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
from scipy.io.wavfile import write
```

In [42]:
```
# 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 [43]:
```
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 [44]:
```
# 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)
```

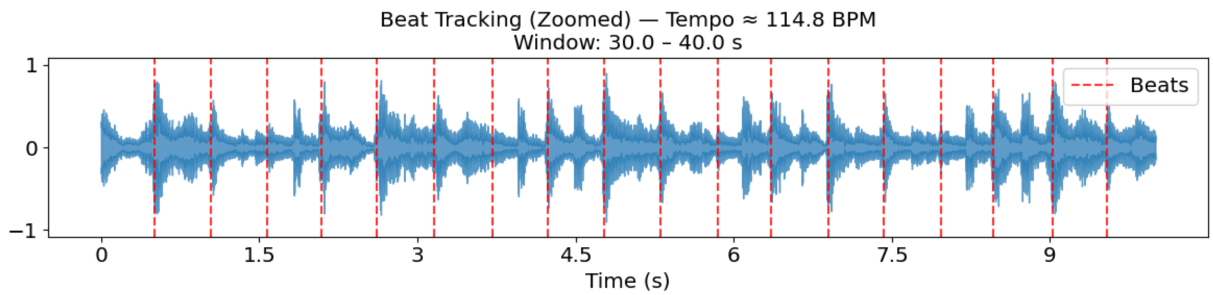
In [45]:
```python
def get_tempo_baseline(y, sr):
    """
    Compute the tempo and beat locations. Returns the global tempo over the
    song and the location of beats.
    """
    tempo, beat_frames = librosa.beat.beat_track(y=y, sr=sr)
    beat_times = librosa.frames_to_time(beat_frames, sr=sr)
    return tempo[0], beat_times
```

In [46]:
```python
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
```

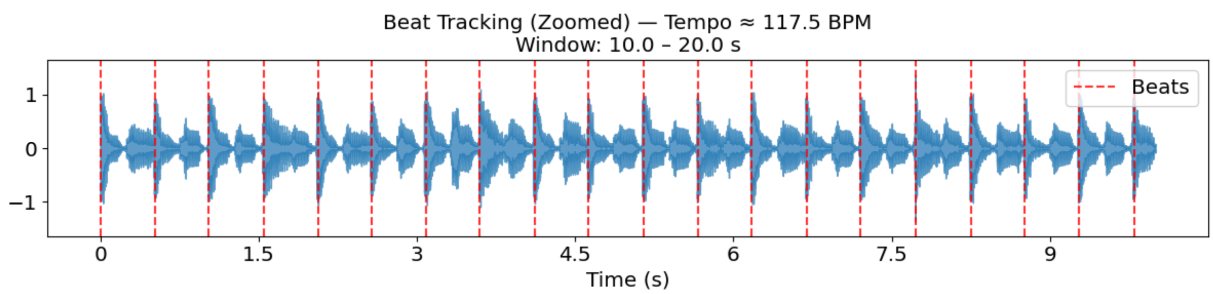
```
Tempo baseline: 114.8 BPM, according to google should be ~112
Tempo baseline: 117.5 BPM, according to google should be ~117
Tempo baseline: 114.8 BPM, according to google should be ~116
```

In [47]:
```python
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()
```

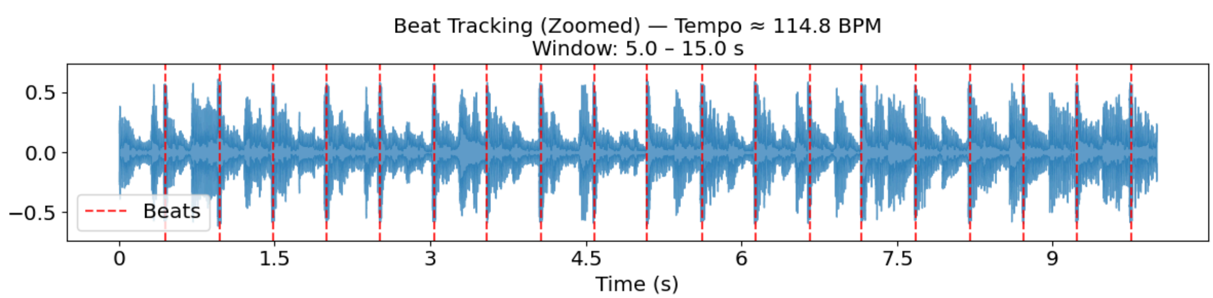
In [48]:
```python
plot_beats_zoom(y_under_pressure, sr, beats_lib_1, tempo_lib_1, start_time=3
```



In [49]:
```
plot_beats_zoom(y_billie_jean, sr, beats_lib_2, tempo_lib_2, start_time=10,
```



