COM3502/4502/6502

SPEECH PROCESSING

Lecture 11

Signals

1

What is a Signal?

- A signal is a physical quantity that can carry ‘information’
- Discrete signals are selected from a finite alphabet or ‘code book’
- Continuous signals derive from …
  - a *single*-dimensional ‘scalar’ measurement
  - a *multi*-dimensional ‘vector’ of measurements

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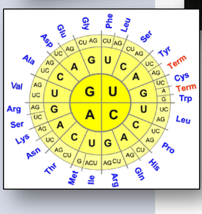
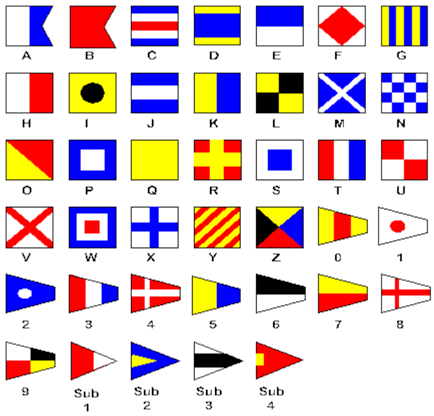
Discrete Signals (*Codes*)





hello

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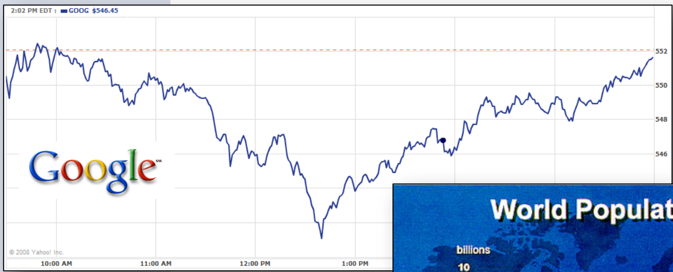
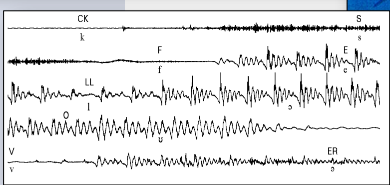
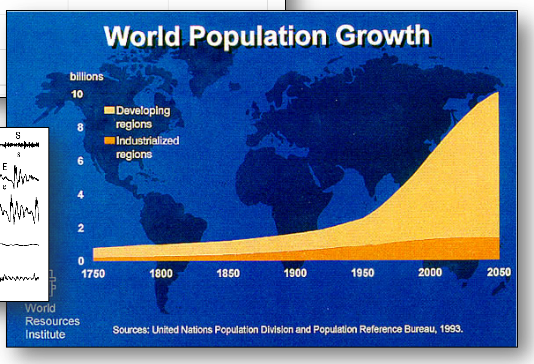
Continuous Scalar Signals







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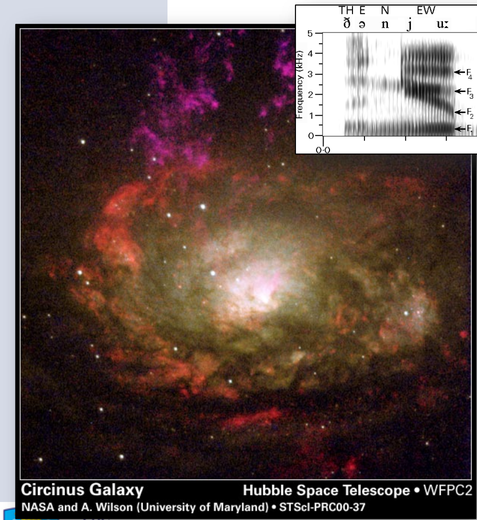
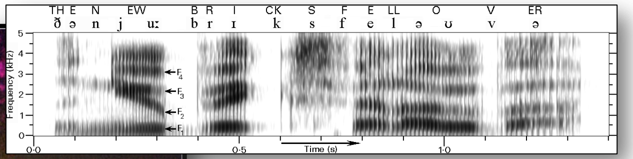
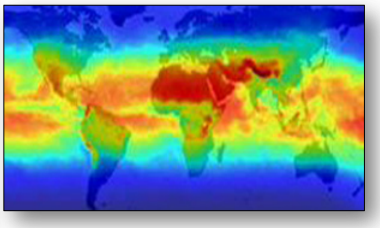
Multidimensional Vector Signals







