Of Bats and Men

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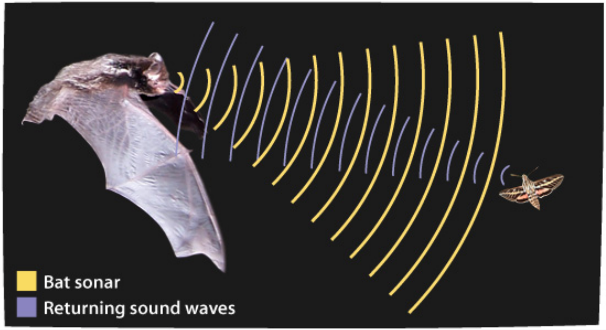
animal “sonar” system

Observation [Spallanzani, 1794]

- navigation *without vision*
- assumption of an active system: *echolocation*



@askabiologist.asu.edu/echolocation

animal “sonar” system

Confirmation [Griffin & Pierce, 1938]

- *acoustic* navigation
- *ultrasonic* waves, of short duration (a few milliseconds) and large bandwidth (from 40 to 100kHz)

example of a pursuit recorded in the field (slowed down 32x)

Hearing evidence

- *"Chirping"* transients
- *Limitation* of Fourier analysis

Beyond Fourier

- Time *evolution* of spectral features
- *Wedding* physical intuition and mathematics
- Development of *time-frequency* techniques

exploratory data analysis

Hearing evidence

- *"Chirping"* transients
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Beyond Fourier

- Time *evolution* of spectral features
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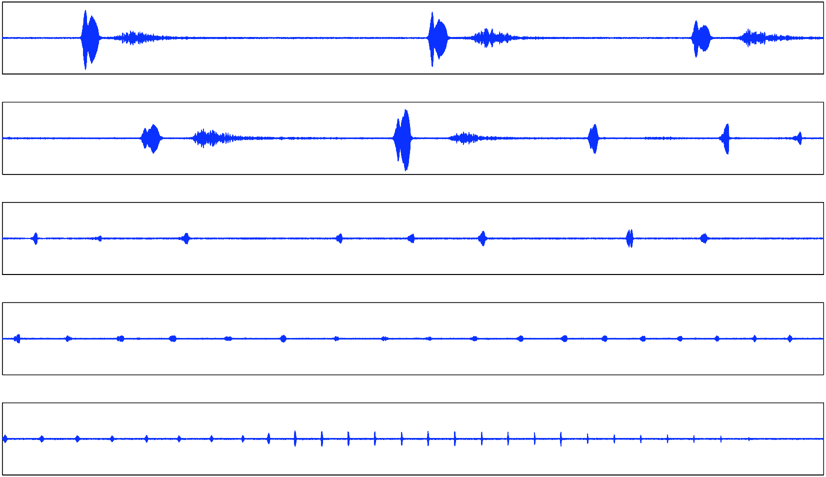
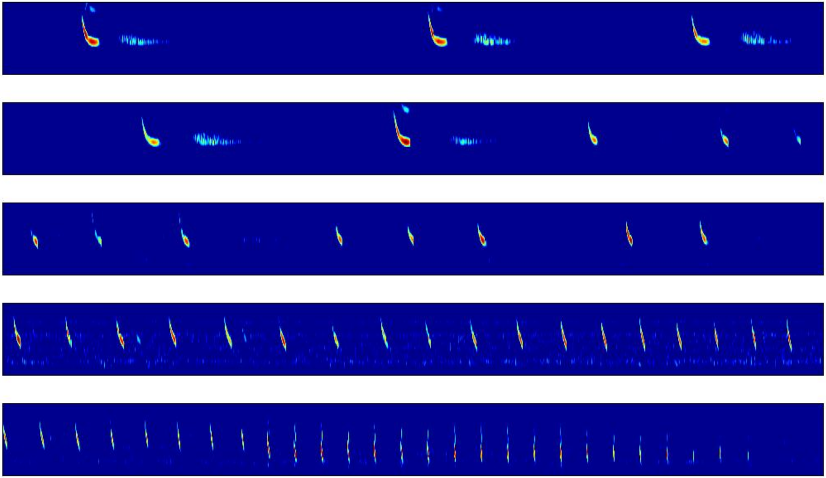
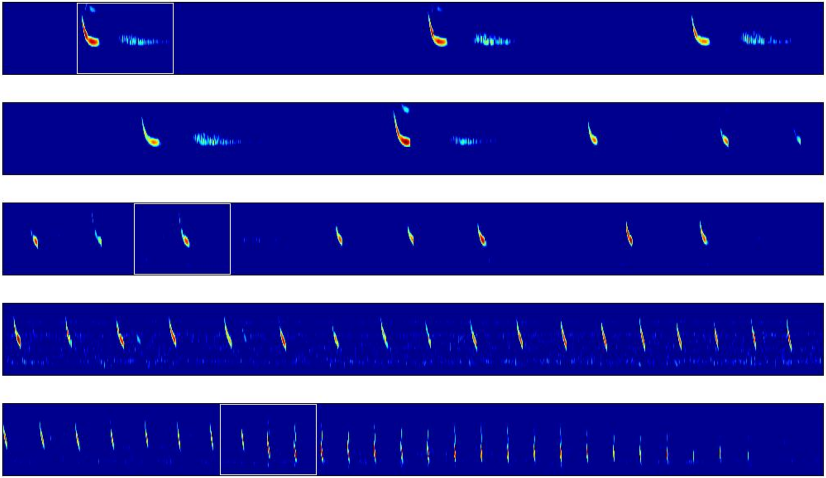
a typical sequence (*Myotis mystacinus*). . .



