separation



Time domain representation of 40dB hyperbolic down sweep frequency modulated broadcast with three echoes of varying spatial glint separation

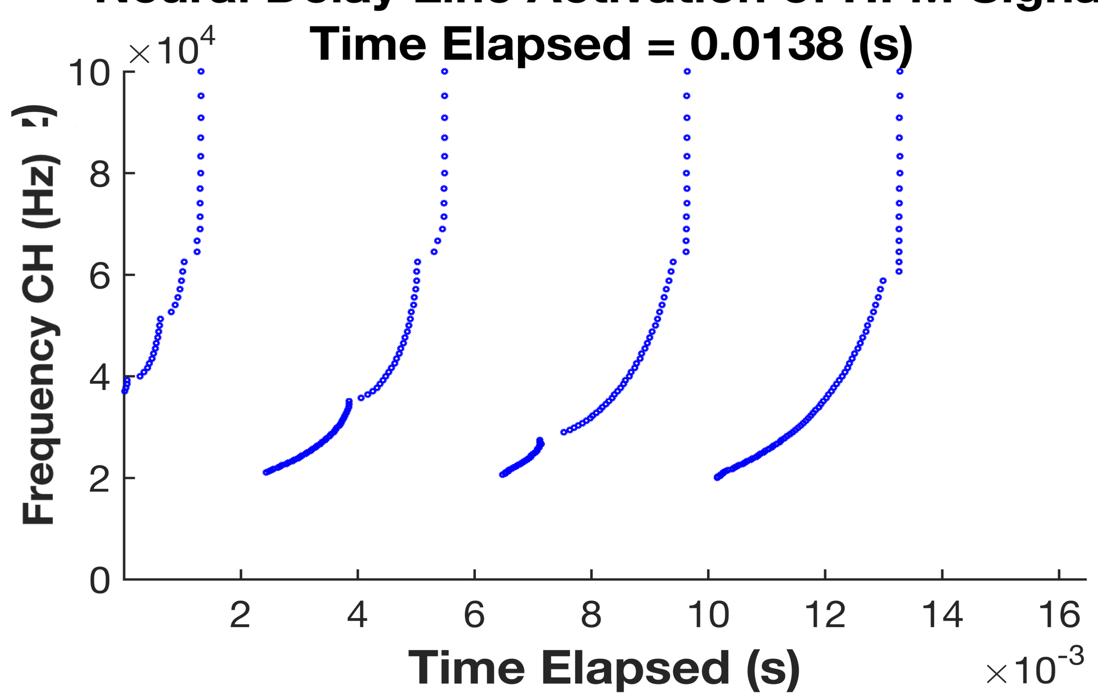
Peripheral Model Parameters	
Parameter	**Significance**
Band Limits	[20kHz, 100kHz]
Gammatone Filter Bank	Models Inner Ear (cochlea), filters signal into parallel frequency bands
Amplitude Latency Trading	ALT delay of -16us/dB converts relative weaker signal amplitudes into a time delay, In the neural delay lines, weaker signals are registered slightly later in time

