Digital Signal Processing for Music

Part 21: Dynamics Processing

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alexander lerch

Georgia Center for Music Tech Technology

Part 21: Dynamics Processing

intro level detection response curve smoothing overall system variants params & usage summar

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dynamics processing introduction



basic principle

- apply time-variant audio gain
- gain depends on signal properties or external factors

applications

- avoid clipping (unknown input level)
- suppress noise
- adjust playback level (playlist)
- decrease dynamic range (environmental noise)
- increase loudness/energy (commercials)
- adjust (recording) level

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dynamics processing introduction: effects



- (noise) gate
 - suppression of low levels in pauses
- compresso
 - reduction of the dynamic range
- expander
 - expansion of the dynamic range
- limiter
 - limitation of maximum gain
- AGC (automatic gain control)
 - slow adaptation of recording/payback gain

intro level detection response curve smoothing overall system variants params & usage summar ○●○ ○○○○○ ○○○○ ○○ ○○ ○○ ○○

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intro level detection response curve smoothing overall system variants params & usage summar ○●○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○

dynamics processing introduction: effects

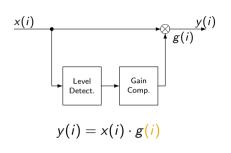


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intro level detection response curve smoothing overall system variants params & usage summar oo oo oo oo oo oo

dynamics processing



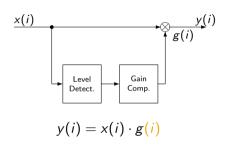


computation of g(i) usually depends on

- 1 input signal level
- 2 properties & characteristics of the dynamics processor
- 3 time-based control mechanism

dynamics processing overview





computation of g(i) usually depends on

- 1 input signal level
- properties & characteristics of the dynamics processor
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dynamics processing level detection



- typical measures
 - peak: physical measure of maximum amplitude
 - rms: physical measure of power level
 - loudness model: models of loudness perception (dBA, Zwicker, BS.1770)
- level computation

$$v_{\rm dB}(i) = 20 \cdot \log_{10} \left(\frac{v(i)}{v_0} \right)$$

- v_0 : reference constant (0 dB point) digital: $v_0 = 1 \Rightarrow dBFS$
- scaling factor: $1 dB \approx JNDL$

dynamics processing level detection



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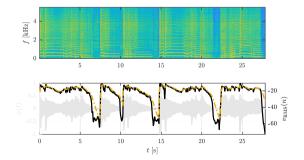
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$$v_{\text{RMS}}(n) = \sqrt{\frac{1}{\mathcal{K}} \sum_{i=i_{\text{s}}(n)}^{i_{\text{e}}(n)} x(i)^2}$$



level detection: root mean square 2/2



sample-by-sample processing:

■ reduce computational complexity

$$egin{array}{lcl} v_{
m RMS}^2(n) & = & rac{x(i_{
m e}(n))^2 - x(i_{
m s}(n-1))^2}{i_{
m e}(n) - i_{
m s}(n) + 1} + v_{
m RMS}^2(n-1) \ & v_{
m RMS}(n) & = & \sqrt{v_{
m RMS}^2(n)} \end{array}$$

■ single pole approximation

$$egin{array}{lll} v_{
m tmp}(i) &=& lpha \cdot v_{
m tmp}(i-1) + (1-lpha) \cdot x(i)^{lpha} \ v_{
m RMS}^*(i) &=& \sqrt{v_{
m tmp}(i)} \end{array}$$

level detection: root mean square 2/2



sample-by-sample processing:

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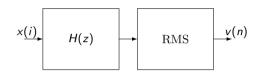
■ single pole approximation

$$v_{\text{tmp}}(i) = \alpha \cdot v_{\text{tmp}}(i-1) + (1-\alpha) \cdot x(i)^{2}$$

 $v_{\text{RMS}}^{*}(i) = \sqrt{v_{\text{tmp}}(i)}$

level detection: weighted root mean square





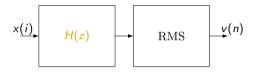
H(z)

A, B, C weighting

■ RLB (BS.1770)

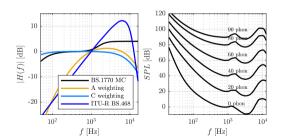
level detection: weighted root mean square

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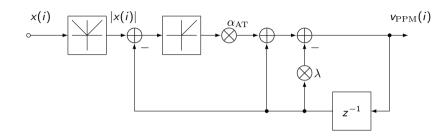
H(z):

