Music Informatics Final Project: Song Transitions

1. **Feature extraction (Matej)** tempo, downbeats, key, energy, spectral flux, segmentation
2. **Tempo match & alignment (Bailin):** time-stretch song B to A's BPM, align downbeats, find overlap windows
3. **Transition scoring (Arvid):** score overlaps, pick best, apply crossfade, output the mix
4. **Evaluation & integration (Matei):** metrics, beat error, key distance, energy smoothness, listening, logging, report

1. **Feature extraction (Matej)** tempo, downbeats, key, energy, spectral flux, segmentation

In [ ]:
```
import matplotlib.pyplot as plt
import numpy as np
from pydub import AudioSegment
import librosa, librosa.display
import scipy
import pickle
```

In [ ]:
```
# Plot parameters
params = {'legend.fontsize': 'x-large',
          'figure.figsize': (12, 4),
         'axes.labelsize': 'x-large',
         'axes.titlesize':'x-large',
         'xtick.labelsize':'x-large',
         'ytick.labelsize':'x-large'}
plt.rcParams.update(params)
```

In [ ]:
```
def load_audio(path, sr=44100):
    """Load audio and return waveform + sample rate."""
    y, sr = librosa.load(path, sr=sr, mono=True)
    return y, sr
```

In [ ]:
```
# Load the songs
path1 = 'under_pressure.mp3'
path2 = 'billie_jean.mp3'
path3 = 'get_lucky.mp3'
y_under_pressure, sr = load_audio(path1)
y_billie_jean, sr = load_audio(path2)
y_get_lucky, sr = load_audio(path3)
```

In [ ]:
```
def get_tempo_baseline(y, sr):
    """
```

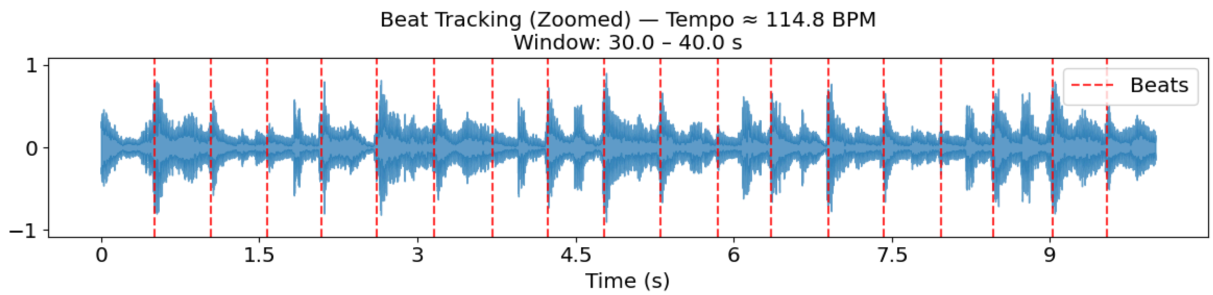
```
    Compute the tempo and beat locations. Returns the global tempo over the
    song and the location of beats.
    """
    tempo, beat_frames = librosa.beat.beat_track(y=y, sr=sr)
    beat_times = librosa.frames_to_time(beat_frames, sr=sr)
    return tempo[0], beat_times
```

In [ ]:
```
tempo_lib_1, beats_lib_1 = get_tempo_baseline(y_under_pressure, sr)
tempo_lib_2, beats_lib_2 = get_tempo_baseline(y_billie_jean, sr)
tempo_lib_3, beats_lib_3 = get_tempo_baseline(y_get_lucky, sr)

print(f"Tempo baseline: {tempo_lib_1:.1f} BPM, according to google should be
print(f"Tempo baseline: {tempo_lib_2:.1f} BPM, according to google should be
print(f"Tempo baseline: {tempo_lib_3:.1f} BPM, according to google should be
```

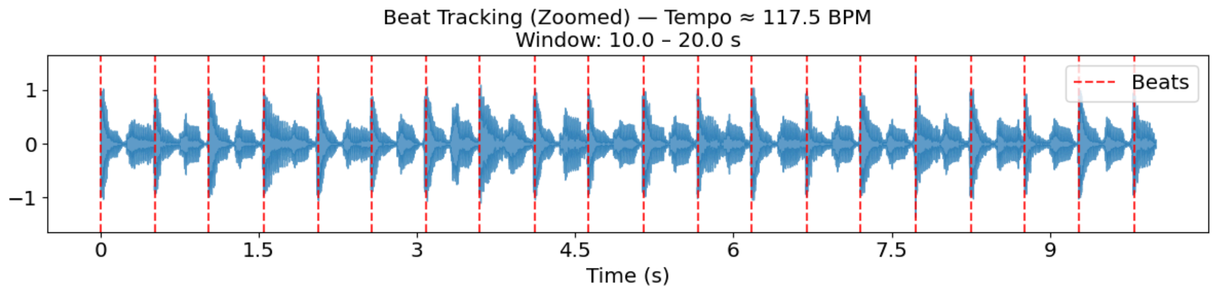
```
Tempo baseline: 114.8 BPM, according to google should be ~112
Tempo baseline: 117.5 BPM, according to google should be ~117
Tempo baseline: 114.8 BPM, according to google should be ~116
```

