小组成员信息

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- 组员：廉涟，李玉昆，王铭慧，王菁
- 贡献度：每人20%

实验目标： 通过本实验，你将学习并实践信号处理中的三个重要任务：端点检测、基音周期检测以及 MFCC 特征提取。这些任务是语音信号处理和音频处理中的基础，对于语音识别和语音分析等应用至关重要。其中，端点检测、基音周期检测实验可以二选一，MFCC特征提取实验必须完成。

实验方法：

1. 端点检测：

- 阅读端点检测的相关文献或资料，了解双门限法的原理和实现方式。
- 使用 Python 编程语言，实现端点检测算法。
- 在代码中设定合适的阈值来检测端点，你可以尝试不同的阈值来获取更好的效果。
- 编写代码以可视化端点检测结果，将检测到的端点在原始信号上标出。

2. 基音周期检测：

- 学习基音周期检测的原理，理解基音周期在语音信号中的重要性。
- 使用 librosa 库或其他音频处理库加载音频数据。
- 探索基音周期检测的方法，并尝试实现其中一种方法。你可以使用自相关函数或其他方法来检测基音周期。
- 编写代码以可视化基音周期检测的结果，将检测到的基音周期在音频信号上标出。

3. MFCC 特征提取：

- 了解 MFCC 特征在语音信号处理中的重要性以及其在语音识别中的应用。
- 使用 librosa 库或其他音频处理库加载音频数据。
- 实现 MFCC 特征提取算法。
- 编写代码以可视化提取的 MFCC 特征，观察不同时间段内的特征变化。

实验要求：

录制一段音频，并开展上述实验，并可视化实验结果，并保存图片到本地。其中实验1和2可任选一个，实验3必做。

In [ ]:
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# #安装依赖库，可以跳过已安装的库
%pip install -r requirements.txt
```

In [ ]:
```
%pip show numpy
%pip show matplotlib
%pip show scipy
%pip show pandas
%pip show pyaudio
%pip show wave
```

```
%pip show librosa
%pip show IPython
# 如果显示WARNING: Package(s) not found,则需要安装对应依赖库
```

```
Name: numpy
Version: 1.24.4
Summary: Fundamental package for array computing in Python
Home-page: https://www.numpy.org
Author: Travis E. Oliphant et al.
Author-email:
License: BSD-3-Clause
Location: /home/bbs/miniconda3/envs/mdx/lib/python3.8/site-packages
Requires:
Required-by: altair, biopython, contourpy, gradio, kneed, librosa, matplotlib, nu
mba, onnxruntime-gpu, openunmix, pandas, pyarrow, pydeck, scikit-learn, scipy, se
aborn, soxr, streamlit, torchlibrosa
Note: you may need to restart the kernel to use updated packages.
Name: matplotlib
Version: 3.7.4
Summary: Python plotting package
Home-page: https://matplotlib.org
Author: John D. Hunter, Michael Droettboom
Author-email: matplotlib-users@python.org
License: PSF
Location: /home/bbs/miniconda3/envs/mdx/lib/python3.8/site-packages
Requires: contourpy, cycler, fonttools, importlib-resources, kiwisolver, numpy, p
ackaging, pillow, pyparsing, python-dateutil
Required-by: gradio, seaborn, voicefixer2
Note: you may need to restart the kernel to use updated packages.
Name: scipy
Version: 1.10.1
Summary: Fundamental algorithms for scientific computing in Python
Home-page: https://scipy.org/
Author:
Author-email:
License: Copyright (c) 2001-2002 Enthought, Inc. 2003-2022, SciPy Developers.
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Files: .libs/libopenb*.so
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Version 3.1, 31 March 2009

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        the library.  If this is what you want to do, use the GNU Lesser General
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        <http://www.gnu.org/philosophy/why-not-lgpl.html>.
Location: /home/bbs/miniconda3/envs/mdx/lib/python3.8/site-packages
Requires: numpy
Required-by: kneed, librosa, scikit-learn, voicefixer2
Note: you may need to restart the kernel to use updated packages.
Name: pandas
Version: 2.0.3
Summary: Powerful data structures for data analysis, time series, and statistics
Home-page: 
Author: 
Author-email: The Pandas Development Team <pandas-dev@python.org>
License: BSD 3-Clause License