- A, B, C weighting
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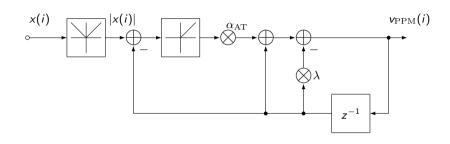
dynamics processing level detection: peak detection (PPM) 1/2

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level detection: peak detection (PPM) 1/2

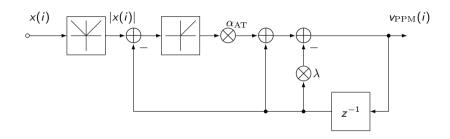




■ release state
$$(|x(i)| \le v_{\text{PPM}}(i-1) \Rightarrow \lambda = \alpha_{\text{RT}})$$

dynamics processing level detection: peak detection (PPM) 1/2



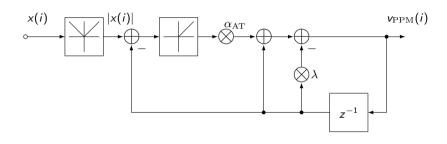


■ release state
$$(|x(i)| \le v_{\text{PPM}}(i-1) \Rightarrow \lambda = \alpha_{\text{RT}})$$

 $v_{\text{PPM}}(i) = v_{\text{PPM}}(i-1) - \alpha_{\text{RT}} \cdot v_{\text{PPM}}(i-1)$
 $= (1 - \alpha_{\text{RT}}) \cdot v_{\text{PPM}}(i-1)$

level detection: peak detection (PPM) 1/2

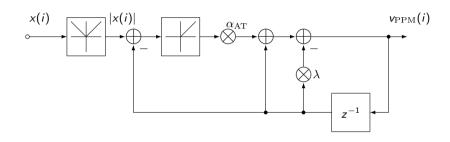




■ attack state
$$(|x(i)| > v_{PPM}(i-1) \Rightarrow \lambda = 0)$$

dynamics processing level detection: peak detection (PPM) 1/2

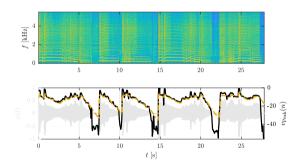
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■ attack state
$$(|x(i)| > v_{\text{PPM}}(i-1) \Rightarrow \lambda = 0)$$

$$v_{\text{PPM}}(i) = \alpha_{\text{AT}} \cdot (|x(i)| - v_{\text{PPM}}(i-1)) + v_{\text{PPM}}(i-1)$$

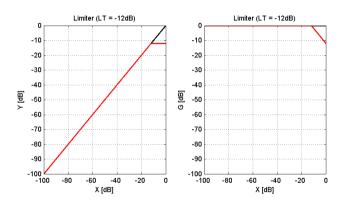
$$= \alpha_{\text{AT}} \cdot |x(i)| + (1 - \alpha_{\text{AT}}) \cdot v_{\text{PPM}}(i-1)$$



intro level detection response curve smoothing overall system variants params & usage summary

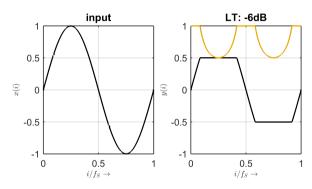
dynamics processing response curve: limiter

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dynamics processing response curve: limiter



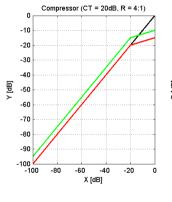


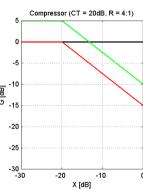
param $LT = -9 \, dB \text{ w/o gain smoothing}$



dynamics processing response curve: compressor

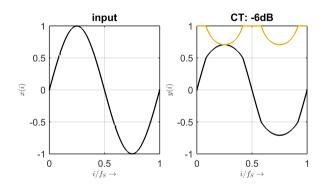
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dynamics processing response curve: compressor

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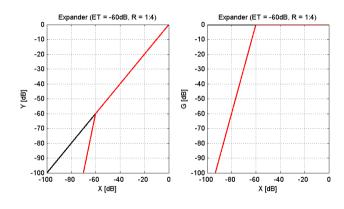


param
$$CT = -9 \, dB \text{ w/o gain smoothing}$$



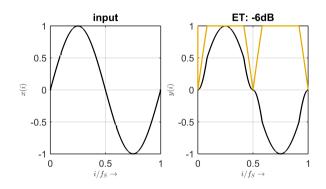
dynamics processing response curve: expander