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Signal Processing

- ‘Signal processing’ is the analysis, interpretation and manipulation of *sensor data*
- E.g., signal processing can be used to …
  - compute global ‘statistics’
    (*means, modes, minima, maxima, etc.*)
  - find ‘patterns’ in the data
    (*trends, repeats, etc.*)
  - deduce ‘causes’ of the data
    (*e.g. conditioning variables*)
  - predict ‘outcomes’ from the data
    (*e.g. the weather forecast*)
  - ‘transform’ the data
    (*scaling, rotation, mapping, etc.*)

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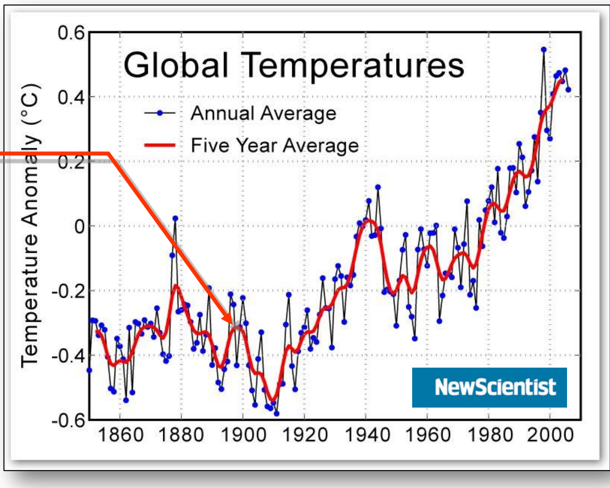
Signal Processing

Trend line (*windowed average*)



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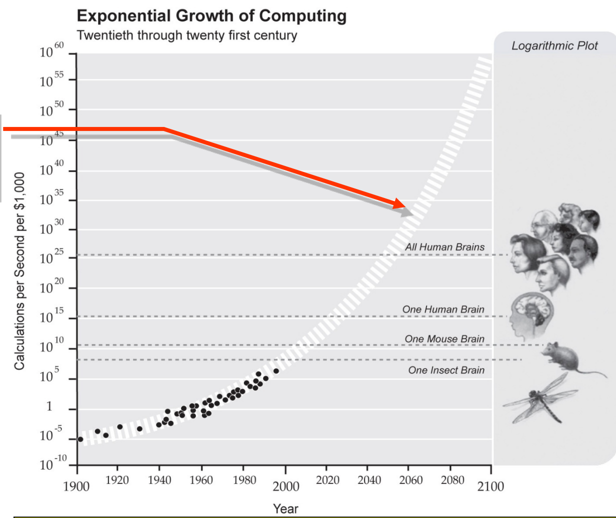
Signal Processing

Prediction (*extrapolation*)