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Location: /home/bbs/miniconda3/envs/mdx/lib/python3.8/site-packages
```

```
Requires: numpy, python-dateutil, pytz, tzdata
Required-by: altair, gradio, seaborn, streamlit
Note: you may need to restart the kernel to use updated packages.
WARNING: Package(s) not found: pyaudio
Note: you may need to restart the kernel to use updated packages.
WARNING: Package(s) not found: wave
Note: you may need to restart the kernel to use updated packages.
Name: librosa
Version: 0.10.1
Summary: Python module for audio and music processing
Home-page: https://librosa.org
Author: Brian McFee, librosa development team
Author-email: brian.mcfee@nyu.edu
License: ISC
Location: /home/bbs/miniconda3/envs/mdx/lib/python3.8/site-packages
Requires: audioread, decorator, joblib, lazy-loader, msgpack, numba, numpy, pooc
h, scikit-learn, scipy, soundfile, soxr, typing-extensions
Required-by: torchlibrosa, voicefixer2
Note: you may need to restart the kernel to use updated packages.
Name: ipython
Version: 8.12.0
Summary: IPython: Productive Interactive Computing
Home-page: https://ipython.org
Author: The IPython Development Team
Author-email: ipython-dev@python.org
License: BSD-3-Clause
Location: /home/bbs/miniconda3/envs/mdx/lib/python3.8/site-packages
Requires: backcall, decorator, jedi, matplotlib-inline, pexpect, pickleshare, pro
mpt-toolkit, pygments, stack-data, traitlets, typing-extensions
Required-by: ipykernel
Note: you may need to restart the kernel to use updated packages.
```

我们鼓励大家使用自己录制的音频进行实验，下面是录制音频的简单示例，可根据自己设备的情况，对录制时长和采样率进行调整

In [ ]:

```python
#录制音频
def record_audio(duration):
    import pyaudio
    import wave

    CHUNK = 1024
    FORMAT = pyaudio.paInt16
    CHANNELS = 1
    RATE = 44100
    WAVE_OUTPUT_FILENAME = "demo.wav"

    p = pyaudio.PyAudio()

    stream = p.open(format=FORMAT,
                    channels=CHANNELS,
                    rate=RATE,
                    input=True,
                    frames_per_buffer=CHUNK)

    print("* 录音中...")

    frames = []

    for i in range(0, int(RATE / CHUNK * duration)):
```

```
        data = stream.read(CHUNK)
        frames.append(data)

    print("* 录音结束!")

    stream.stop_stream()
    stream.close()
    p.terminate()

    wf = wave.open(WAVE_OUTPUT_FILENAME, 'wb')
    wf.setnchannels(CHANNELS)
    wf.setsampwidth(p.get_sample_size(FORMAT))
    wf.setframerate(RATE)
    wf.writeframes(b''.join(frames))
    wf.close()

record_audio(duration=5) #录音5秒,并保存为demo.wav
```

In [ ]:
```
import IPython
IPython.display.Audio('demo.wav') #播放demo.wav
```

Out[ ]:

0:00 / 0:04

In [ ]:
```
#读取音频
import numpy as np
import scipy.io.wavfile as wav
sr, signal = wav.read('demo.wav')
print('采样率: ', sr)
print("信号长度: ", signal.shape)
```