In [ ]:
```
def plot_beats_zoom(y, sr, beat_times, tempo, start_time=0.0, duration=5.0,
    """
    Plot song waveform and beat locations for a specified time window.
    """
    # Get the specified segment
    start_sample = int(start_time * sr)
    end_sample = int((start_time + duration) * sr)
    y_segment = y[start_sample:end_sample]

    # Only keep beats within this segment
    mask = (beat_times >= start_time) & (beat_times <= start_time + duration
    beats_in_window = beat_times[mask]

    # Compute amplitude limits (for nicer plot so it dynamically scales)
    y_max = np.max(np.abs(y_segment))
    y_margin = y_max * margin_ratio
    ymin, ymax = -y_max - y_margin, y_max + y_margin

    # Plot
    plt.figure(figsize=(12, 3))
    librosa.display.waveshow(y_segment, sr=sr, alpha=0.7)
    plt.vlines(beats_in_window - start_time, ymin=ymin, ymax=ymax,
               color='r', linestyle='--', alpha=0.8, label='Beats')
    plt.ylim(ymin, ymax)
    plt.title(f"Beat Tracking (Zoomed) — Tempo ≈ {tempo:.1f} BPM\n"
              f"Window: {start_time:.1f} – {start_time+duration:.1f} s")
    plt.xlabel("Time (s)")
    plt.legend()
    plt.tight_layout()
    plt.show()
```

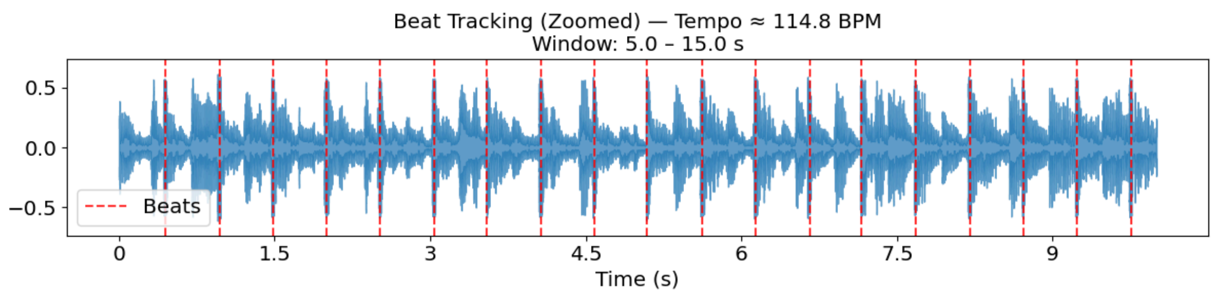
In [ ]:
```
plot_beats_zoom(y_under_pressure, sr, beats_lib_1, tempo_lib_1, start_time=3
```




```
In [ ]: plot_beats_zoom(y_billie_jean, sr, beats_lib_2, tempo_lib_2, start_time=10,
```



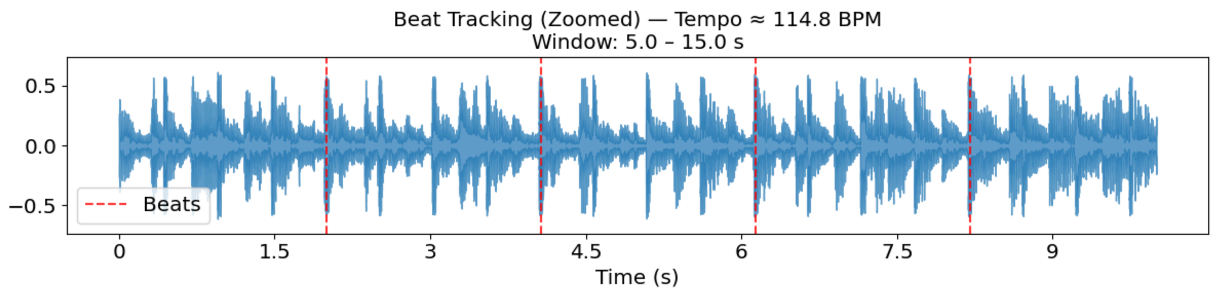

```
In [ ]: plot_beats_zoom(y_get_lucky, sr, beats_lib_3, tempo_lib_3, start_time=5, dur
```




```
In [ ]: def get_downbeats_baseline(beat_times):
            """
            Get downbeats by assuming 4/4 time (same as paper) and the first beat is
            """
            # Naive assumption: first beat is a downbeat. The paper uses a logistic
            # to determine whether the first downbeat is on the first, second, third
            downbeat_times = beat_times[::4]
            return downbeat_times
```

```
In [ ]: downbeats_lib_1 = get_downbeats_baseline(beats_lib_1)
        downbeats_lib_2 = get_downbeats_baseline(beats_lib_2)
        downbeats_lib_3 = get_downbeats_baseline(beats_lib_3)

        print(f"Under Pressure: Found {len(beats_lib_1)} beats and {len(downbeats_li
        plot_beats_zoom(y_get_lucky, sr, downbeats_lib_3, tempo_lib_3, start_time=5,
```

```
Under Pressure: Found 457 beats and 115 downbeats.
```



In [ ]:
```
def get_key(y, sr):
    """
    Find the key of the song using chromagram
    """
    # Compute the chromagram
    chroma = librosa.feature.chroma_cqt(y=y, sr=sr)
    chroma_mean = np.mean(chroma, axis=1)
    # Major/minor templates
    maj = np.array([1,0,0,0,1,0,0,1,0,0,0,0])
    min_ = np.array([1,0,0,1,0,0,0,1,0,0,1,0])
    labels = ['C','C#','D','D#','E','F','F#','G','G#','A','A#','B']
    scores = []
    # Compute a correlation score for each key
    for i in range(12):
        scores.append(np.correlate(np.roll(maj, i), chroma_mean))
        scores.append(np.correlate(np.roll(min_, i), chroma_mean))
    best = np.argmax(scores)
    key_name = labels[best//2] + ('m' if best%2 else '')
    return key_name, float(np.max(scores))
```