http://nyinquirer.typepad.com/nyinquirer/2006/08/human_20_kurzwe.html

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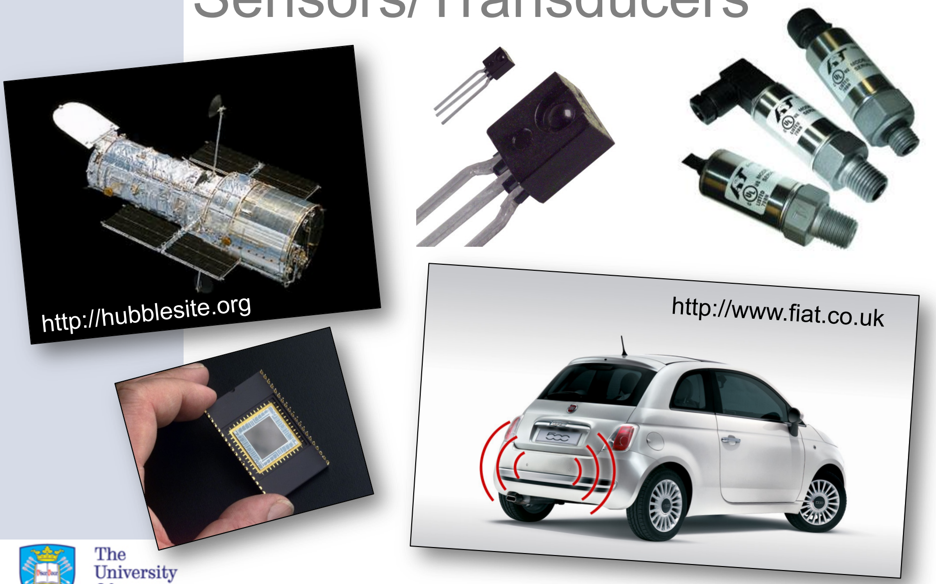
Sensors/Transducers



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Sensors for Speech Signals

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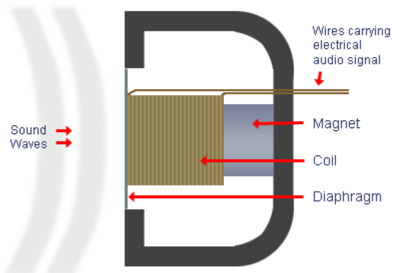
Microphones

- Convert ('*transduce*') acoustic energy into electrical energy
- Dynamic (*moving coil*) microphones
  - based on electromagnetic induction
  - rugged
  - can handle high sound levels
  - limited frequency response
  - cheap

Cross-Section of Dynamic Microphone



http://www.mediacollege.com/audio/microphones/how-microphones-work.html

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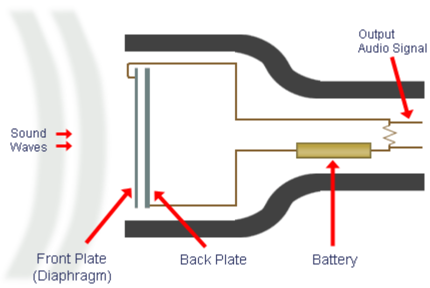
Microphones

- Convert ('*transduce*') acoustic energy into electrical energy
- Condenser (*electrostatic*) microphones
  - based on variable capacitance
  - flat frequency response
  - sensitive (*but can distort with loud sounds*)
  - requires own power
  - expensive

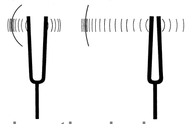
Cross-Section of a **Condenser** Microphone



http://www.mediacollege.com/audio/microphones/how-microphones-work.html

Acoustic Signals

- Physical systems can …
  - respond to changes in air pressure (*e.g. a microphone*)
  - generate changes in air pressure (*e.g. a loudspeaker*)
- The mechanical properties of physical systems can cause them to …
  - 'oscillate' (*e.g. a tuning fork*)
  - 'resonate' (*e.g. an organ pipe*)



- The physical dimensions determine the behaviour:
  - a long string vibrates at a lower frequency than a short string (*e.g. on a stringed musical instrument*)
  - a large cavity resonates at a lower frequency than a small cavity (*e.g. in a wind musical instrument*)

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Acoustic Signals

- When *energy* is supplied continuously, then a resonant oscillation can be sustained, e.g. …
  - blowing into a wind instrument
  - bowing a stringed instrument
  - whistling
  - voicing into a vocal tract

- When *energy* is supplied for a limited time period, then a resonant oscillation will be initiated and then decay over time, e.g. …
  - plucking a stringed instrument
  - hitting a percussion instrument
  - a pulse from the vocal cords

