CHAPRO

Compression Hearing-Aid Processing Library
API Documentation

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CHAPRO LIBRARY OVERVIEW

CHAPRO is a library of functions that may be used to implement simulations of compression hearing-aid signal processing. Two different types of signal processing strategies are included: (1) gammatone filter-bank frequency analysis with instantaneous compression and (2) FIR filter-bank frequency analysis with automatic gain control.

A modular design has been adopted to facilitate replacement of library functions with alternative signal-processing implementations. Each of the five major modules contains (1) a *preparation* function that allocates memory and initializes variables and (2) one or more *processing* functions that perform signal processing.

1. Complex Gammatone filter-bank
    a. `cgtfb_prepare`
    b. `cgtfb_analyze`
    c. `cgtfb_synthesize`
2. Instantaneous compression
    a. `compressor_prepare`
    b. `compressor_process`
3. FIR filter-bank Fourier Transform
    a. `firfb_prepare`
    b. `firfb_analyze`
    c. `firfb_synthesize`
4. IIR filter-bank Fourier Transform
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    c. `iirfb_synthesize`
5. Automatic gain control
    a. `agc_prepare`
    b. `agc_input`
    c. `agc_channel`
    d. `agc_output`
6. Adaptive feedback cancelation
    a. `afc_prepare`
    b. `afc_input`
    c. `afc_output`

All variables are initialized and related data memory is allocated by the preparation functions. This storage is combined into a single data structure to facilitate the creation of firmware for real-time implementation on signal-processing hardware. The CHAPRO library includes a function that generates a C-code representation of this initialized data.

- `data_gen`

For desktop simulation, the CHAPRO library includes core functions for memory allocation and disposal.

- `prepare`

- `allocate`
- `cleanup`

Functions for FFT of real signals are included among the core functions.

- `fft_rc`
- `fft_cr`

Finally, the CHAPRO library includes a function that returns a version description string.

- `version`

To simulate gammatone filter-bank frequency analysis with instantaneous compression, variable initialization and memory allocation is performed by calling the following functions.

- `cgtfb_prepare`
- `compressor_prepare`

Subsequent signal processing is performed by calling the following functions.

- `cgtfb_analyze`
- `compressor_process`
- `cgtfb_synthesize`

Several examples test basic aspects of these functions.

- `tst_gfa` – tests gammatone filter-bank analysis
- `tst_gfio` – tests simple waveform gammatone processing
- `tst_gfsc` – tests simple waveform gammatone processing with soundcard

To simulate FIR filter-bank frequency analysis with AGC compression, variable initialization and memory allocation is performed by calling the following functions.

- `firfb_prepare`
- `agc_prepare`

Subsequent signal processing is performed by calling the following functions.

- `agc_input`
- `firfb_analyze`
- `agc_channel`
- `firfb_synthesize`
- `agc_output`
- `feedback_record`

Several examples test basic aspects of these functions.

- `tst_ffa` – tests filter-bank analysis
- `tst_ffio` – tests simple waveform FIR processing
- `tst_ffsc` – tests speech-waveform FIR processing

To simulate IIR filter-bank frequency analysis with AGC compression and adaptive feedback cancelation, variable initialization and memory allocation is performed by calling the following functions.

- `agc_prepare`

- `iirfb_prepare`
- `afc_prepare`

Subsequent signal processing is performed by calling the following functions.

- `afc_input`
- `agc_input`
- `iirfb_analyze`
- `agc_channel`
- `iirfb_synthesize`
- `agc_output`
- `afc_output`

Several examples test basic aspects of these functions.

- `tst_ifa` – tests filter-bank analysis
- `tst_ifio` – tests simple waveform IIR processing
- `tst_ifsc` – tests speech-waveform IIR processing with soundcard
- `tst_iffb` – tests speech-waveform IIR & AFC processing with soundcard

All examples require the SIGPRO library from BTNRH (http://audres.org/rc/sigpro). The soundcard examples also require the ARSC library (http://audres.org/rc/arsc).

CHAPRO FUNCTION DESCRIPTIONS

cha_allocate
Allocates memory attached to CHAPRO data structure.