```
采样率:  8000
信号长度:  (32000,)
```

In [ ]:
```
# 下面是一些会用到的音频处理函数
from speechlib import *
import os
```

实验1-1：基于双门限法的端点检测 需要补充下列方法: STEn、STZcr、vad_TwoThr

所有需要补充的代码都注释有TODO, 按要求补充即可【未选择该实验】

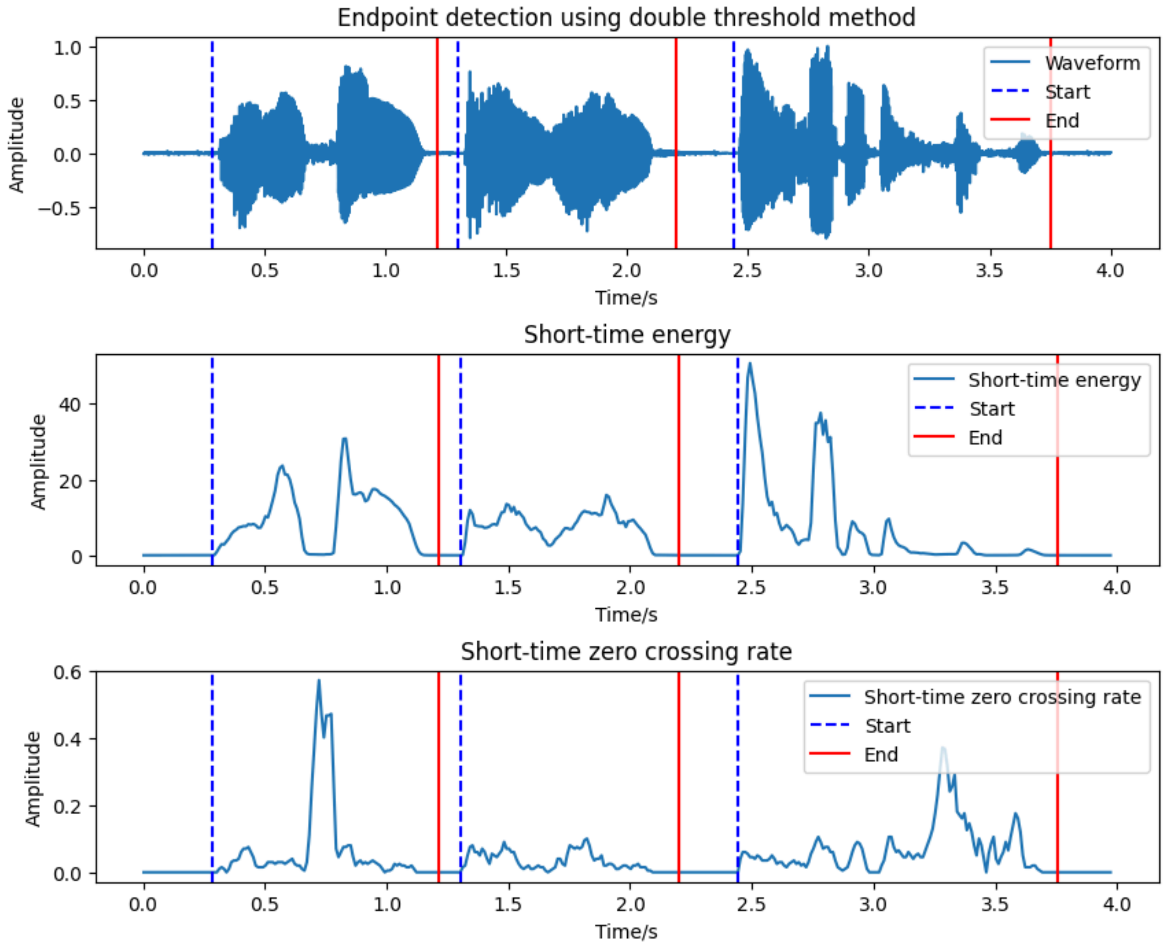
In [ ]:
```
def STEn(x: object, win: object, inc: object) -> object:
    """
    计算短时能量函数
    :param x: 语音信号
    :param win: 窗长
    :param inc: 帧移
    :return: 短时能量，即每一帧的能量
    """
    # TODO 需要补充
    # 1.分帧
    # 2.计算短时能量
    # 3.返回短时能量

def STZcr(x, win, inc, delta=0):
    """
    计算短时过零率
```

```
    :param x: 语音信号
    :param win: 窗长
    :param inc: 帧移
    :return: 短时过零率，即每一帧的过零率
    """
    # TODO 需要补充
    # 1.分帧
    # 2.计算短时过零率
    # 3.返回短时过零率