Neural Delay Line Activation Representation of HFM Signal

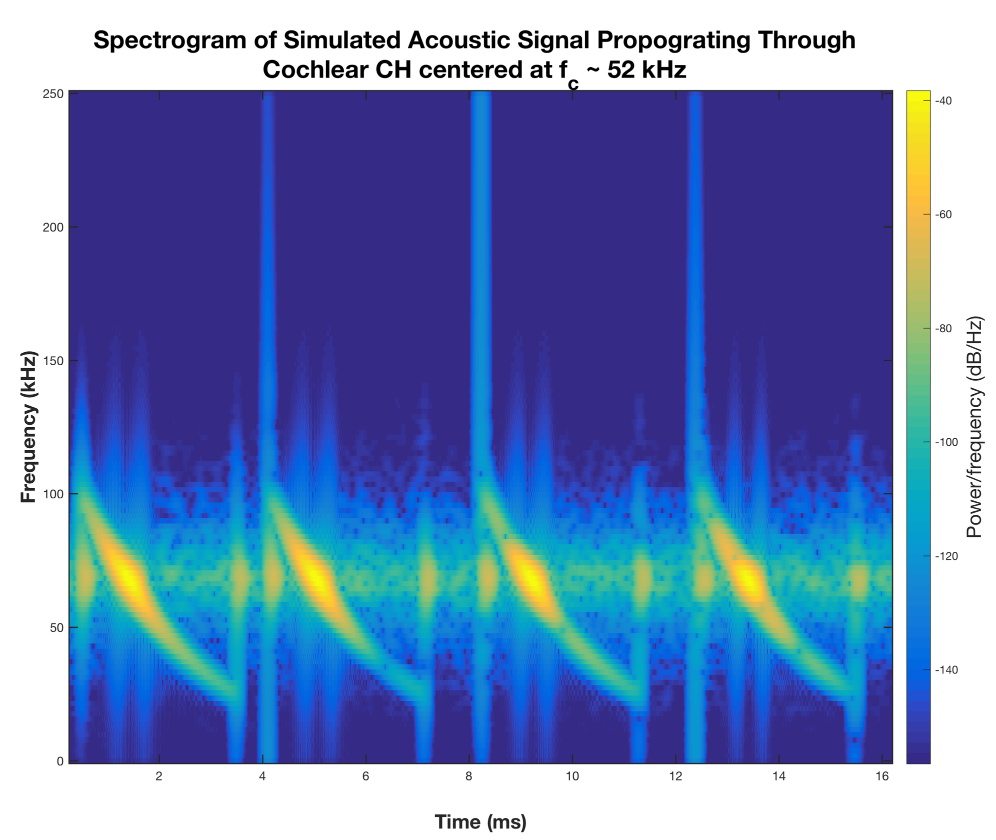


Neural delay line activation representation of the entire HFM sweep. Application of activation threshold and inhibition time following registration of acoustic signal propagating through cochlear channel transduces the signal into one activated neural tap per sound on channel.

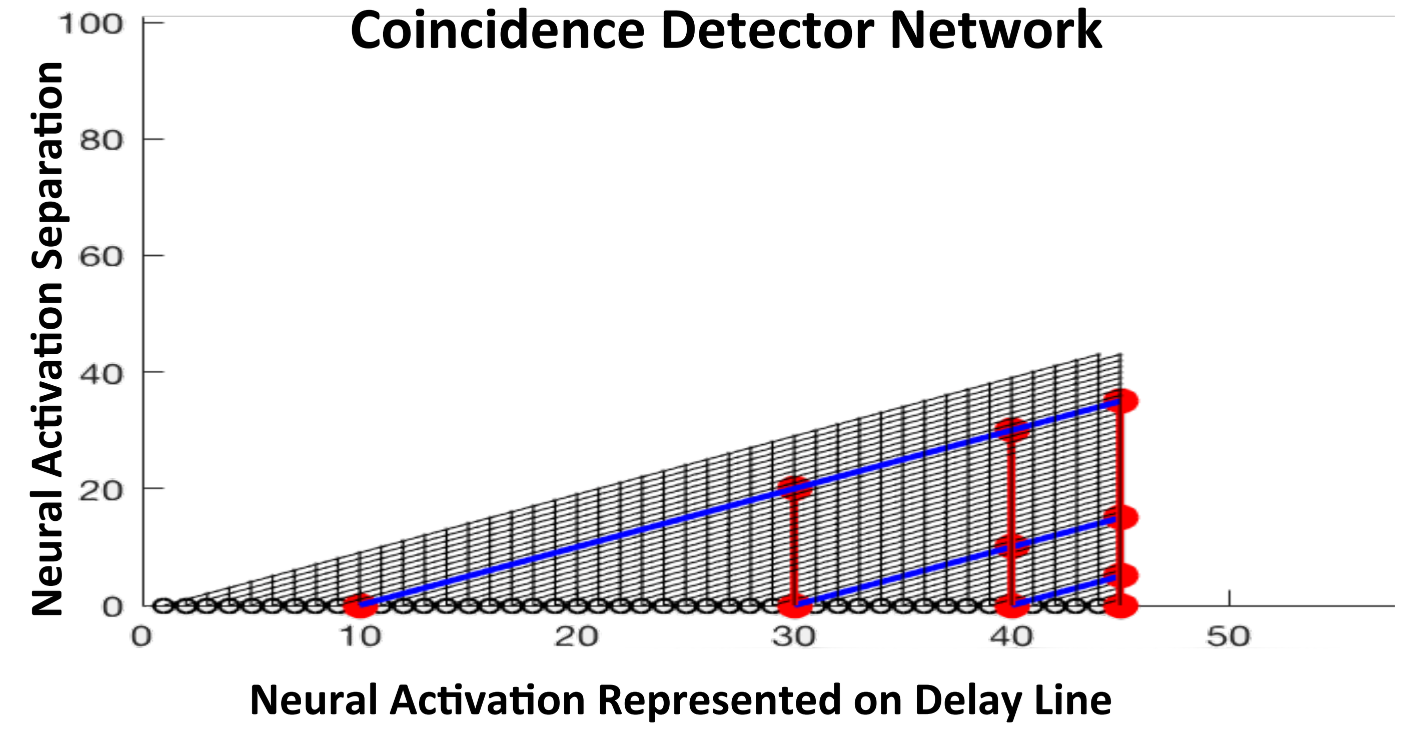
Neural Delay Line Activation of HFM Signal Time Elapsed = 0.0138 (s)