(void) **cha_allocate**(CHA_PTR **cp**, int **cnt**, int **siz**, int **idx**)

Function arguments

cp	pointer to CHAPRO data structure
cnt	Number of elements to allocate.
siz	Size of each element.
idx	Index into CHAPPRO data structure.

Return Value
none

Remarks
A pointer to the allocated memory is stored in the CHAPRO data structure at the location specified by **idx**.

See Also
cha_cleanup

cha_cleanup
Frees all memory attached to CHAPRO data structure.

(void) **cha_cleanup**(CHA_PTR **cp**)

Function arguments

cp	pointer to CHAPRO data structure

Return Value
none

Remarks
Should always be the last function called in the CHAPRO library.

See Also
cha_allocate

cha_data_gen
Generates C code that represents the CHAPRO data structure.

(int) **cha_data_gen**(CHA_PTR **cp**, char ***fn**)

Function arguments

cp	pointer to CHAPRO data structure
fn	Pointer to output filename.

Return Value

Error code:
0 – no error
1 – can't open output file
2 – data structure not yet initialized
3 – data structure contains no data

Remarks
The C code generated by this function represents the CHAPRO data structure after variables have been initialized and data memory has been allocated by prior calls to any preparation functions. The code is written to the file specified by **fn**.

cha_hex_patch
Patch hex file by replacing cha_data.

(int) **cha_hex_patch**(CHA_PTR **cp**, char *i**fn**, char *o**fn**)

Function arguments

cp	pointer to CHAPRO data structure
i**fn**	Pointer to input filename.
o**fn**	Pointer to output filename.

Return Value

Error code:
0 – no error
1 – can't open output file
2 – data structure not yet initialized
3 – data structure contains no data

Remarks
Copies the input hex file **ofn** to an output hex file **ifn** with replacement of cha_data.

cha_scale
Applies scales factor to a chuck of the input or output stream.

(void) **cha_scale**(float ***x**, int **cs**, float **scale**)

Function arguments

x	pointer to input signal
cs	chunk size
scale	pointer to CHAPRO data structure

Return Value
None.

Remarks
The scaled output signal overwrites the input signal.

cha_fft_cr

Inverse Fourier transform complex frequency components into real signal.

(void) **cha_fft_cr**(float ***x,** int **n**)

Function arguments

x	Complex frequency components are replaced by real-valued signal.
n	Number of points in the signal.

Return Value

None

Remarks

The input array must be dimensioned to accommodate **n+2** float values. The number of complex frequency components is **(n+2)/2.**

cha_fft_rc

Fourier transform real signal into complex frequency components.

(void) **cha_fft_rc**(float ***x,** int **n**)

Function arguments

x	Real-valued signal is replaced by complex frequency components
n	Number of points in the signal.

Return Value

None

Remarks

The input array must be dimensioned to accommodate **n+2** float values. The number of complex frequency components is **(n+2)/2.**

cha_fft

Fourier transform a complex time signal to complex frequency components.

(void) **cha_fft**(float ***x,** int **n**)

Function arguments

x	Complex frequency components are replaced by a complex signal.
n	Number of points in the signal.

Return Value

None

Remarks

The input array must be dimensioned to accommodate **n×2** float values.

cha_ifft

Inverse Fourier transform complex frequency components into a complex-valued signal.

(void) **cha_ifft**(float ***x,** int **n**)

Function arguments

x	Complex signal is replaced by complex frequency components
n	Number of points in the signal.

Return Value

None

Remarks

The input array must be dimensioned to accommodate **n×2** float values.

cha_prepare
CHAPRO data structure preparation function.

(void) **cha_prepare**(CHA_PTR **cp**)

Function arguments

cp	pointer to CHAPRO data structure

Return Value

None.

Remarks

Should be called only once and prior to calling other library functions; however, violations of this rule may be tolerated.

cha_version
Returns a string that describes the current version of the CHAPRO library.

(char *) **cha_version**(void)

Function arguments
none

Return Value
Pointer to version string.

Remarks
An example of the return value, "CHAPro version 0.03, 6-Nov-2016".

cha_agc_prepare
Automatic-gain-control preparation function.