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dynamics processing response curve: expander

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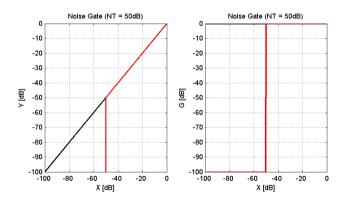


param
$$ET = -6 \, dB \text{ w/o gain smoothing}$$

intro level detection **response curve** smoothing overall system variants params & usage summary 000 000000 000●000 000 000 000 000 0

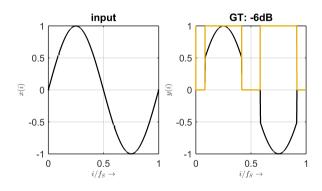
dynamics processing response curve: noise gate

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dynamics processing response curve: noise gate

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param $NT = -12 \, dB$ w/o gain smoothing

response curve: mathematical description (compressor)



• output:
$$Y = g(X) + X$$
 [dB]

ratio:
$$R = \frac{\Delta L_i}{\Delta L_o}$$

■ slope:
$$CS = 1 - \frac{1}{R}$$

■ linear equation (offset CT):
$$Y = \frac{1}{R}(X - CT) + CT$$

gain
$$(g = Y - X)$$
:

$$g = \frac{1}{R}(X - CT) + CT - CT$$
$$= \left(1 - \frac{1}{R}\right) \cdot (CT - X)$$
$$= CS \cdot (CT - X)$$

response curve: mathematical description (compressor)



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logarithmic description, nonlinear part

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$$= CS \cdot (CT - X)$$

response curve: mathematical description (summary 1/2)



logarithmic description, nonlinear part

■ limiter

$$R = \infty$$

$$Y = LT$$

$$g = LT - X$$

compressor

$$R > 1$$

 $Y = \frac{1}{R}(X - CT) + CT$
 $g = \left(1 - \frac{1}{R}\right) \cdot (CT - X)$

response curve: mathematical description (summary 1/2)



logarithmic description, nonlinear part

■ limiter

$$R = \infty$$

$$Y = LT$$

$$g = LT - X$$

compressor

$$R > 1$$

$$Y = \frac{1}{R}(X - CT) + CT$$

$$g = \left(1 - \frac{1}{R}\right) \cdot (CT - X)$$

response curve: mathematical description (summary 2/2)



logarithmic description, nonlinear part

expander

$$R < 1$$

 $Y = \frac{1}{R}(X - ET) + ET$
 $g = \left(1 - \frac{1}{R}\right) \cdot (ET - X)$

gate

$$R = 0$$

$$Y = -\infty$$

response curve: mathematical description (summary 2/2)



logarithmic description, nonlinear part

expander

$$R < 1$$

 $Y = \frac{1}{R}(X - ET) + ET$
 $g = \left(1 - \frac{1}{R}\right) \cdot (ET - X)$

■ gate

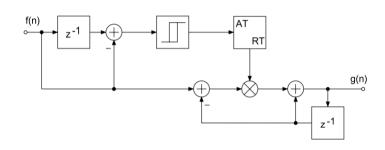
$$R = 0$$

$$Y = -\infty$$

$$\sigma = -\infty$$

dynamics processing smoothing: attack and release 1/2



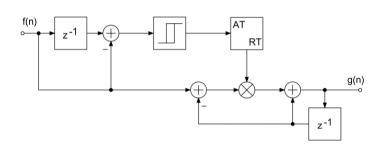


- lacktriangledown α_{AT} : attack constant
- \bullet α_{RT} : release constant

$$g(n) = \alpha \cdot (f(n) - g(n-1)) + g(n-1)$$
$$= \alpha f(n) + (1-\alpha) \cdot g(n-1)$$

dynamics processing smoothing: attack and release 1/2



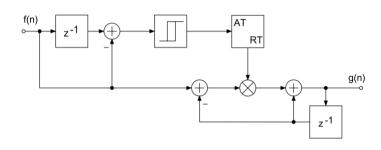


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dynamics processing smoothing: attack and release 1/2