Instantaneous snapshot of the HFM signal propagating through the neural delay line. Sounds that were heard first are represented in the delay line earlier, newer sounds are concatenated to end of delay line.

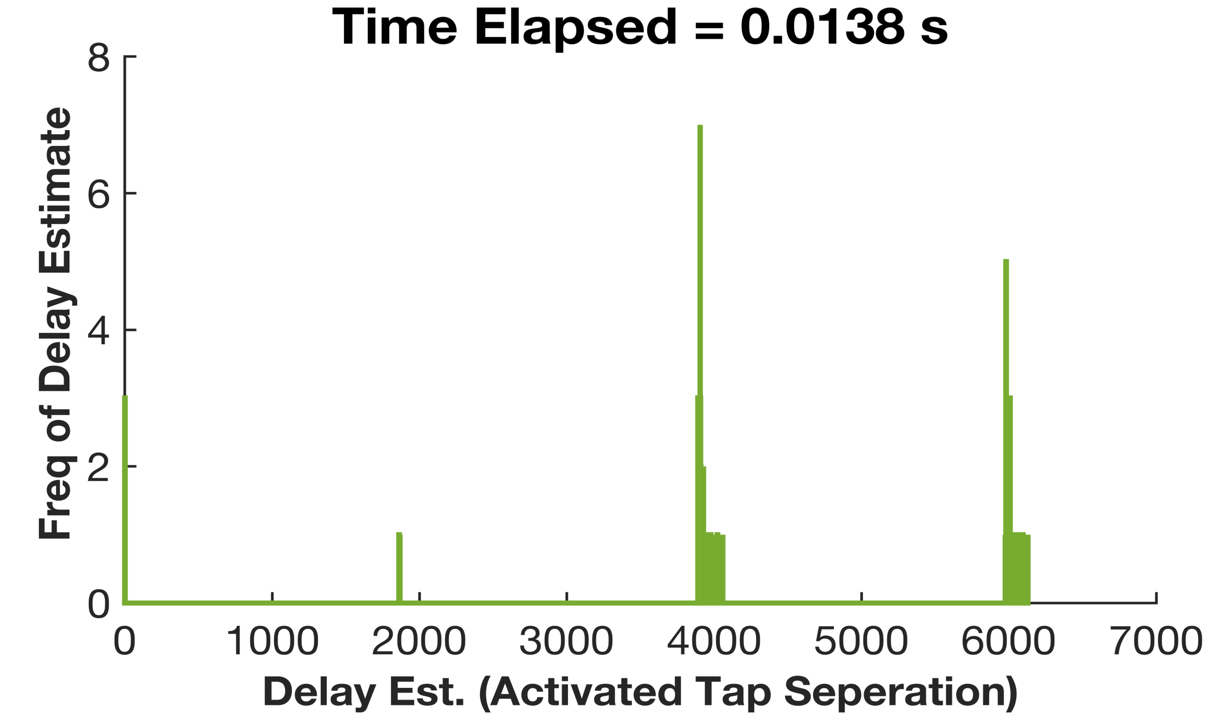


Spectrogram of HFM signal propagating through cochlear filter bank centered at 52kHz. Spectral leakage present due to sharp edges of simulated data. Naturally generated FM sweeps have more gradual build up and decay at sweep boundaries.