(int) **cha_agc_prepare**(CHA_PTR **cp**, CHA_DSL ***dsl**, CHA_WDRC ***gha**)

Function arguments

cp	pointer to CHA data structure
dsl	pointer to DSL prescription structure (see Appendix C)
gha	pointer to WDRC prescription structure (see Appendix D)

Return Value

Error code:
0 – no error

Remarks

Initializes variables and allocates memory for automatic gain control. Chunk size is the number of samples read from the input signal and written to the output signal with each call to cha_agc_process.

See Also

cha_agc_process

cha_agc_input
Automatic-gain-control processing function.

(void) **cha_agc_input**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value

none

Remarks

Performs single-channel, automatic-gain-control processing on CHAPRO input signal. Chunk size is the number of samples read from the input signal and written to the output signal.

See Also

cha_agc_prepare, cha_agc_output

cha_agc_channel
Automatic-gain-control processing function.

(void) **cha_agc_channel**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs multi-channel, automatic-gain-control processing. Chunk size is the number of samples read from the input signal and written to the output signal.

See Also
cha_agc_prepare

cha_agc_output
Automatic-gain-control processing function.

(void) **cha_agc_output**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs single-channel, automatic-gain-control processing on CHAPRO output signal. Chunk size is the number of samples read from the input signal and written to the output signal.

See Also
cha_agc_prepare, cha_agc_input

cha_compressor_prepare
Instantaneous-compression preparation function.

(int) **cha_compressor_prepare**(CHA_PTR **cp**,
float ***Lc**, float ***Gc**, double **lr**, int **np**, int **ds**)

Function arguments

cp	pointer to CHA data structure
Lc	pointer to level array
Lc	pointer to gain array
lr	level reference
np	number of points in level and gain arrays
ds	down-sample factor

Return Value
Error code:
0 – no error

Remarks
Initializes variables and allocates memory for instantaneous compression. Chunk size is the number of samples read from the input signal and written to the output signal with each call to cha_compressor_process.

See Also
cha_compressor_process

cha_compressor_process
Instantaneous-compression processing function.

(void) **cha_compressor_process**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs automatic-gain-control processing. Chunk size is the number of samples read from the input signal and written to the output signal.

See Also
cha_compressor_prepare

cha_afc_prepare
Save output signal for feedback management.

(int) **cha_afc_prepare**(CHA_PTR **cp**,
double **mu**, double **rho**, int **afl**, double **fbg**, int **sqm**)

Function arguments

cp	pointer to CHAPRO data structure
mu	AFC filter-estimation step size
rho	AFC filter-estimation forgetting factor
fbg	simulated-feedback gain between 0 and 1
sqm	option to save quality metric

Return Value
Error code:
0 – no error

Remarks
Initializes variables and allocates memory for automatic gain control.

See Also
cha_afc_input, cha_afc_output

cha_afc_input
Process input signal to remove feedback.

(void) **cha_afc_input**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHAPRO data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Removes estimated feedback from input signal. Chunk size is the number of samples read from the input signal and written to the output signal. Optionally simulates feedback and saves misalignment error as a quality metric.

See Also
cha_afc_prepare, cha_afc_output

cha_afc_output
Save output signal for feedback management.

(void) **cha_afc_output**(CHA_PTR **cp**, float ***x**, int **cs**)

Function arguments

cp	pointer to CHAPRO data structure
x	pointer to input signal
cs	chunk size

Return Value
none

Remarks
Assists feedback management by saving the output of the hearing-aid processing. Chunk size is the number of samples read from the input signal.

See Also
cha_afc_prepare, cha_afc_input

cha_cgtfb_prepare
Gammatone filter-bank preparation function.

(int) **cha_cgtfb_prepare**(CHA_PTR **cp**, double ***fc**, double ***bw**,
double **sr**, double **gd**, double **tw**, int **nc**, int **cs**)

Function arguments

cp	pointer to CHA data structure
fc	pointer to list of center frequencies (Hz)
bw	pointer to list of bandwidths (Hz)
sr	sampling rate (samples/second)
gd	target group delay (ms)
tw	buffer length (ms) for determining zero gain
nc	number of channels
cs	chunk size

Return Value

Error code:
0 – no error

Remarks

Initializes variables and allocates memory for the gammatone filter-bank. Chunk size is the number of samples read from the input and written to the output.