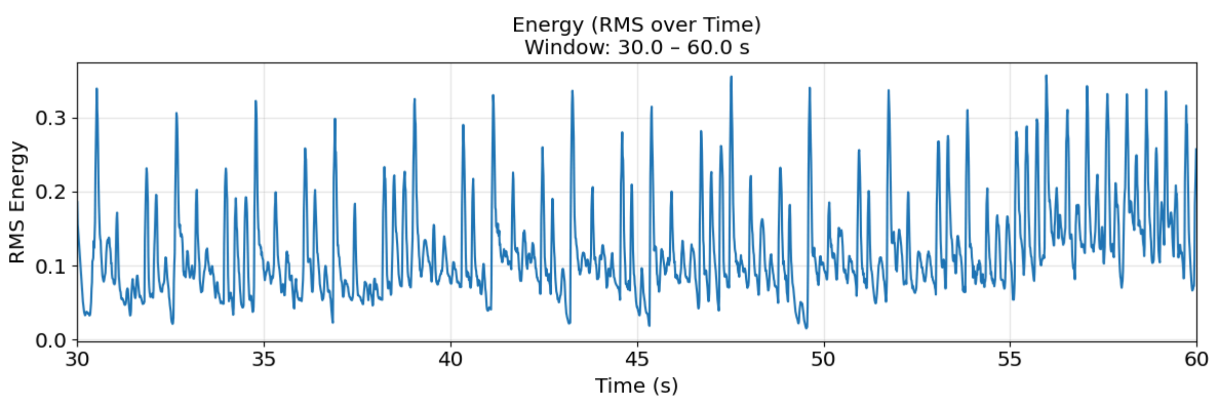
In [ ]:
```
# Key
key_pap, conf_pap = get_key(y_under_pressure, sr)
print(f"Key baseline Under Pressure: {key_pap} ({conf_pap:.2f}), according t

key_pap, conf_pap = get_key(y_billie_jean, sr)
print(f"Key baseline Billie Jean: {key_pap} ({conf_pap:.2f}), according to g

key_pap, conf_pap = get_key(y_get_lucky, sr)
print(f"Key baseline Get Lucky: {key_pap} ({conf_pap:.2f}), according to goo
```

```
Key baseline Under Pressure: Em (2.20), according to google should be D majo
r
Key baseline Billie Jean: F#m (2.15), according to google should be F sharp
minor
Key baseline Get Lucky: Bm (2.58), according to google should be F sharp min
or
```

In [ ]:
```
def get_energy_baseline(y, sr, hop_length=512):
    """
    Compute the RMS energy, which represents the loudness.
    """
    rms = librosa.feature.rms(y=y, hop_length=hop_length)[0]
    times = librosa.times_like(rms, sr=sr)
    return times, rms
```

In [ ]:
```
def plot_energy(times, energy, title="Energy (RMS over Time)", start_time=0.
    """
    Plot energy (RMS) for a specified time window.
    """
    # Calculate end time
    end_time = start_time + duration

    # Get data only from the specified segment
    mask = (times >= start_time) & (times <= end_time)
    times_segment = times[mask]
    energy_segment = energy[mask]

    # Plot
    plt.figure()
    plt.plot(times_segment, energy_segment)
    plt.title(f"{title}\nWindow: {start_time:.1f} – {end_time:.1f} s")
    plt.xlabel("Time (s)")
    plt.ylabel("RMS Energy")
    plt.xlim(start_time, end_time)
    plt.grid(alpha=0.3)
    plt.tight_layout()
    plt.show()
```

In [ ]:
```
t_e, rms = get_energy_baseline(y_under_pressure, sr)
plot_energy(t_e, rms, start_time=30)

print(len(t_e))
```



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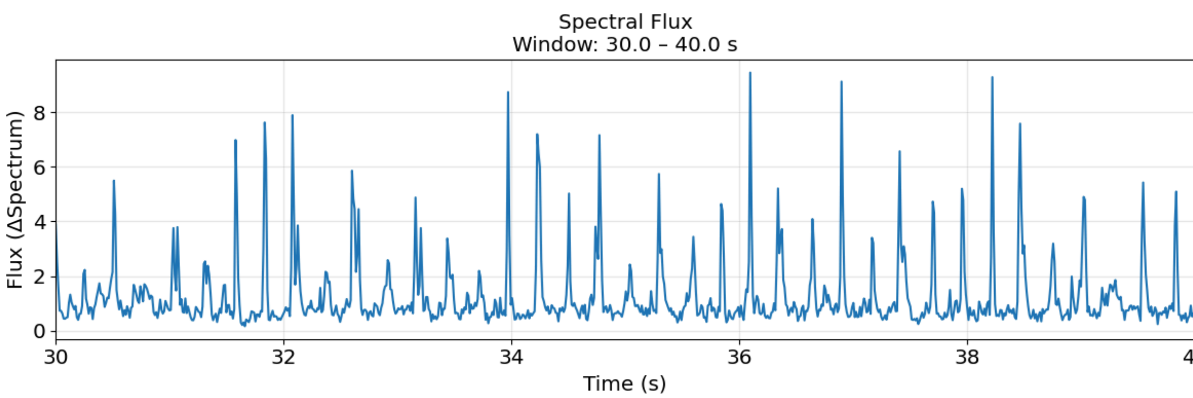
In [ ]:
```
def get_spectral_flux_baseline(y, sr):
    """
    Compute the spectral flux using a melspectrogram.
    """
    # Use Melflux ODF
    onset_env = librosa.onset.onset_strength(y=y, sr=sr, feature=librosa.fea
    times = librosa.times_like(onset_env, sr=sr)
    return onset_env, times
```