def vad_TwoThr(x, wlen, inc, NIS):
    """
    使用门限法进行端点检测
    :param x: 语音信号
    :param wlen: 分帧长度
    :param inc: 帧移
    :param NIS: 用于计算门限的无话段长度
    :return: 语音段的起始点和终止点，语音段数，语音段标记，非语音段标记，短时能量
    """
    maxsilence = 15
    minlen = 5
    status = 0
    y = # TODO 需要补充：调用enframe方法进行分帧
    fn = y.shape[0] # 帧数
    amp = STEn(x, wlen, inc) # 计算短时能量，需要在上方方法定义里补充
    zcr = STZcr(x, wlen, inc, delta=0.01) # 计算短时过零率，需要在上方方法定义里
    ampth = np.mean(amp[:NIS]) # 计算短时能量的平均值
    zcrth = np.mean(zcr[:NIS]) # 计算短时过零率的平均值
    amp2 = 2 * ampth
    amp1 = 4 * ampth
    zcr2 = 2 * zcrth
    xn = 0
    count = np.zeros(fn)
    silence = np.zeros(fn)
    x1 = np.zeros(fn)
    x2 = np.zeros(fn)
    for n in range(fn):
    # 0-静音，1-可能开始，2-确定开始，3-语音段

        if status == 0 or status == 1:
            if amp[n] > amp1: # 语音段的起始点
                x1[xn] = # TODO 需要补充
                status = 2
                silence[xn] = 0
                count[xn] += 1
            elif amp[n] > amp2 or zcr[n] > zcr2: # 可能开始
                status = 1
                count[xn] += 1
            else: # 静音
                status = 0
                count[xn] = 0
                x1[xn] = 0
                x2[xn] = 0

        elif status == 2:
            if # TODO 需要补充
                count[xn] += 1
            else:
                silence[xn] += 1
                if silence[xn] < maxsilence:
```

```
                    count[xn] += 1
                elif count[xn] < minlen:
                    status = 0
                    silence[xn] = 0
                    count[xn] = 0
                else:
                    status = 3
                    x2[xn] = x1[xn] + count[xn]
        elif status == 3:
            status = 0
            xn += 1
            count[xn] = 0
            silence[xn] = 0
            x1[xn] = 0
            x2[xn] = 0
    el = len(x1[:xn])
    if x1[el - 1] == 0:
        el -= 1
    if x2[el - 1] == 0:
        print('Error: Not find endding point!\n')
        x2[el] = fn
    SF = np.zeros(fn)
    NF = np.ones(fn)
    for i in range(el):
        SF[int(x1[i]):int(x2[i])] = 1 # 语音段标记
        NF[int(x1[i]):int(x2[i])] = 0 # 非语音段标记
    voiceseg = findSegment(np.where(SF == 1)[0]) # 找到语音段
    vsl = len(voiceseg.keys())
    return voiceseg, vsl, SF, NF, amp, zcr # 返回语音段的起始点和终止点，语音段数
```

In [ ]:
```
(fs, data) = wavfile.read('demo.wav') # 读取音频
data1 = data/np.max(np.abs(data))     # 幅值归一化

N = len(data1)
wlen = 200
inc = 80
IS = 0.1
overlap = wlen - inc
NIS = int((IS * fs - wlen) // inc + 1)
fn = (N - wlen) // inc + 1

frameTime = FrameTimeC(fn, wlen, inc, fs) # 计算每帧的时间刻度
time = [i / fs for i in range(N)]

voiceseg, vsl, SF, NF, amp, zcr = vad_TwoThr(data1, wlen, inc, NIS) # 语音段检测

# 打印语音段信息
fig, axs = plt.subplots(3, 1, figsize=(10, 8))  # Adjust figsize as needed 调整
plt.subplots_adjust(hspace=0.5)  # Adjust hspace for vertical spacing between su

axs[0].plot(time, data1)
axs[0].set_title('Endpoint detection using double threshold method')
axs[0].set_ylabel('Amplitude')
axs[0].set_xlabel('Time/s')

axs[1].plot(frameTime, amp)
axs[1].set_title('Short-time energy')
axs[1].set_ylabel('Amplitude')
axs[1].set_xlabel('Time/s')
```