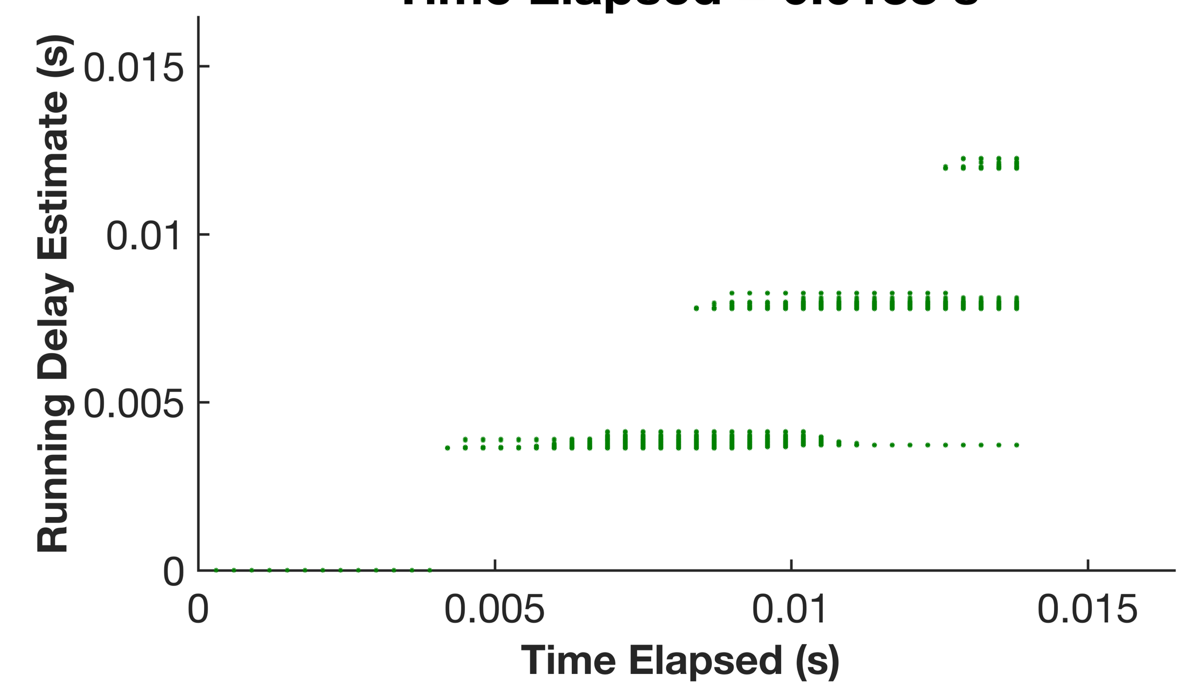
Broadcast and echo pairs are processed by coincidence detector networks applied within numerous parallel frequency bands, which provides the separation between activated neural taps on delay line.

Instantaneous Delay Estimate Histogram Time Elapsed = 0.0138 s



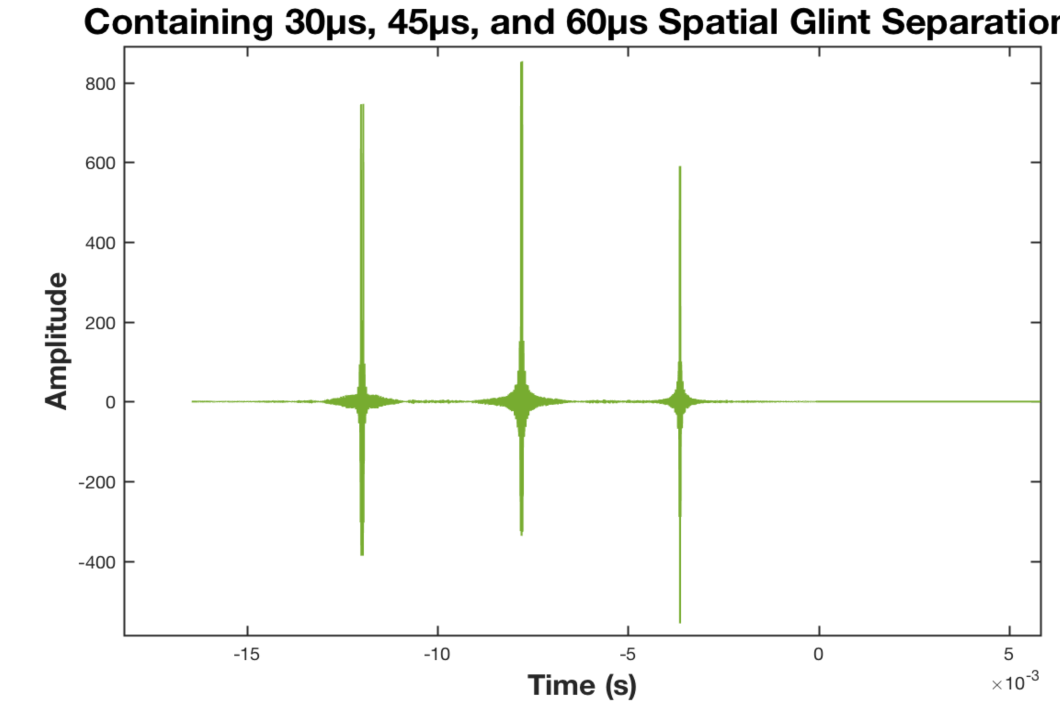
Histogram illustrates the delay estimate locations. Due to fine resolution of bin width, there is a distribution of delays around the true delay between broadcast and echoes. This is the representation of distance information in the scene, updated in real-time.