In [ ]:
```
def plot_flux(times, flux, title="Spectral Flux", start_time=0.0, duration=3
    """
    Plot spectral flux for a specified time window.
    """
```

```python
    # Calculate end time
    end_time = start_time + duration

    # Get data only from the specified segment
    mask = (times >= start_time) & (times <= end_time)
    times_segment = times[mask]
    flux_segment = flux[mask]

    # Plot
    plt.figure(figsize=(12, 4))
    plt.plot(times_segment, flux_segment)
    plt.title(f"{title}\nWindow: {start_time:.1f} – {end_time:.1f} s")
    plt.xlabel("Time (s)")
    plt.ylabel("Flux (ΔSpectrum)")
    plt.xlim(start_time, end_time)
    plt.grid(alpha=0.3)
    plt.tight_layout()
    plt.show()
```

In [ ]:

```python
flux_1, flux_times_1 = get_spectral_flux_baseline(y_under_pressure, sr)
plot_flux(flux_times_1, flux_1, start_time=30, duration=10)
```



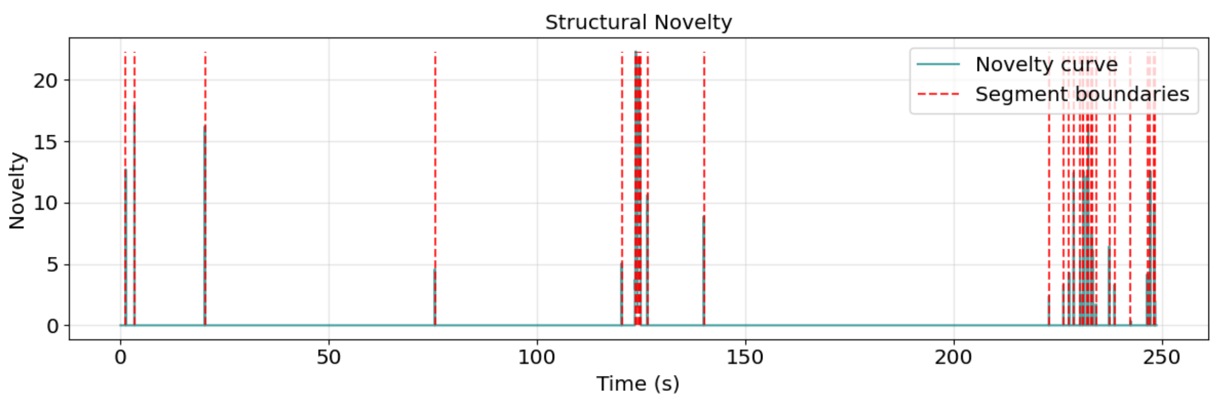
In [ ]:

```python
def get_segments_baseline(y, sr, hop_length=512):
    """
    Compute structural novelty curve and segment boundaries (baseline versic
    """
    # Step 1: Compute chroma
    chroma = librosa.feature.chroma_cqt(y=y, sr=sr, hop_length=hop_length)

    # Step 2: Build recurrence matrix (self-similarity)
    R = librosa.segment.recurrence_matrix(chroma, mode='affinity', sym=True)

    # Step 3: Gaussian blur for smoothing
    Rf = scipy.ndimage.gaussian_filter(R, sigma=1.0)

    # Step 4: Build kernel
    L = 16
    kernel = np.outer(np.concatenate([np.ones(L), -np.ones(L)]),
                      np.concatenate([-np.ones(L), np.ones(L)]))

    # Step 5: Compute novelty by 2D convolution along the diagonal
    novelty = np.zeros(Rf.shape[0])
    for i in range(L, Rf.shape[0]-L):
```

```
        novelty[i] = np.sum(Rf[i-L:i+L, i-L:i+L] * kernel)
    novelty = np.maximum(0, novelty)  # half-wave rectify

    # Step 6: Peak picking for boundaries
    peaks = librosa.util.peak_pick(novelty, pre_max=8, post_max=8,
                                   pre_avg=8, post_avg=8, delta=0.1, wait=10
    boundaries = librosa.frames_to_time(peaks, sr=sr, hop_length=hop_length)

    return boundaries, novelty
```

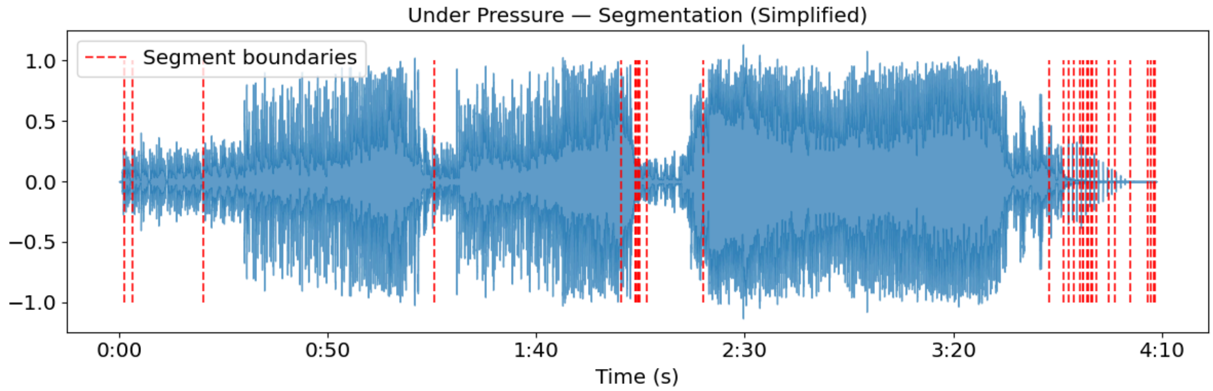
In [ ]:
```
def plot_segments(novelty, boundaries, sr, hop_length=512, title="Structural
    """
    Plot structural novelty curve and segment boundaries.
    """
    times = librosa.frames_to_time(np.arange(len(novelty)), sr=sr, hop_lengt

    plt.figure()

    plt.plot(times, novelty, color='teal', alpha=0.7, label='Novelty curve')
    plt.vlines(boundaries, 0, np.max(novelty), color='r', linestyle='--', al

    plt.title(title)
    plt.xlabel("Time (s)")
    plt.ylabel("Novelty")
    plt.legend()
    plt.grid(alpha=0.3)
    plt.tight_layout()
    plt.show()
```