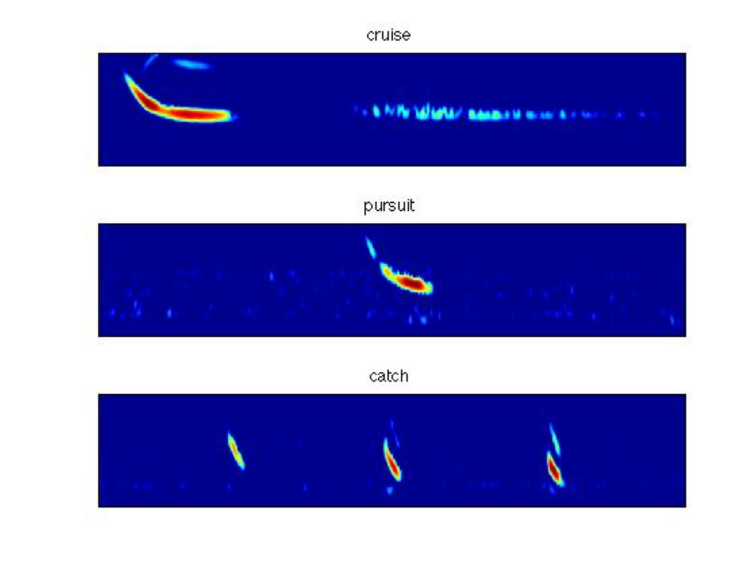
. . . and its time-frequency reading



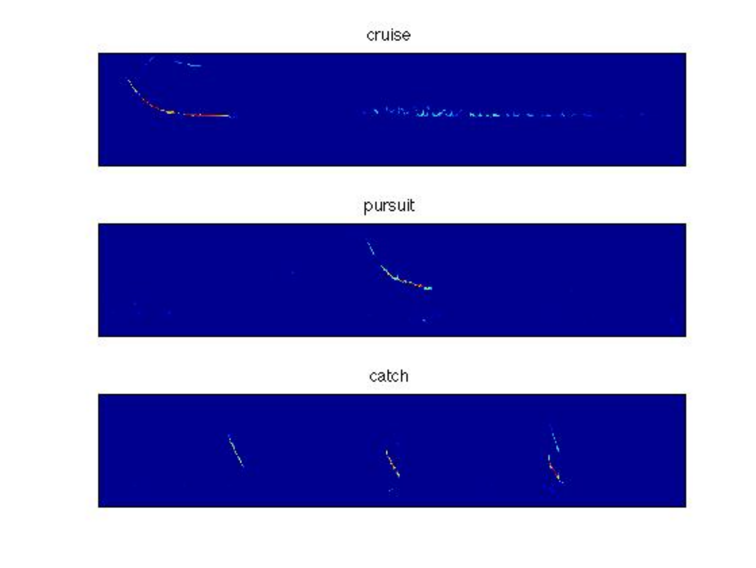
cruise, pursuit, catch



details



refined time-frequency analysis (reassignment)



optimality of a natural system?