See Also

cha_cgtfb_analyze, cha_cgtfb_synthesize

cha_cgtfb_analyze
Gammatone filter-bank frequency-analysis function.

(void) **cha_cgtfb_analyze**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs automatic-gain-control processing. Chunk size is the number of samples read from the input and written to the output.

See Also
cha_cgtfb_prepare, cha_cgtfb_synthesize

cha_cgtfb_synthesize
Gammatone filter-bank frequency-synthesis function.

(void) **cha_cgtfb_synthesize**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs automatic-gain-control processing. Chunk size is the number of samples read from the input and written to the output.

See Also
cha_cgtfb_prepare, cha_cgtfb_analyze

cha_cfirfb_prepare
Complex FIR filter-bank preparation function.

(int) **cha_cfirfb_prepare**(CHA_PTR **cp**, double ***cf**, int **nc**, double **sr**,
int **nw**, int **wt**, int **cs**)

Function arguments

cp	pointer to CHA data structure
cf	list frequency band edges (kHz)
nc	number of frequency bands
sr	sampling rate (samples/second)
nw	window size (samples)
wt	window type (0=Hamming, 1=Blackman)
cs	chunk size

Return Value
Error code:
0 – no error

Remarks
Initializes variables and allocates memory for the complex FIR filter-bank. Chunk size is the number of samples read from the input and written to the output.

See Also
cha_cfirfb_analyze, cha_cfirfb_synthesize

cha_cfirfb_analyze
Complex FIR filter-bank frequency-analysis function.

(void) **cha_cfirfb_analyze**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to real input signal
y	pointer to complex output signal
cs	chunk size

Return Value
none

Remarks
Performs complex FIR filter-bank analysis. Chunk size is the number of samples read from the input and written to the output.

See Also
cha_cfirfb_prepare, cha_cfirfb_synthesize

cha_cfirfb_synthesize
Complex FIR filter-bank frequency-synthesis function.

(void) **cha_cfirfb_synthesize**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to complex input signal
y	pointer to real output signal
cs	chunk size

Return Value
none

Remarks
Performs complex FIR filter-bank synthesis. Chunk size is the number of samples read from the input and written to the output.

See Also
cha_cfirfb_prepare, cha_cfirfb_analyze

cha_firfb_prepare
FIR filter-bank preparation function.

(int) **cha_firfb_prepare**(CHA_PTR **cp**,
double ***cf**, int **nc**, double **sr**, int **nw**, int **wt**, int **cs**)

Function arguments

cp	pointer to CHA data structure
cf	list frequency band edges (kHz)
nc	number of frequency bands
sr	sampling rate (samples/second)
nw	window size (samples)
wt	window type (0=Hamming, 1=Blackman)
cs	chunk size

Return Value
Error code:
0 – no error

Remarks
Initializes variables and allocates memory for the FIR filter-bank. Chunk size is the number of samples read from the input and written to the output.

See Also
cha_firfb_analyze, cha_firfb_synthesize

cha_firfb_analyze
FIR filter-bank frequency-analysis function.

(void) **cha_firfb_analyze**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs FIR filter-bank analysis. Chunk size is the number of samples read from the input signal and written to the output signal.

See Also
cha_firfb_prepare, cha_firfb_synthesize

cha_firfb_synthesize
FIR filter-bank frequency-synthesis function.

(void) **cha_firfb_synthesize**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs FIR filter-bank synthesis. Chunk size is the number of samples read from the input signal and written to the output signal.

cha_iirfb_prepare
IIR filter-bank preparation function.

(int) **cha_iirfb_prepare**(CHA_PTR **cp**,
double ***z**, double ***p**, double ***g**, double ***d**, int **nc**, int **op**, double **sr**)

Function arguments

cp	pointer to CHA data structure
z	pointer to IIR filter zeros
b	pointer to IIR filter poles
g	pointer IIR filter gain
d	pointer IIR filter delay
nc	number of frequency bands
op	number of filter coefficients for each band
sr	sampling rate (samples/second)

Return Value

Error code:
0 – no error

Remarks

Initializes variables and allocates memory for the IIR filter-bank. The poles and zeros are complex numbers, so are stored as sequential real and imaginary parts. The size of the zeros & poles arrays (**z** & **p**) is two times the product of the number of frequency bands (**nc**) and the number of zeros per band (**nz**). The number of filter gains and filter delays (**g** & **d**) is the number of frequency bands (**nc**). Chunk size is the number of samples read from the input and written to the output.