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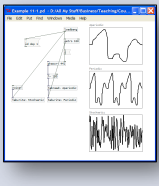
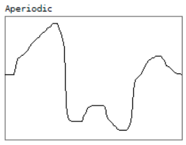
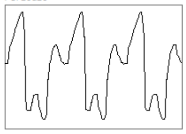
Types of Signal

Example 11-1

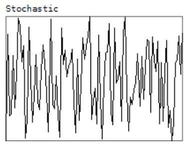


- Deterministic signals
  (*fully predictable, given the generator*)
  - ‘aperiodic’ signals
  - ‘periodic’ signals





- Non-deterministic signals
  (*a function of a random variable, so not fully predictable*)



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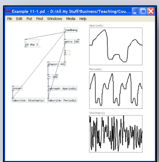
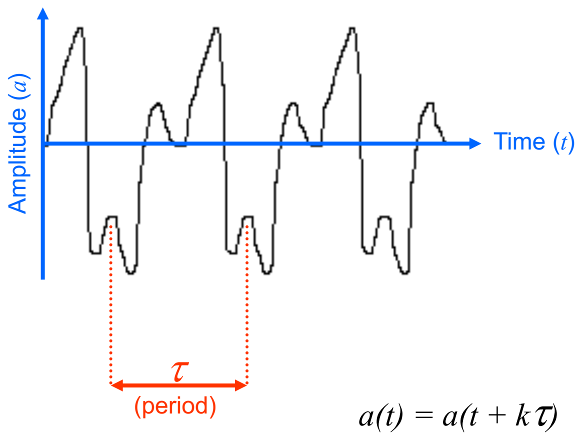
Periodic Signals

Example 11-1





$a(t) = a(t + k\tau)$
for all t and integer k

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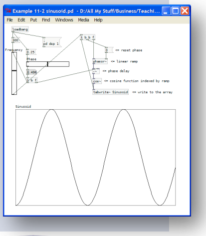
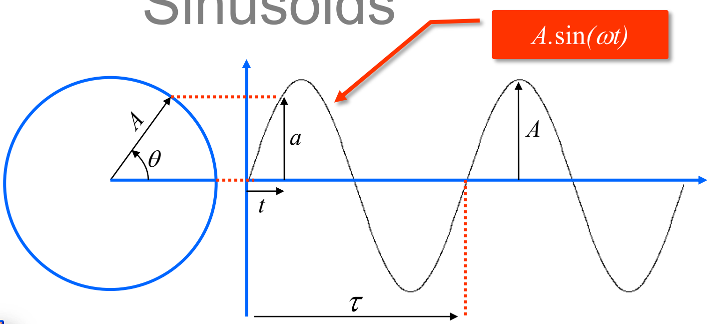
Sinusoids

Projection of a fixed length vector rotating at a constant velocity

Example 11-2





A	radius = length of rotating vector = peak amplitude
θ	angle (*radians*)
$f = 1/\tau$	frequency (*cycles per second*, *Hertz*)
$\omega = 2\pi f$	angular frequency (*radians/second*)

$\theta = \omega t$

$a = A.\sin(\theta) = A.\sin(\omega t)$

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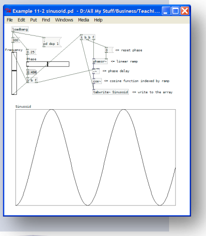
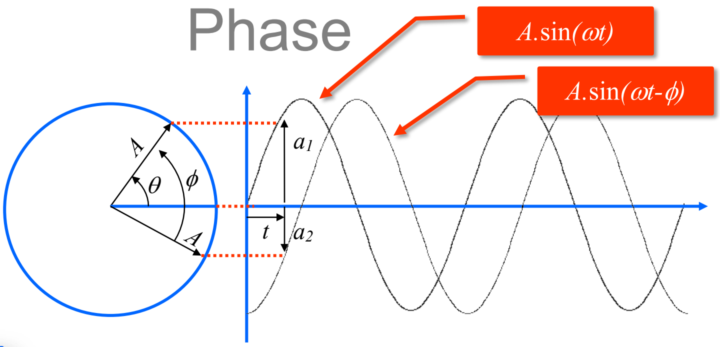
Phase