In [ ]:
```
boundaries, novelty = get_segments_baseline(y_under_pressure, sr)
plot_segments(novelty, boundaries, sr)
```



In [ ]:
```
def plot_segments_over_waveform(y, sr, boundary_times, title="Structural Seg
    plt.figure(figsize=(12, 4))
    librosa.display.waveshow(y, sr=sr, alpha=0.7)
    plt.vlines(boundary_times, ymin=-1, ymax=1,
               color='r', linestyle='--', alpha=0.8, label='Segment boundari
    plt.title(title)
    plt.xlabel("Time (s)")
    plt.legend()
    plt.tight_layout()
    plt.show()
```

In [ ]:
```
plot_segments_over_waveform(y_under_pressure, sr, boundaries, title="Under P
```



In [ ]:
```
"""
Run all the code and all three songs (extend to more if we add them), store
"""
print("Starting feature extraction for all songs...")

# All songs
audio_files = [
    ('Under Pressure', y_under_pressure),
    ('Billie Jean', y_billie_jean),
    ('Get Lucky', y_get_lucky)
]

song_library = []

# Loop through each song and extract all features
for name, y in audio_files:
    print(f"\nProcessing: {name}...")

    # 1. Tempo and Beats
    tempo, beat_times = get_tempo_baseline(y, sr)

    # 2. Downbeats
    downbeat_times = get_downbeats_baseline(beat_times)

    # 3. Key
    key, _ = get_key(y, sr)

    # 4. Energy (RMS)
    energy_values, energy_times = get_energy_baseline(y, sr)

    # 5. Spectral Flux
    flux_times, flux_values = get_spectral_flux_baseline(y, sr)

    # 6. Segmentation
    segment_boundaries, novelty_curve = get_segments_baseline(y, sr)

    # Create the dictionary for this song
    song_data = {
        'name': name,
        'y': y,
        'tempo': tempo,
```

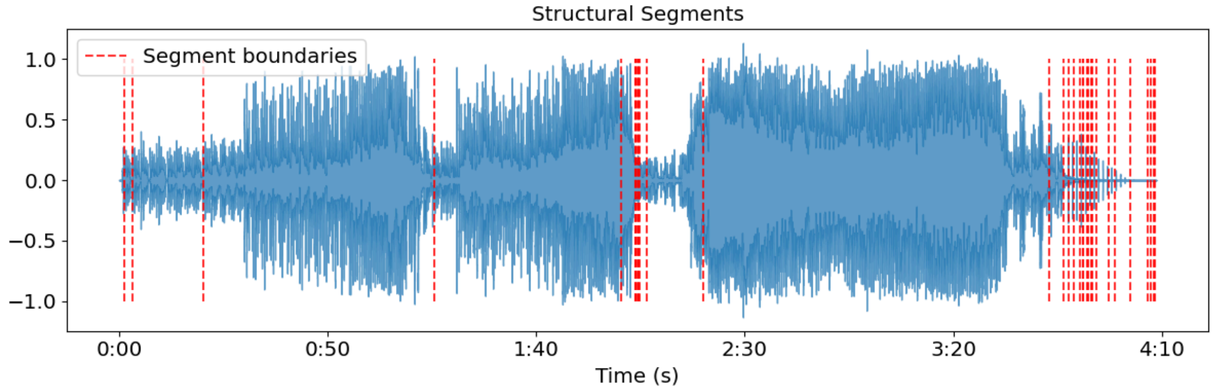
```python
        'beat_times': beat_times,
        'downbeat_times': downbeat_times,
        'key': key,
        'energy_values': energy_values,
        'energy_times': energy_times,
        'flux_values': flux_values,
        'flux_times': flux_times,
        'segment_boundaries': segment_boundaries,
        'novelty_curve': novelty_curve
    }

    song_library.append(song_data)

print("\nFeature extraction complete!")


# Save
filename = 'song_library.pkl'
with open(filename, 'wb') as f:
    pickle.dump(song_library, f)
```

```
Starting feature extraction for all songs...

Processing: Under Pressure...

Processing: Billie Jean...

Processing: Get Lucky...

Feature extraction complete!
```