Running Delay Estimate Time Elapsed = 0.0138 s

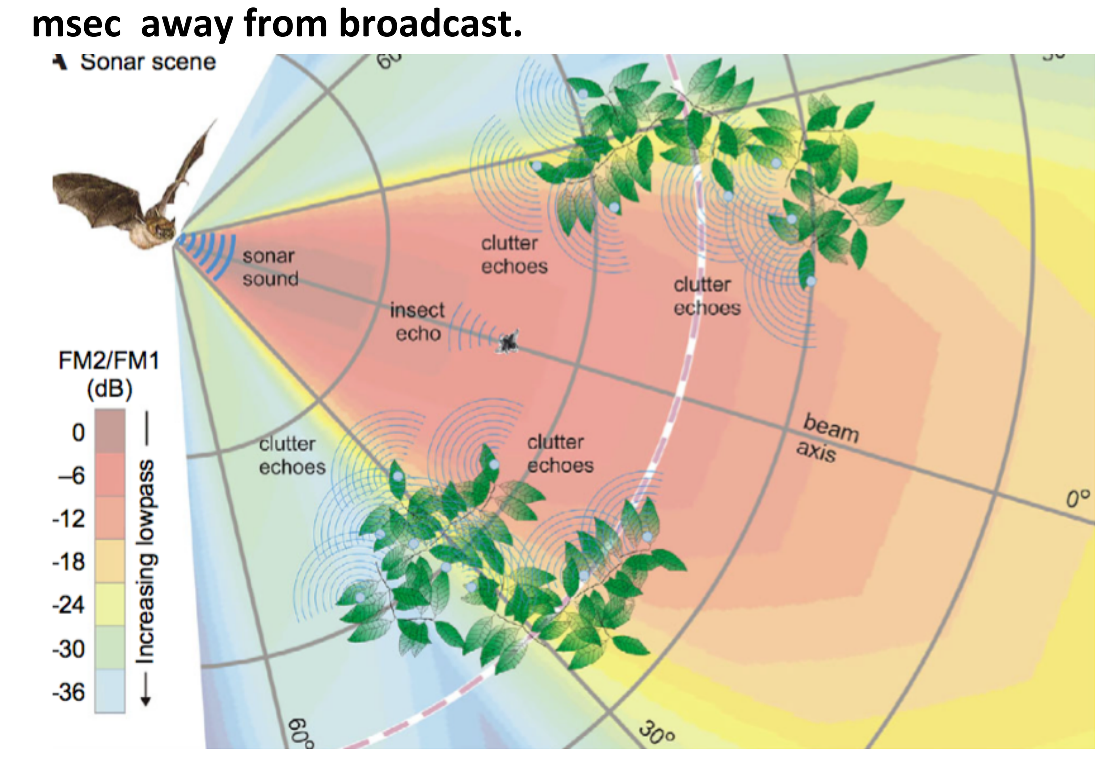


Running delay estimate plotted against elapsed time. Bats have calibrated themselves to understand that sound propagates through air at speed of 340m/s which means the three echoes in signal represent objects at distances approximately 1.4, 2.7, and 4.0 m away.