Two sinusoids with equal frequency and amplitude may still be different in their 'phase'

Example 11-2





A	radius = length of rotating vectors = peak amplitudes
θ	phase angle of 1st vector (*radians*)
ϕ	phase lag/delay of 2nd vector wrt 1st (*radians*)

$a_1 = A.\sin(\theta) = A.\sin(\omega t)$

$a_2 = A.\sin(\theta - \phi) = A.\sin(\omega t - \phi)$

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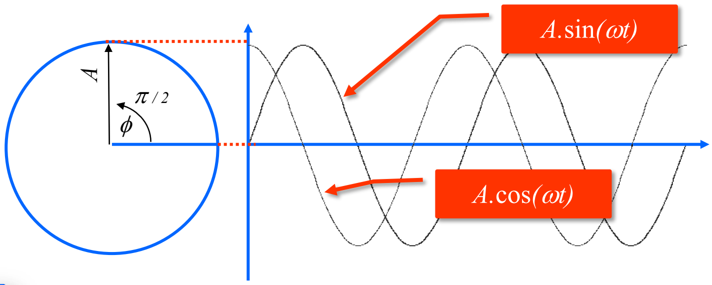
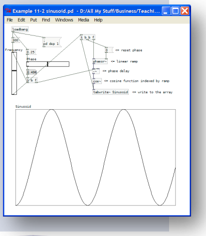
Sine and Cosine Waves

The special case of a 90° (*orthogonal*) phase angle



Example 11-2



A radius = length of rotating vector = peak amplitude

$\theta = 0$ phase angle of 1st vector (*radians*)

$\phi = \pi / 2$ phase angle (*radians*)

$A.\sin(\theta) = 0$

$A.\sin(\theta + \phi) = 1$

$A.\sin(\omega t + \pi/2) = A.\cos(\omega t)$

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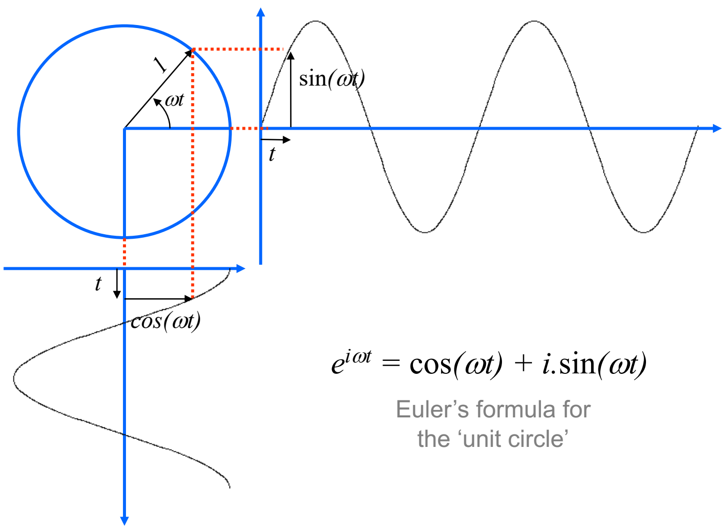
Sine and Cosine Waves

Orthogonal projections of a rotating unit vector



$$e^{i\omega t} = \cos(\omega t) + i.\sin(\omega t)$$

Euler's formula for the 'unit circle'