In [ ]:

```python
"""
If you have the song_library file, you can use this to load all the data so
Could be useful as the segmentation takes about a minute or two (which is nc
"""

filename = 'song_library.pkl'

# Open the file in 'read-binary' (rb) mode and load the data
with open(filename, 'rb') as f:
    loaded_song_library = pickle.load(f)

print(f"Successfully loaded {len(loaded_song_library)} songs from {filename}

# E.g. use like this
song_a = loaded_song_library[0]
print(f"\nLoaded song name: {song_a['name']}")
print(f"Loaded song tempo: {song_a['tempo']}")

plot_segments_over_waveform(song_a['y'], sr, song_a['segment_boundaries'])
```

```
Successfully loaded 3 songs from song_library.pkl

Loaded song name: Under Pressure
Loaded song tempo: 114.84375
```



2. **Tempo match & alignment (Bailin):** time-stretch song B to A's BPM, align downbeats, find overlap window

In [ ]:
```
import numpy as np
import librosa

def local_tempo(y, sr, center_s, window_s=12.0):
    """Median of tempogram peak tempi in a window around center_s."""
    a = max(0, int((center_s - window_s/2) * sr))
    b = min(len(y), int((center_s + window_s/2) * sr))
    y_win = y[a:b]
    onset = librosa.onset.onset_strength(y=y_win, sr=sr)
    if len(onset) < 4:
        t, _ = librosa.beat.beat_track(y=y_win, sr=sr)
        return float(t)
    tg = librosa.feature.tempogram(onset_envelope=onset, sr=sr)
    tempi = librosa.tempo_frequencies(tg.shape[0], sr=sr)
    curve = tempi[np.argmax(tg, axis=0)]
    return float(np.median(curve))

def match_tempo_B_to_A_local(yA, yB, sr, tA_center_s, tB_center_s=0.0, clamp
    """Stretch B so its local tempo near tB_center_s matches A near tA_cente
    tempoA = local_tempo(yA, sr, center_s=tA_center_s)
    tempoB = local_tempo(yB, sr, center_s=tB_center_s)
    raw = tempoA / max(tempoB, 1e-6)
    # optional comfort clamp to reduce artifacts
    if clamp:
        raw = float(np.clip(raw, clamp[0], clamp[1]))
    return librosa.effects.time_stretch(yB, rate=raw), raw, tempoA, tempoB
```

In [ ]:
```
def start_time_A_20th_last_beat(beatsA, k=20):
    """
    beatsA: 1D np.array of beat times (seconds) for Track A
    k:      how many beats before the end (default 20)
    """
    if beatsA is None or len(beatsA) == 0:
        raise ValueError("No beats found for Track A.")
    if len(beatsA) <= k:
        return float(beatsA[0])
    return float(beatsA[-k])
```

```python
def nearest_downbeat_at_or_before(t, downbeats, tol=0.08):
    """
    Return nearest downbeat <= t within 'tol' seconds; else None.
    """
    if downbeats is None or len(downbeats) == 0:
        return None
    idx = np.searchsorted(downbeats, t, side="right") - 1
    if idx < 0:
        return None
    cand = float(downbeats[idx])
    return cand if (t - cand) <= tol else None

def start_time_A_20th_last_with_downbeat(beatsA, downbeatsA=None, k=20, snap
    """
    Pick the k-th last beat as the transition start and, if a downbeat is
    at/just before that moment (within snap_tol), snap to that downbeat.
    """
    tA = start_time_A_20th_last_beat(beatsA, k=k)
    db = nearest_downbeat_at_or_before(tA, downbeatsA, tol=snap_tol)
    return float(db) if db is not None else float(tA)

def split_track_A_for_transition(yA, sr, start_time_A, overlap_beats, beatsA
    """
    Split Track A around the chosen transition start.

    Returns:
      A_pre      : samples before the transition start
      A_overlap  : samples during the overlap window (length = overlap_beats
      A_after    : samples after the overlap window
      end_time_A : end time (seconds) of the overlap window on A
    """
    # find beat index at/after start_time_A
    i0 = np.searchsorted(beatsA, start_time_A)
    # end index = i0 + overlap_beats (clamped)
    i1 = min(i0 + overlap_beats, len(beatsA) - 1)

    s0 = int(round(start_time_A * sr))
    s1 = int(round(float(beatsA[i1])   * sr))
    s0 = max(0, min(s0, len(yA)))
    s1 = max(s0, min(s1, len(yA)))

    A_pre     = yA[:s0]
    A_overlap = yA[s0:s1]
    A_after   = yA[s1:]
    return A_pre, A_overlap, A_after, float(beatsA[i1])
```

In [ ]:

```python
# ---------- ENERGY MATCH + EQUAL-POWER CROSSFADE ----------

def _rms(x: np.ndarray) -> float:
    return float(np.sqrt(np.mean(np.square(x)) + 1e-12))

def loudness_match_gain(A_overlap: np.ndarray, B_overlap: np.ndarray, sr: in
    """
    Compute a gain to scale B so its loudness near the seam matches A.
    Uses the last 'ref' window of A and the first 'ref' window of B.
    """
```

```python
    if len(A_overlap) == 0 or len(B_overlap) == 0:
        return 1.0
    ref_samples = int(min(max_ref_seconds, 0.5 * len(A_overlap) / sr) * sr)
    ref_samples = max(ref_samples, int(0.25 * sr))  # ensure >= ~250 ms

    A_ref = A_overlap[-ref_samples:] if len(A_overlap) >= ref_samples else A
    B_ref = B_overlap[:ref_samples]  if len(B_overlap) >= ref_samples else B

    rms_A = _rms(A_ref)
    rms_B = _rms(B_ref)
    return (rms_A / max(rms_B, 1e-9))

def equal_power_crossfade(A_overlap: np.ndarray, B_overlap: np.ndarray) -> n
    """
    Apply an equal-power crossfade (sin/cos law) over the overlap.
    Inputs must be the same length; returns the mixed overlap.
    """
    n = min(len(A_overlap), len(B_overlap))
    if n == 0:
        return np.zeros(0, dtype=np.float32)
    # trim/pad to same length
    a = A_overlap[:n]
    b = B_overlap[:n]
    t = np.linspace(0.0, 1.0, n, dtype=np.float32)
    gA = np.cos(0.5 * np.pi * t)   # 1 -> 0
    gB = np.sin(0.5 * np.pi * t)   # 0 -> 1
    return gA * a + gB * b

def energy_match_and_crossfade(A_overlap: np.ndarray, B_overlap: np.ndarray,
    """
    Scales B to match A's loudness near the seam, then equal-power crossfade
    """
    # 1) loudness match B to A (near the join)
    gain_B = loudness_match_gain(A_overlap, B_overlap, sr)
    B_matched = B_overlap * gain_B
    # 2) equal-power crossfade
    return equal_power_crossfade(A_overlap, B_matched)
```

