

**DSP for Digital Artists**  
a 3-Day Short Course, by Perry R. Cook, PhD  
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**Day 2: More Filters, Feedback Filters, More Sine Waves, Spectrum Analysis, Modal Synthesis**

**Some More Time-Domain “Pitch” Detection:**

**AMDF:** pick m that minimizes:  $y(n) = \sum_n |x(n) - x(n-m)|$   
**Autocorrelation:** pick m that maximizes:  $y(n) = \sum_n x(n) * x(n-m)$

**Impulse Response:**

$h(n) = y(n)$ , in response to input  $x(n) = \delta(n)$   
 $\delta(n) = 1$  if  $n=0$ , 0 otherwise

**Transfer Function:**

$H(f) = Y(f)$ , for every  $x(t) = \sin(2\pi ft)$   
Digital:  $H(n) = Y(n)$ , for  $x(n) = \sin(2\pi fn/SR)$

**Linear, Time Invariant (LTI) Systems**

Linearity: Homogeneity ( $\alpha x \rightarrow \alpha y$ ) and Superposition ( $x_1 + x_2 \rightarrow y_1 + y_2$ )  
Time Invariance:  $x(\tau + t) \rightarrow y(\tau + t)$  for all  $\tau$   
OnePole: (1<sup>st</sup> Order feedback)  $y(n) = gx(n) + ry(n-1)$  NOTE:  $r \leq 1.0$  !!!  
Set r and g exactly 1.0 yields “Digital Integrator”  
Set  $0.0 < r < 1.0$  and  $g = (1.0 - r)$  Low-pass filter  
High-pass Cousin: set  $-1.0 < r < 0.0$  High-pass filter

**Convolution**  $y(n) = \sum_m x(n-m) h(m)$  implement Impulse Response as FIR filter

**Filters:**  $y(n) = F(x(n))$  Operations on Digital Signals

Popular Simple Filters: **Linear Gain:**  $y(n) = g x(n)$  where  $g$  = some constant  
**Moving Average:**  $y(n) = 0.5x(n) + 0.5x(n-1)$  (low-pass)  
High-Pass Cousin:  $y(n) = x(n) - x(n-1)$  (digital differentiator)  
Also called **OneZero Filter**, Averaging more samples: More Zeroes!!  
Also type of **Finite Impulse Response (FIR) Filter**

**Recursive Filters:** **Feedback, Auto Regressive, IIR, Pole(s)**

OnePole Filter:  $y(n) = g x(n) + r y(n-1)$  NOTE:  $|r| < 1.0$   
NPole Filter:  $y(n) = g x(n) + \sum_{m=1toN} -b_m y(n-1)$

**Super Special Filter, 2-Pole “Resonator”**  $y(n) = g x(n) + 2r \cos(2\pi f/SR) y(n-1) - r^2 y(n-2)$

**Modal Synthesis:** Modes = natural resonances of system. Excite those and let them ring!

**Code and Demos:** See Day2.zip

**Assignment:** Impulse Responses & Modes: Look around, listen, find some systems. Find/Record Modal sound. Use FFTFindModes to analyze it. If you’re brave, use FFTResynth (Noise and/or Residue) to recreate it.