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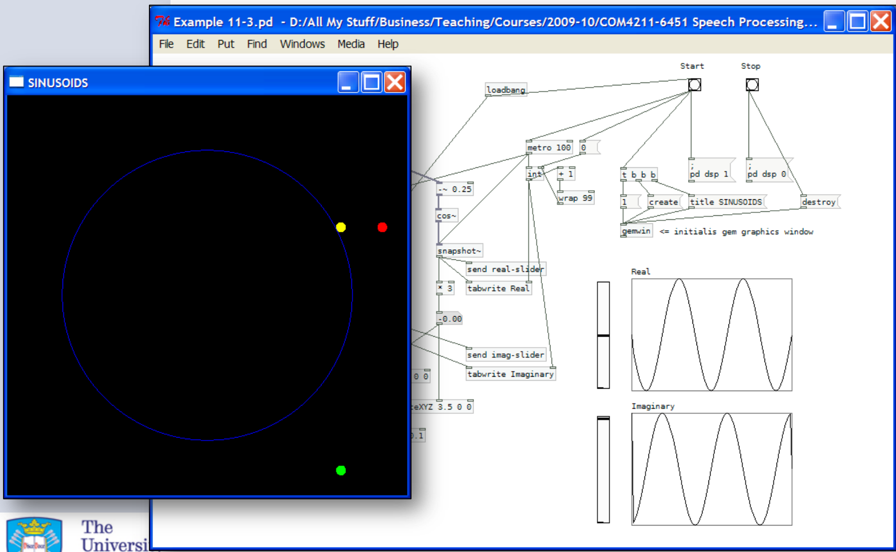
Sine and Cosine Waves



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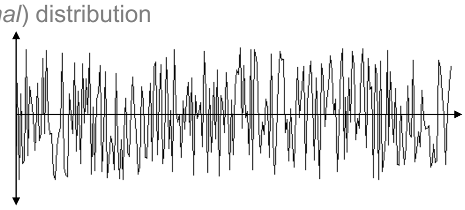
White Noise

- Completely random 'stochastic' signal
- The value of the signal at time t gives no information about the value of the signal at time $t + \delta t$ (*i.e. they are completely 'uncorrelated'*)
- White noise is characterised by …
  - mean value μ
  - standard deviation σ (*or variance* σ^2)
- White noise can follow an arbitrary 'noise distribution' …
  - uniform distribution
  - Gaussian (*normal*) distribution



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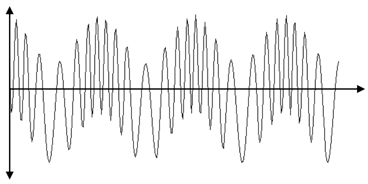
Stationary Signals

- A '**stationary signal**' is one whose properties *do not* vary with time …
  - a sine wave of constant amplitude and frequency
  - noise of constant mean and variance
- '**Non-stationary signals**' change with time …
  - amplitude modulation
  - frequency modulation
  - modulated mean (*and variance*)



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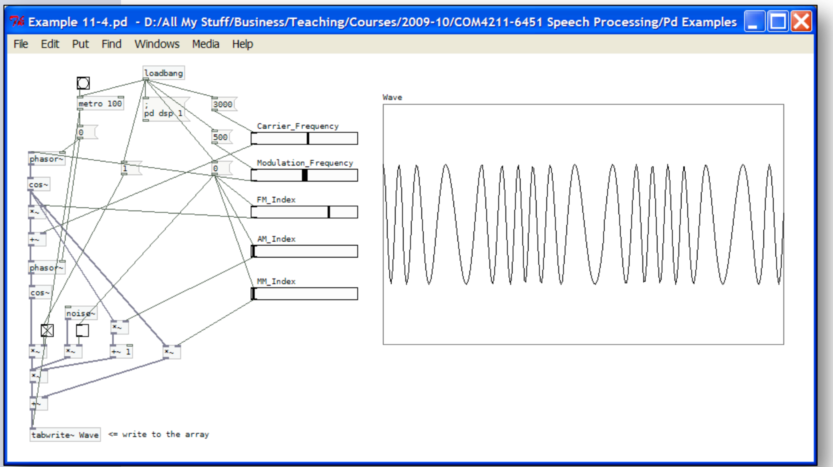
Non-Stationary Signals