In [ ]:

```python
# ---------- KEY / PITCH HELPERS ----------

_KEY_NAMES = ['C','C#','D','D#','E','F','F#','G','G#','A','A#','B']

_KEY_NAMES_MAP = {name: i for i, name in enumerate(_KEY_NAMES)}

def format_key(tonic: int, mode: str) -> str:
    return f"{_KEY_NAMES[int(tonic) % 12]} {mode}"

def semitone_diff_to_match(
    tonic_src: int, mode_src: str,
    tonic_tgt: int, mode_tgt: str,
    prefer_same_mode: bool = True
) -> int:
    """
    Smallest signed semitone shift to move src key center to tgt key center.
    If prefer_same_mode and modes match, just align tonics directly.
    If modes differ, still align pitch class (keeps harmonic proximity simpl
```

```
    Returned range is [-6, +6].
    """
    diff = (int(tonic_tgt) - int(tonic_src)) % 12
    if diff > 6: diff -= 12
    return int(diff)

def maybe_pitch_shift_B_to_A(
    yB: np.ndarray, sr: int,
    keyA_tonic: int, keyA_mode: str,
    keyB_tonic: int, keyB_mode: str,
    max_semitones: int = 3,       # clamp to avoid artifacts
    prefer_same_mode: bool = True
):
    """
    Compute nearest semitone shift to align B's key center to A's.
    Shift only if |n_steps| <= max_semitones.
    Returns: (yB_shifted, n_steps_applied, keyA_str, keyB_str)
    """
    keyA_str = format_key(keyA_tonic, keyA_mode)
    keyB_str = format_key(keyB_tonic, keyB_mode)

    n_steps = semitone_diff_to_match(keyB_tonic, keyB_mode, keyA_tonic, keyA
    if abs(n_steps) > max_semitones:
        # too large: skip to avoid quality loss
        return yB, 0, keyA_str, keyB_str

    if n_steps == 0:
        return yB, 0, keyA_str, keyB_str

    yB_shifted = librosa.effects.pitch_shift(yB, sr=sr, n_steps=float(n_step
    return yB_shifted, int(n_steps), keyA_str, keyB_str
```

In [ ]:
```
# 1. MATCH TEMPO
# ratio = get_tempo_baseline(y_A) / get_tempo_baseline(y_B)
# librosa.effects.time_stretch(y_A, ratio)

# 2. START NEW SONG AT 20TH LAST BEAT OF FIRST SONG
# 20

# 3. MATCH ENERGY
# crossfade A into B


# 4. MATCH PITCH
# (EITHER LIBROSA)
# https://librosa.org/doc/0.11.0/generated/librosa.effects.pitch_shift.html

# (OR TORCH)
# https://pypi.org/project/torch-pitch-shift/#
# https://kentonishi.com/torch-pitch-shift/usage/
```

3. **Transition scoring (Arvid):** generate outputs, evaluation.

In [ ]:
```
# Compare transition positions between A and B
# Rate each position by beat offset/key/energy
# Pick best position, match loudness, apply crossfade, save to WAV/MP3
```

In [ ]:
```
def parse_key_string(key_str):
    """
    Parses a key string into tonic (INT) and mode (STR)
    """
    key_str = key_str.strip()
    if key_str.endswith('m'):
        tonic_str = key_str[:-1]
        mode = 'minor'
    else:
        tonic_str = key_str
        mode = 'major'

    tonic_int = _KEY_NAMES_MAP.get(tonic_str, 0)
    return tonic_int, mode
```

In [ ]:
```
def candidate_transitions(songA, songB, sr, overlap_beats=8, num_downbeats=5
    """
    Generate candidate transition positions between A and B.
    Returns: List of tuples (tA_start, tB_start) of transition times
    """
    beatsA = songA['beat_times']
    beatsB = songB['beat_times']
    downbeats_A = songA['downbeat_times']
    downbeats_B = songB['downbeat_times']

    num_A = min(num_downbeats, len(downbeats_A)) # number of downbeats to ta
    num_B = min(num_downbeats, len(downbeats_B)) # number of downbeats to ta

    # Combine last num_A downbeats of A with first num_B downbeats of B
    # Each pair (tA, tB) is a possible transition point
    candidates = []
    for tA in downbeats_A[-num_A:]:
        for tB in downbeats_B[:num_B]:
            candidates.append((tA, tB))
    return candidates
```