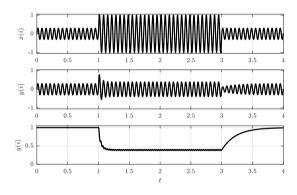
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$$g(n) = \alpha \cdot (f(n) - g(n-1)) + g(n-1)$$

= $\alpha f(n) + (1-\alpha) \cdot g(n-1)$

dynamics processing smoothing: attack and release 2/2

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smoothing: attack and release coefficients



- single pole step response $\rightarrow g(t) = 1 e^{\frac{-t}{\tau}}$
- define single pole integration time between 10% and 90%

$$t_{
m I} = t_{90} - t_{10} \ 0.1 = 1 - e^{rac{-t_{10}}{ au}} \ 0.9 = 1 - e^{rac{-t_{90}}{ au}} \ 0.9 = e^{rac{t_{90} - t_{10}}{ au}} \ 0.9 = t_{90} - t_{10} \ 0.9 = t_{10} - t_{10} - t_{10} \ 0.9 = t_{10} - t_{10} = t_{10} - t_{10} - t_{10} = t_{10} = t_{10} - t_{10} = t_{10}$$



- single pole step response $\rightarrow g(t) = 1 e^{\frac{-t}{\tau}}$
- define single pole integration time between 10% and 90%

$$t_{
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m 90} - t_{
m 10} = 2.197 au \
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m 10}/2.2$$



- single pole step response $\rightarrow g(t) = 1 e^{\frac{-t}{\tau}}$
- define single pole integration time between 10% and 90%

$$egin{array}{lll} t_{
m I} &=& t_{90} - t_{10} \ 0.1 &=& 1 - e^{rac{-t_{10}}{ au}} \ 0.9 &=& 1 - e^{rac{-t_{90}}{ au}} \ &\Rightarrow 0.9/0.1 &=& e^{rac{t_{90} - t_{10}}{ au}} \ &\Rightarrow (0.9/0.1) &=& t_{90} - t_{10}/ au \ &t_{90} - t_{10} &=& 2.197 au \ & au &pprox &t_{1/2.2} \ \end{array}$$

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- single pole step response $\rightarrow g(t) = 1 e^{\frac{-t}{\tau}}$
- define single pole integration time between 10% and 90%

$$t_{
m I} = t_{
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 $0.1 = 1 - e^{rac{-t_{
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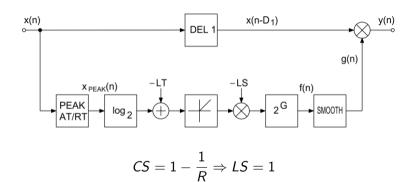
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- single pole step response $\rightarrow g(t) = 1 e^{\frac{-t}{\tau}}$
- define single pole integration time between 10% and 90%

$$egin{array}{lll} t_{
m I} &=& t_{
m 90} - t_{
m 10} \ 0.1 &=& 1 - e^{rac{-t_{
m 10}}{ au}} \ 0.9 &=& 1 - e^{rac{-t_{
m 90}}{ au}} \ &\Rightarrow 0.9/0.1 &=& e^{rac{t_{
m 90} - t_{
m 10}}{ au}} \ \log \left(0.9/0.1
ight) &=& t_{
m 90} - t_{
m 10}/ au} \ t_{
m 90} - t_{
m 10} &=& 2.197 au \ au &pprox & t_{
m I}/2.2 \ \end{array}$$

dynamics processing overall system: limiter

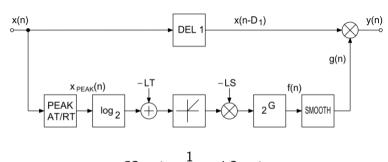
Georgia Center for Music Tech Technology



$$X < LT \rightarrow g = 1$$

$$\blacksquare X > LT \rightarrow g = (LT - X)$$

dynamics processing overall system: limiter

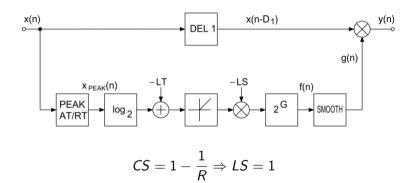


$$CS = 1 - \frac{1}{R} \Rightarrow LS = 1$$

$$\blacksquare X < LT \rightarrow g = 1$$

$$\blacksquare X > LT \rightarrow g = (LT - X)$$

dynamics processing overall system: limiter

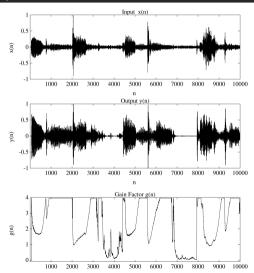


$$\blacksquare X < LT \rightarrow g = 1$$

$$\blacksquare X > LT \rightarrow g = (LT - X)$$

dynamics processing gain visualization: combined system





overall system

dynamics processing audio examples





- Gate ◀》 Expander ◀》
- Compressor ◄»
- Limiter **◄**》

ro level detection response curve smoothing overall system **variants** params & usage summai oo ooooo oo oo oo oo