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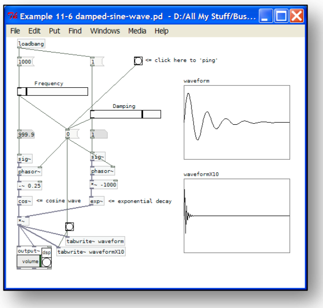
Non-Stationary Signals

- *Stationary* signals imply that there is a constant source of energy into the system
- Signals will be *non-stationary* if the energy in a system decays
- For example, a 'damped' sine wave …

$$a = e^{-At}.\sin(\omega t)$$



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Quasi-Stationary Signals

- Speech is a mixture of periodic, aperiodic and stochastic signals, hence it is *non-stationary* by nature
- In practice, it is normally assumed that speech is stationary over a short time interval *(10-30 msecs)*
  - if the interval is too short, there is insufficient time to determine the signal properties accurately
  - if the interval is too long, the speech properties vary significantly
- This 'quasi-stationary' assumption is used in nearly all speech signal processing (*despite being a gross approximation*)

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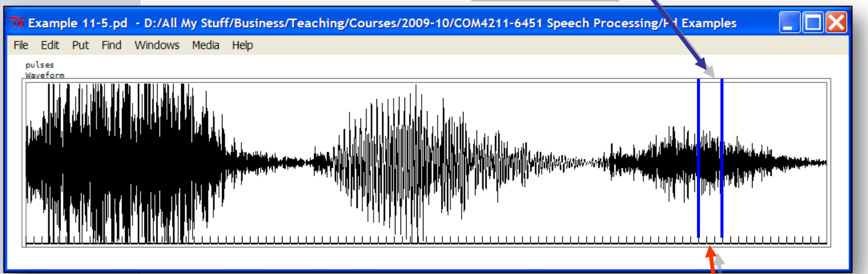
The Quasi-Stationarity of "*Speech*"

30 msec 'window'



[s] [p] [i:] [tʃ]

10 msec ticks

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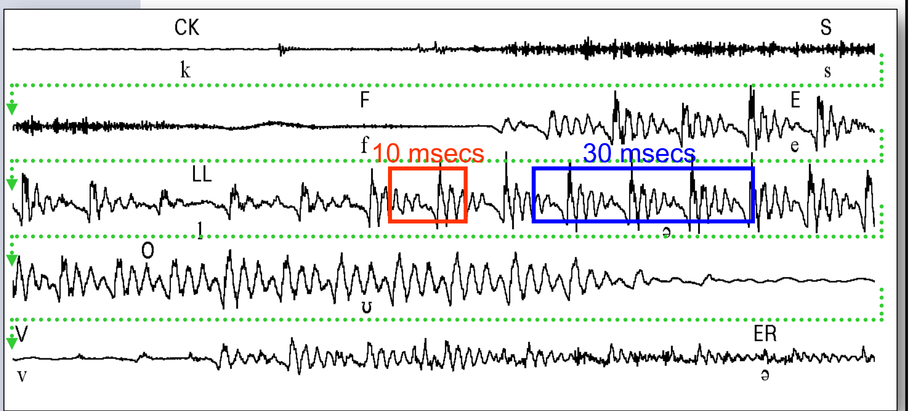
The Quasi-Stationarity of Speech



"briCKS FELL OVER"

Taken from 'Speech Synthesis and Recognition', J. Holmes & W. Holmes, Taylor & Francis, London and New York, 2001.

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This lecture has covered …

- Discrete/continuous signal
- Signal Processing
- Sensors/transducers
- Microphones
- Periodic signals (*sines & cosines*)
- White noise
- Stationarity

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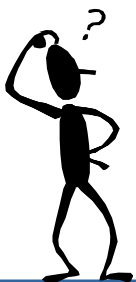
Any Questions ?



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Next time …

Frequency Analysis