In [ ]:
```
def rate_transition(songA, songB, tA, tB, sr):

    # Beat offset
    beat_diff = abs((tA % 1.0) - (tB % 1.0))

    # Key distance
    if songA['key'] == songB['key']:
      key_diff = 0   # same key
    else:
      key_diff = 1   # different key

    # Energy match
    tA_idx = np.argmin(abs(songA['energy_times'] - tA))
    tB_idx = np.argmin(abs(songB['energy_times'] - tB))
```

```python
    eA = songA['energy_values'][tA_idx]
    eB = songB['energy_values'][tB_idx]
    energy_diff = abs(eA - eB)

    # Weighted score
    score = beat_diff * 3 + key_diff * 2 + energy_diff

    return score
```

In [ ]:
```python
def find_best_transition(songA, songB, sr, num_downbeats=5):
    """
    Evaluate candidate transitions and return the best one.
    """
    candidates = candidate_transitions(songA, songB, sr, num_downbeats=num_d

    scored = []
    for (tA, tB) in candidates:
        score = rate_transition(songA, songB, tA, tB, sr)
        scored.append((score, tA, tB))

    # Sort candidates by score
    scored.sort(key=lambda x: x[0])

    # Choose the best one
    best_score, best_tA, best_tB = scored[0]

    return best_tA, best_tB
```

In [ ]:
```python
def make_transition(songA, songB, sr, overlap_beats=8):
    print(f"Starting transition: {songA['name']} & {songB['name']}")

    yA = np.asarray(songA['y'])
    yB = np.asarray(songB['y'])

    # Find best (tA, tB) anchor points
    best_tA, best_tB = find_best_transition(songA, songB, sr)
    print(f"Found best anchor points: tA={best_tA:.2f}s, tB={best_tB:.2f}s")

    # Match Tempo
    yB_stretched, stretch_rate, tempoA, tempoB = match_tempo_B_to_A_local(
        yA, yB, sr, tA_center_s=best_tA, tB_center_s=best_tB
    )
    print(f"Target Tempo (A): {tempoA:.1f} BPM, Original Tempo (B): {tempoB:

    # Pitch match
    keyA_tonic, keyA_mode = parse_key_string(songA['key'])
    keyB_tonic, keyB_mode = parse_key_string(songB['key'])
    yB_final, n_steps, keyA_str, keyB_str = maybe_pitch_shift_B_to_A(
        yB_stretched, sr, keyA_tonic, keyA_mode, keyB_tonic, keyB_mode
    )

    # Split A into pre-overlap and overlap sections
    A_pre, A_overlap, _, _ = split_track_A_for_transition(
        yA, sr, best_tA, overlap_beats, songA['beat_times']
    )
```

```python
    # Compute B overlap
    start_B_new_s = best_tB / stretch_rate
    start_B_sample = int(round(start_B_new_s * sr))
    overlap_samples = len(A_overlap)
    end_B_sample = start_B_sample + overlap_samples
    B_overlap = yB_final[start_B_sample:end_B_sample]
    B_post = yB_final[end_B_sample:]

    # Crossfade
    mixed_overlap = energy_match_and_crossfade(A_overlap, B_overlap, sr)

    # Concatenate final mix
    full_mix = np.concatenate([A_pre, mixed_overlap, B_post])
    print("Transition complete!")

    return full_mix
```

In [ ]:
```python
from scipy.io.wavfile import write

def save_mix(y, sr, filename="mix.wav"):
    y16 = np.int16(y / np.max(np.abs(y)) * 32767)
    write(filename, sr, y16)
    print(f"Saved mix to {filename}")

song_A = loaded_song_library[0]
song_B = loaded_song_library[1]

mix = make_transition(song_A, song_B, sr, overlap_beats=16)
save_mix(mix, sr, "final_output.wav")
```

```
Starting transition: Under Pressure & Billie Jean
Found best anchor points: tA=232.68s, tB=9.50s
```

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
/tmp/ipython-input-2012828397.py in <cell line: 0>()
      9 song_B = loaded_song_library[1]
     10 
---> 11 mix = make_transition(song_A, song_B, sr, overlap_beats=16)
     12 save_mix(mix, sr, "final_output.wav")

/tmp/ipython-input-1834794015.py in make_transition(songA, songB, sr, overla
p_beats)
     10 
     11     # Match Tempo
---> 12     yB_stretched, stretch_rate, tempoA, tempoB = match_tempo_B_to_A_
local(
     13         yA, yB, sr, tA_center_s=best_tA, tB_center_s=best_tB
     14     )

/tmp/ipython-input-2801542903.py in match_tempo_B_to_A_local(yA, yB, sr, tA_
center_s, tB_center_s, clamp)
     24     if clamp:
     25         raw = float(np.clip(raw, clamp[0], clamp[1]))
---> 26     return librosa.effects.time_stretch(yB, rate=raw), raw, tempoA,
tempoB

/usr/local/lib/python3.12/dist-packages/librosa/effects.py in time_stretch
(y, rate, **kwargs)
    381 
    382     # Stretch by phase vocoding
--> 383     stft_stretch = core.phase_vocoder(
    384         stft,
    385         rate=rate,

/usr/local/lib/python3.12/dist-packages/librosa/core/spectrum.py in phase_vo
coder(D, rate, hop_length, n_fft)
   1434         hop_length = int(n_fft // 4)
   1435 
-> 1436     time_steps = np.arange(0, D.shape[-1], rate, dtype=np.float64)
   1437 
   1438     # Create an empty output array

ValueError: arange: cannot compute length
```

4. **Evaluation & integration (Matei):** evaluation, logging, report

In [ ]:

Resources: https://asmp-eurasipjournals.springeropen.com/articles/10.1186/s13636-018-0134-8