```
axs[2].plot(frameTime, zcr)
axs[2].set_title('Short-time zero crossing rate')
axs[2].set_ylabel('Amplitude')
axs[2].set_xlabel('Time/s')

# 画出语音段的起始和终止点
for i in range(vsl):
    nx1 = voiceseg[i]['start']
    nx2 = voiceseg[i]['end']

    axs[0].axvline(frameTime[nx1], np.min(data1), np.max(data1), color='blue', l
    axs[0].axvline(frameTime[nx2], np.min(data1), np.max(data1), color='red', li
    axs[0].legend(['Waveform', 'Start', 'End'])

    axs[1].axvline(frameTime[nx1], np.min(amp), np.max(amp), color='blue', lines
    axs[1].axvline(frameTime[nx2], np.min(amp), np.max(amp), color='red', linest
    axs[1].legend(['Short-time energy', 'Start', 'End'])

    axs[2].axvline(frameTime[nx1], 0, 1, color='blue', linestyle='--')
    axs[2].axvline(frameTime[nx2], 0, 1, color='red', linestyle='-')
    axs[2].legend(['Short-time zero crossing rate', 'Start', 'End'], loc='upper

os.makedirs('figs', exist_ok=True) # 创建文件夹
plt.savefig('figs/vad.png') # 保存图片
plt.show()
```



实验1-2：基于自相关法的基音周期检测 需要补充下列方法: pitch_Corr【已补充✅】

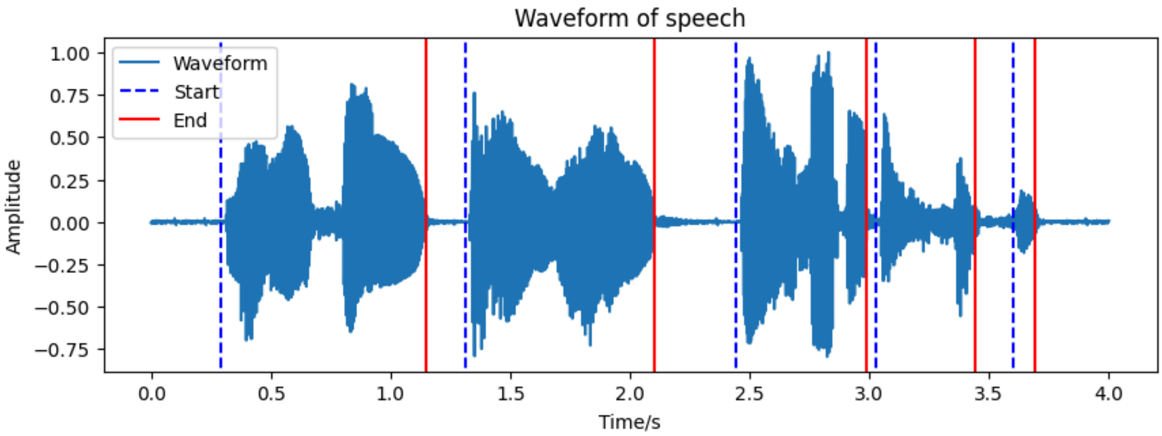
In [ ]:
```
def pitch_Corr(x, wnd, inc, T1, fs, miniL=10):
    """
    自相关法基音周期检测函数
```

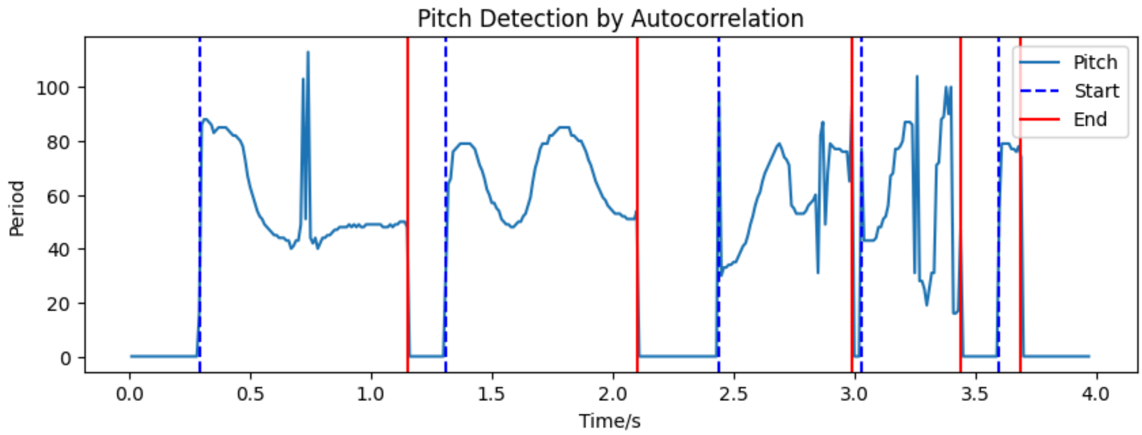
```
    :param x: 语音信号
    :param wnd: 窗函数或窗长
    :param inc: 帧移
    :param T1: 门限
    :param fs: 采样率
    :param miniL: 语音段的最小帧数
    :return voiceseg, vsl, SF, Ef, period: 语音段的起始点和终止点，语音段数，语音
    """
    y = enframe(x, wnd, inc)    # 调用enframe方法进行分帧
    fn = y.shape[0]
    if isinstance(wnd, int):
        wlen = wnd
    else:
        wlen = len(wnd)
    voiceseg, vsl, SF, Ef = pitch_vad(x, wnd, inc, T1, miniL)  # 语音分段
    lmin = fs // 500  # 基音周期的最小值
    lmax = fs // 60  # 基音周期的最大值
    period = np.zeros(fn)
    for i in range(vsl):    # 在所有语音段中
        ixb = voiceseg[i]['start'] # 语音段的起始帧
        ixd = voiceseg[i]['duration'] # 语音段的帧数
        for k in range(ixd):
            ru = np.correlate(y[ixb + k, :], y[ixb + k, :], mode='full')   # 计算
            ru = ru[wlen:]
            tloc = np.argmax(ru[lmin:lmax])
            period[ixb + k] = tloc + lmin
    return voiceseg, vsl, SF, Ef, period
```

In [ ]:

```
import numpy as np
from scipy.io import wavfile
import matplotlib.pyplot as plt

# 读取WAV文件
(fs, data) = wavfile.read('demo.wav')

# 去除直流偏移
data = data - np.mean(data)

# 幅值归一化
data = data / np.max(data)

# 分析参数
wlen = 320  # 分析窗口长度
inc = 80    # 连续窗口间隔
N = len(data)
time = [i / fs for i in range(N)]  # 时间向量
T1 = 0.05  # 用于基音校正的阈值

# 进行基音校正并检测有声段
voiceseg, vsl, SF, Ef, period = pitch_Corr(data, wlen, inc, T1, fs)

# 计算帧数
fn = len(SF)

# 计算帧时间位置
frameTime = FrameTimeC(fn, wlen, inc, fs)

# 设置子图布局
fig, axs = plt.subplots(2, 1, figsize=(10, 8))
plt.subplots_adjust(hspace=0.5)  # 调整垂直间距
```

```
# 绘制波形图
axs[0].plot(time, data)
axs[0].set_title('Waveform of speech')
axs[0].set_ylabel('Amplitude')
axs[0].set_xlabel('Time/s')

# 绘制自相关基音周期检测图
axs[1].plot(frameTime, period)
axs[1].set_title('Pitch Detection by Autocorrelation')
axs[1].set_ylabel('Period')
axs[1].set_xlabel('Time/s')

# 标记有声段
for i in range(vsl):
    nx1 = voiceseg[i]['start']
    nx2 = voiceseg[i]['end']

    # 在波形图上标记有声段
    axs[0].axvline(frameTime[nx1], np.min(data), np.max(data), color='blue', lin
    axs[0].axvline(frameTime[nx2], np.min(data), np.max(data), color='red', line