dynamics processing variants 1/3

■ attack & release constant selection

- depending on "abruptness" of change
- hold time
 - before release, hold gain constant (avoid pumping with low frequency signals)
- oversampling
 - high time resolution for peak detection

level detection response curve smoothing overall system variants params & usage summar oooooo oo oo oo oo oo

dynamics processing variants 1/3

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dynamics processing variants 1/3

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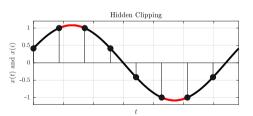
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tro level detection response curve smoothing overall system **variants** params & usage summary ○○ ○○○○○ ○○○ ○○ ○○

dynamics processing variants 2/3



■ stereo link

- consider both channels (avoid level-dependent changes of stereo image)
 - one master channel (left or right)
 - mean of both channels
 - channel with higher level (max)

soft knee

smooth crossover from linear area to compressed area

- very short attack times
- high compression ratios

tro level detection response curve smoothing overall system **variants** params & usage summary ○○ ○○○○○ ○○○ ○○ ○○

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 level detection
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 smoothing
 overall system
 variants
 params & usage
 summary

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dynamics processing variants 2/3



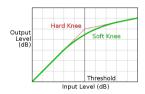
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tro level detection response curve smoothing overall system variants params & usage summar ○○ ○○○○○ ○○○ ○○ ○○ ○○ ○○

dynamics processing variants 3/3



■ side chain

• choose different input signal for level control ("ducking")

■ look-ahead

- introduce higher delay in signal path
 - ▶ shift gain modification in time
 - combine "future" measurement with current

multi-band compression

- apply one compressor to each frequency band
- advantages:
 - avoid pumping: varying level in one band (e.g. bass drum) does not influence gain of other bands
 - maximize power, overall loudness

o level detection response curve smoothing overall system variants params & usage summar ○ ○○○○○○ ○○○ ○○○ ○○ ○○ ○○

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level detection response curve smoothing overall system variants params & usage summary ooooo oo oo oo oo

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level detection response curve smoothing overall system variants params & usage summary ooooo oo oo oo oo

dynamics processing parameter ranges



threshold

−120...0 dE

ratio

0.05...20 (Limiter: ∞

■ attack

0...10 ms

■ release

20...300 ms

■ hold

0...10 ms

■ stereo-link

On/Off

oversampling

1 . . . 8

■ look-ahead

0...500 r

Part 21: Dynamics Processing

level detection response curve smoothing overall system variants params & usage summar occord occord occord occ

dynamics processing



threshold

−120 . . . 0 dB

■ ratio

0.05...20 (Limiter: ∞)

■ attack

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■ release

20...300 ms

hold

0...10 ms

■ stereo-link

On/Off

oversampling

1...8

■ look-ahead

0...500 ms

tro level detection response curve smoothing overall system variants **params & usage** summar ○○ ○○○○○○ ○○○ ○○ ○○ ○○ ○○ ○○

dynamics processing dynamic range target (opinionated)

92		240 230	7	200 200	7	DR14 &<	DR13	DR12	DR11	DR10	DR9	DR8	DR7	DR6	DR5	DR4	red: over-compressed = unpleasant yellow = transition area green: dynamic and pleasant
Goa	-		Disco	S 10	Techno												sample-based music, electronic music with primarily synthetic generated sounds
Hardrock	Blues	НірНор	R'n B	Rock	Pop												Pop, Rock, Mainstream "radio music" with acoustic sound fractions
Relax	Chillout	Classic	Country	Folk	Jazz												primarily acoustic music: jazz, folk, country, classic, music for relaxation

somewhere on the internet

dynamics processing summary



dynamics processing systems are

- time variant: gain changes over time
- signal adaptive: gain depends on (input) signal
- sometimes non-linear: at very short attack times (limiting)