Necessity of adapting to multiple tasks

- *detection* (obstacles, preys,. . .)
- *estimation* (range, velocity, bearing,. . .)
- *recognition* (scenes, targets,. . .)
- *interference rejection* (reverberation, other bats,. . .)
- . . .

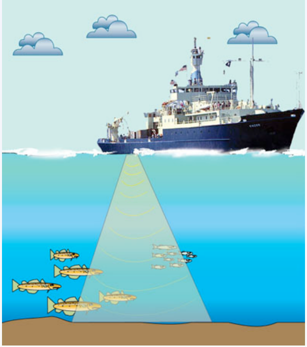
Why the observed signals?

- *waveforms*?
- *evolution* within a sequence?
- physiological *constraints*?
- . . .

the perspective of man-made systems

Two “historic” families of active systems

1. *sonar* (acoustic waves) : Navy, fisheries,. . .
2. *radar* (electromagnetic waves) : air controle, road traffic, wheather forecast,. . .)



from natural to man-made systems, and back

A two-way approach

1. Learn *from Nature*, towards artificial systems *mimicking* natural solutions
2. Apply *to Nature* concepts, models and evaluation criteria used in *technological* systems

Pros and cons

- A *“natural”* perspective on optimality
- The *“bionic temptation”* (e.g., planes vs. birds!)

sonar/radar as a paradigm

Principle

1. target detection via presence of an *echo*
2. range estimation by *time-of-flight* measurement
3. speed estimation from *Doppler*
4. bearing estimation by *binaural reception*
5. target characterization from *modifications* (attenuation, filtering) of the emitted signal

How?

comparaison by *correlating* signal and echo: *matched filtering*

correlation

correlation

bearing

Doppler effect

signal theory. . .

Signal?

- physical outcome of some “useful” information
- characterized in a 1st approximation by properties in
  - *time* (duration,. . .)
  - *frequency* (bandwidth,. . .)

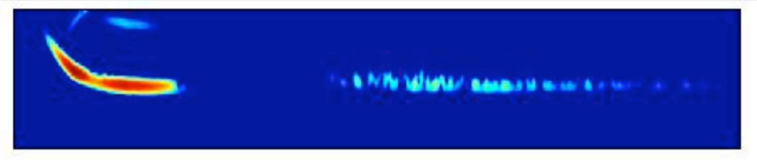
“Optimal” signals?

- mathematical properties of correlation
- accurate estimation of
  - *range* $\longrightarrow$ large bandwidth
  - *speed* $\longrightarrow$ narrow bandwidth
- possible trade-off with *frequency modulated* signals (“chirps”)

. . . and biosonar (bat)

Observation and interpretation

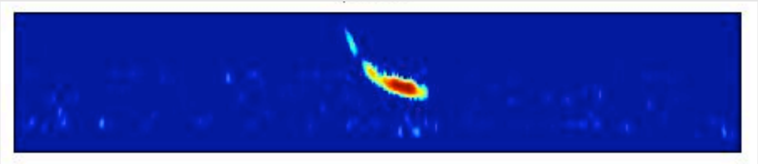
- **Cruise** — Importance of estimating both *range* (delay) and *speed* (Doppler)
  $\Rightarrow$ *large bandwidth* whistle + part with an *almost constant frequency*



. . . and biosonar (bat)

Observation and interpretation

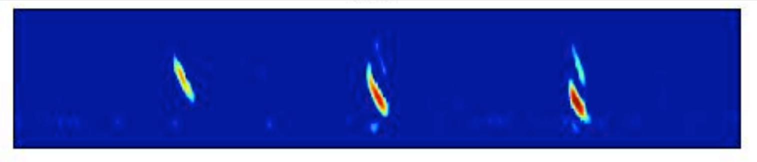
- **Pursuit** — Importance of estimating *range* whatever the Doppler rate
  $\Rightarrow$ matched whistle + *progressive suppression* of the part with an almost constant frequency