    # 在自相关基音周期检测图上标记有声段
    axs[1].axvline(frameTime[nx1], np.min(period), np.max(period), color='blue',
    axs[1].axvline(frameTime[nx2], np.min(period), np.max(period), color='red',

axs[0].legend(['Waveform', 'Start', 'End'])
axs[1].legend(['Pitch', 'Start', 'End'])

os.makedirs('figs', exist_ok=True) # 创建文件夹
plt.savefig('figs/pitch.png') # 保存图片
plt.show()
```





实验1-3：MFCC提取 需要补充下列方法: Nmfcc【已补充✅】

In [ ]:
```
def Nmfcc(x, fs, p, frameSize, inc, nfft=512, n_dct=12):
    """
    计算mfcc系数
    :param x: 输入信号
    :param fs: 采样率
    :param p: Mel滤波器组的个数
    :param frameSize: 分帧的每帧长度
    :param inc: 帧移
    :return: mfcc系数
    """
    # 预加重处理
    x_preemphasized = lfilter([1, -0.9375], [1], x)

    # 分帧
    frames = enframe(x_preemphasized, frameSize, inc)

    # 加窗
    frames = np.multiply(frames, np.hanning(frameSize))

    # 计算FFT
    fft_result = np.fft.rfft(frames)

    # 计算能量谱
    power_spectrum = np.abs(fft_result) ** 2

    # 计算通过Mel滤波器的能量
    bank = melbankm(p, nfft, fs, 0, 0.5 * fs, 0)
    ss = np.matmul(power_spectrum, bank.T)
```

```
    # 计算DCT倒谱
    M = bank.shape[0] # 滤波器个数
    m = np.array([i for i in range(M)])
    mfcc = np.zeros((ss.shape[0], n_dct)) # 初始化mfcc系数
    for n in range(n_dct):
        mfcc[:, n] = np.sqrt(2 / M) * np.sum(np.multiply(np.log(ss), np.cos((2 *
    return mfcc
```

In [ ]:

```
import librosa
import matplotlib.pyplot as plt
from scipy.io import wavfile
import numpy as np

# 读取WAV文件
(framerate, wave_data) = wavfile.read("demo.wav")

# 参数设置
wlen = 256
inc = 128
num = 8
nfft = 256
n_dct = 24

# 归一化处理
x = wave_data / max(np.abs(wave_data))
time = np.arange(0, len(wave_data)) / framerate

# 绘制原始波形
plt.figure(1)
plt.subplot(411)
plt.plot(time, x, 'b')
plt.title("(a) Waveform")
plt.ylabel("Amplitude")
plt.xlabel("Time/s")

# 计算MFCC特征
ccc1 = librosa.feature.mfcc(y=x,
                            n_fft=wlen,
                            sr=framerate,
                            n_mfcc=24,
                            fmax=4000,
                            dct_type=2,
                            hop_length=inc,
                            win_length=wlen)
ccc2 = np.transpose(ccc1)

# 进行NMFCC计算
ccc1 = Nmfcc(x, framerate, num, wlen, inc, nfft, n_dct)
fn = ccc1.shape[0]
cn = ccc1.shape[1]
frameTime = FrameTimeC(fn, wlen, inc, framerate)

# # 计算语谱图
D = librosa.stft(x, n_fft=wlen, hop_length=inc)
D_db = librosa.amplitude_to_db(np.abs(D), ref=np.max)
# 绘制语谱图
plt.subplot(412)
librosa.display.specshow(D_db, sr=framerate, hop_length=inc, x_axis='time', y_ax
plt.title("(b) Spectrogram")
```

```
plt.colorbar(format='%+2.0f dB')

# 绘制MFCC系数
plt.subplot(413)
plt.plot(frameTime, ccc1[:, 0:int(cn/2)])
plt.title("(c) MFCC Coefficients")
plt.ylabel("Amplitude")
plt.xlabel("Time/s")


# 绘制MFCC特征图
plt.subplot(414)
plt.imshow(ccc1, cmap='hot', interpolation='nearest', aspect='auto')
plt.xlabel('Frame')
plt.ylabel('MFCC Coefficient')
plt.title('(d) MFCC Features')
plt.colorbar(label='Magnitude')

# 调整子图间距
plt.subplots_adjust(hspace=2)

os.makedirs('figs', exist_ok=True) # 创建文件夹
plt.savefig('figs/mfcc.png') # 保存图片
plt.show()
```