See Also

cha_iirfb_analyze, cha_iirfb_synthesize

cha_iirfb_analyze
IIR filter-bank frequency-analysis function.

(void) **cha_iirfb_analyze**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs IIR filter-bank analysis. Chunk size is the number of samples read from the input signal and written to the output signal.

See Also
cha_iirfb_prepare, cha_iirfb_synthesize

cha_firfb_synthesize
IIR filter-bank frequency-synthesis function.

(void) **cha_iirfb_synthesize**(CHA_PTR **cp**, float ***x**, float ***y**, int **cs**)

Function arguments

cp	pointer to CHA data structure
x	pointer to input signal
y	pointer to output signal
cs	chunk size

Return Value
none

Remarks
Performs IIR filter-bank synthesis. Chunk size is the number of samples read from the input signal and written to the output signal.

See Also
cha_iirfb_prepare, cha_iirfb_analyze

Appendix A. Test programs

Several examples that test basic aspects of complex-gammatone filter-bank and instantaneous-compression.

- `tst_gfa` – tests complex-gammatone filter-bank analysis
- `tst_gfio` – tests simple waveform gammatone processing
- `tst_gfsc` – tests simple waveform gammatone processing with soundcard

Several examples that test basic aspects of FIR filter-bank and automatic-gain-control.

- `tst_ffa` – tests FIR filter-bank analysis
- `tst_ffio` – tests simple waveform FIR processing
- `tst_ffsc` – tests speech-waveform FIR processing with soundcard

Several examples that test basic aspects of FIR filter-bank with automatic-gain-control and adaptive feedback cancelation.

- `tst_ifa` – tests FIR filter-bank analysis
- `tst_ifio` – tests simple waveform IIR processing
- `tst_ifsc` – tests speech-waveform IIR processing
- `tst_iffb` – tests speech-waveform IIR & AFC processing

Appendix B. CLS Prescription

Structure CHA_CLS specifies the CLS prescription.

```
#define CLS_MXCH 32         // maximum number of channels

typedef struct {
    int cm;                 // compression mode
    int nc;                 // number of channels
    double fc[CLS_MXCH];    // center frequency
    double bw[CLS_MXCH];    // bandwith
    double Gcs[CLS_MXCH];   // gain at compression start
    double Gcm[CLS_MXCH];   // gain at compression middle
    double Gce[CLS_MXCH];   // gain at compression end
    double Gmx[CLS_MXCH];   // maximum gain
    double Lcs[CLS_MXCH];   // level at compression start
    double Lcm[CLS_MXCH];   // level at compression middle
    double Lce[CLS_MXCH];   // level at compression end
    double Lmx[CLS_MXCH];   // maximum output level
} CHA_CLS;
```

Appendix C. DSL Prescription

Structure CHA_DSL specifies the DSL prescription.

```
#define DSL_MXCH 32               // maximum number of channels

typedef struct {
    double attack;                // attack time (ms)
    double release;               // release time (ms)
    double maxdB;                 // maximum output (dB SPL)
    int ear;                      // 0=left, 1=right
    int nchannel;                 // number of channels
    double cross_freq[DSL_MXCH]; // cross frequencies (Hz)
    double tkgain[DSL_MXCH];     // compression-start gain
    double cr[DSL_MXCH];          // compression ratio
    double tk[DSL_MXCH];          // compression-start kneepoint
    double bolt[DSL_MXCH];        // broadband output limiting threshold
} CHA_DSL;
```

Appendix D. WDRC Parameters

Structure CHA_WDRC specifies single-channel WDRC parameters

```
typedef struct {
    double attack;              // attack time (ms)
    double release;             // release time (ms)
    double fs;                  // sampling rate (Hz)
    double maxdB;               // maximum signal (dB SPL)
    double tkgain;              // compression-start gain
    double tk;                  // compression-start kneepoint
    double cr;                  // compression ratio
    double bolt;                // broadband output limiting threshold
} CHA_WDRC;
```