. . . and biosonar (bat)

Observation and interpretation

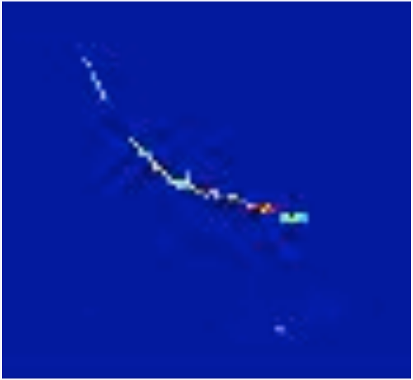
- **Catch** — Importance of maximizing the *emission rate* thanks to short duration signals
  $\Rightarrow$ increase of the effective bandwidth by *lowering the pitch* and increasing distortion (*harmonics*)



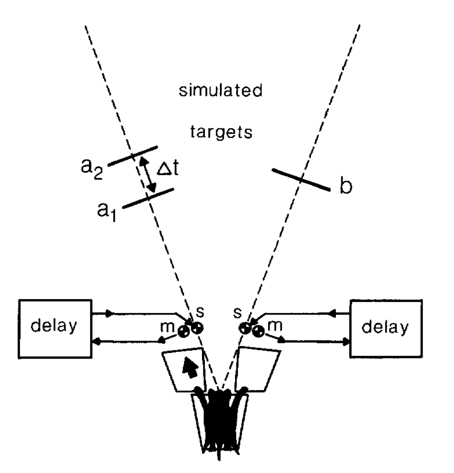
a time-frequency view of detection

Doppler tolerance

Doppler tolerance

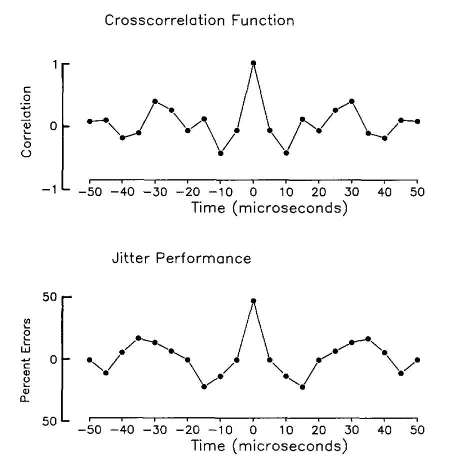


a “built-in” matched filter?



J.A. Simmons *et al.*, *J. Comp. Phys. A* (1990)

a “built-in” matched filter!



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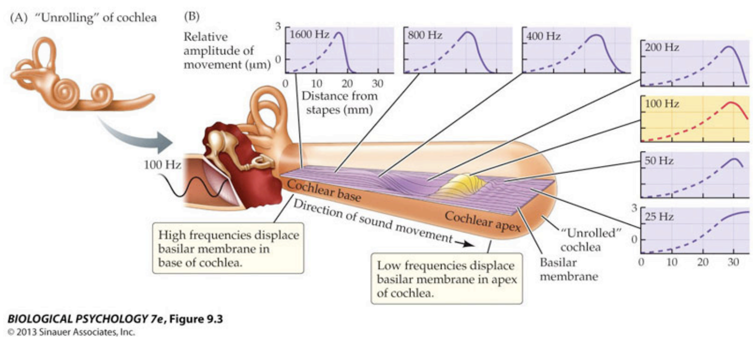
a “built-in” time-frequency matched filter?

Mammals cochlea as a filter bank



- **Dispersive** delay line
- **“Tonotopic”** organization
- **Time-frequency** information

to conclude

A general principle

1. a signal *questions* a system (natural or man-made)
2. the system *answers* with an echo
3. the useful information is derived from a *comparison* between signal and echo

Multiple variations

- the example of *Nature*
- the *bionic* approach (and its limits. . .)

One quote [J. Fourier, 1811]

"L'étude approfondie de la nature est la source la plus féconde des découvertes mathématiques."

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