Cross Correlation of 40dB Broadcast with Echoes Containing 30μs, 45μs, and 60μs Spatial Glint Separations

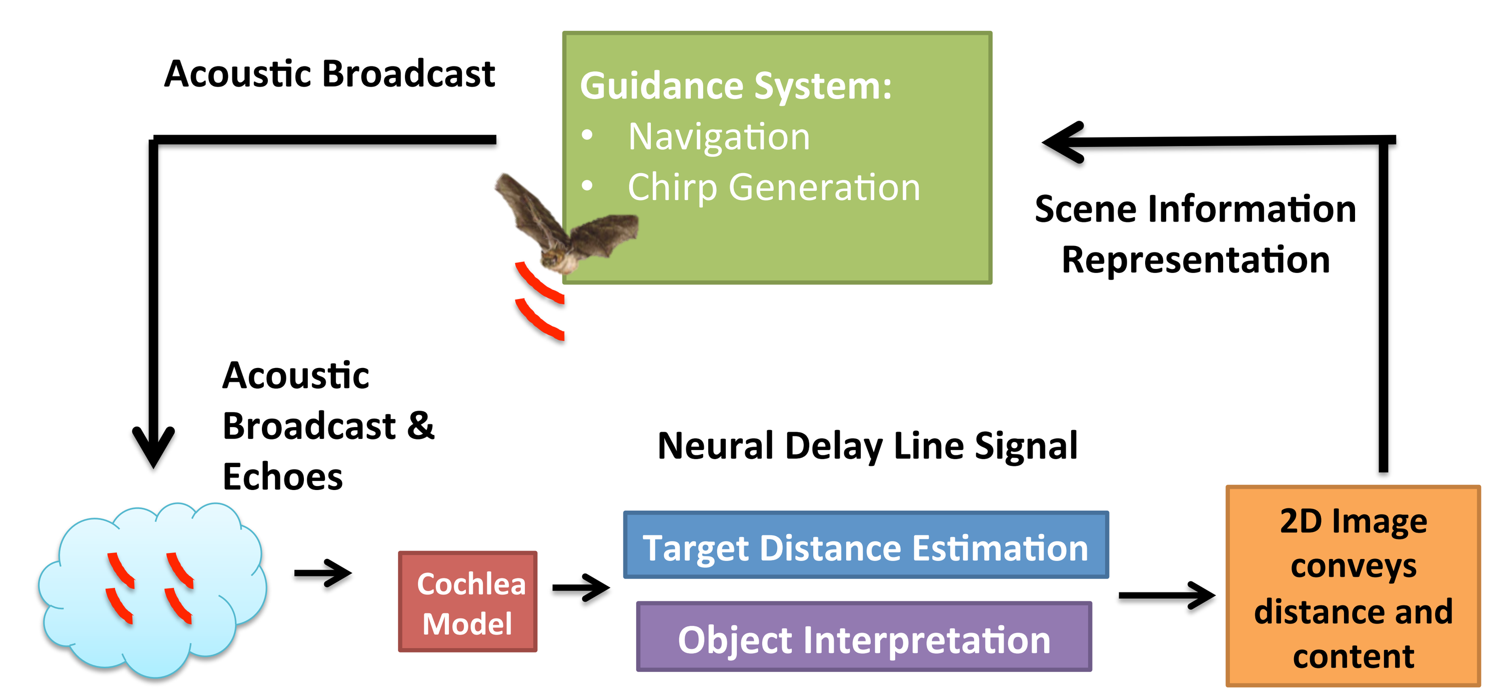


Conventional cross correlation method indicates that echoes are located at a temporal separation of approximately 4, 8, and 12 msec away from broadcast.



Representation of sonar scene generated by Simmons, J. (2014). Future work will be done on implementing object, clutter, and Doppler shift detection. The figure above demonstrates the complicated nature of the scene that is processed in real time by bat.

Guidance System Overview



Works Referenced

1. Simmons, James A., and James E. Gaudette. "Biosonar Echo Processing by Frequency-modulated Bats." IET Radar, Sonar and Navigation (2012), DOI: 10.1049/iet-rsn.2012.0009
2. Sanderson, Mark I., Nicola Neretti, Nathan Intrator, and James A. Simmons. "Evaluation of an Auditory Model for Echo Delay Accuracy in Wideband Biosonar." Acoustical Society of America (2003). DOI: 10.1121/1.1598195
3. Simmons, James A. " Temporal binding of neural responses for focused attention in biosonar", The Journal of Experimental Biology (2014), DOI: 10.1242/jeb.104380