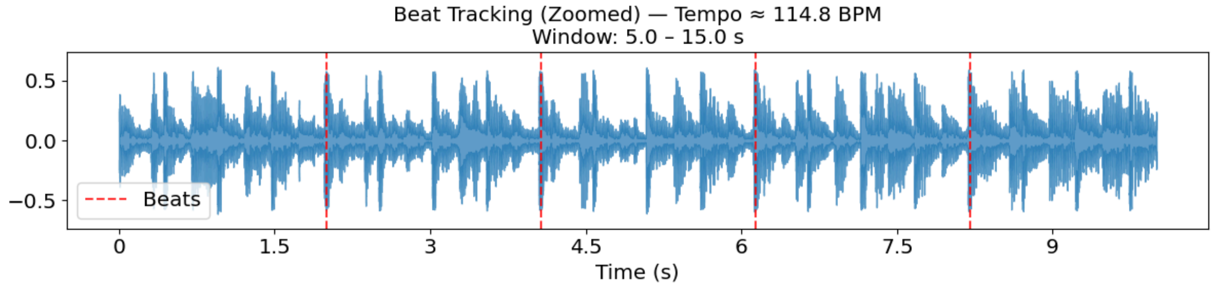
In [50]:
```
plot_beats_zoom(y_get_lucky, sr, beats_lib_3, tempo_lib_3, start_time=5, dur
```



In [51]:
```
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 [52]:
```
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 [53]:
```
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))
```

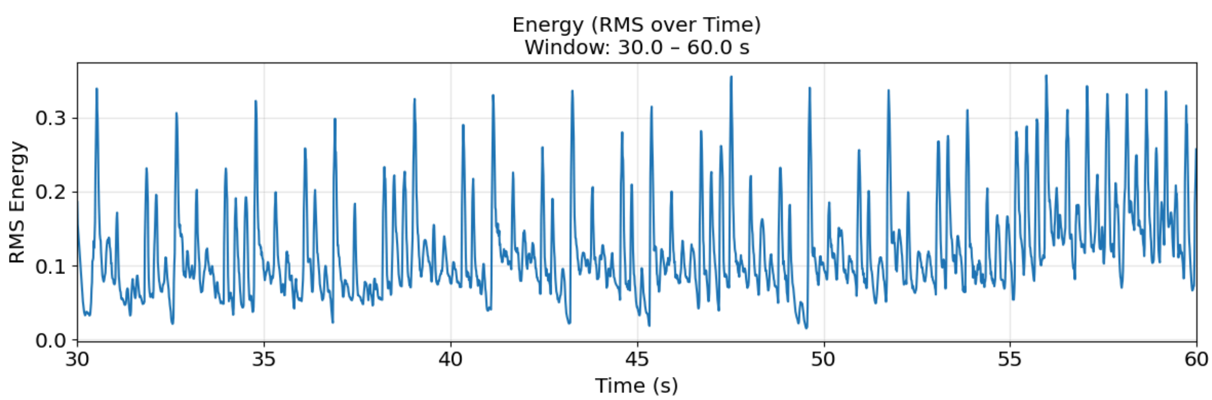
In [54]:
```
# Key
key_pap, conf_pap = get_key(y_under_pressure, sr)
print(f"Key baseline Under Pressure: {key_pap} ({conf_pap:.2f}), according t

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 [55]:
```
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 [56]:
```
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 [57]:
```
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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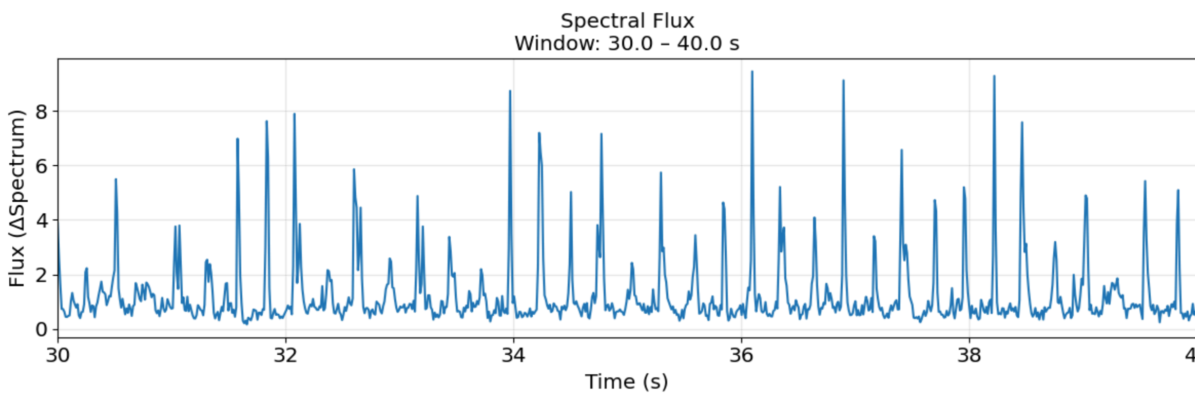
In [58]:
```
def get_spectral_flux_baseline(y, sr):
    """
    Compute the spectral flux using a melspectrogram.
    """
    # Use Melflux ODF
    onset_env = librosa.onset.onset_strength(y=y, sr=sr, feature=librosa.fea
    times = librosa.times_like(onset_env, sr=sr)
    return onset_env, times
```

In [59]:
```
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 [60]:
```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)
```

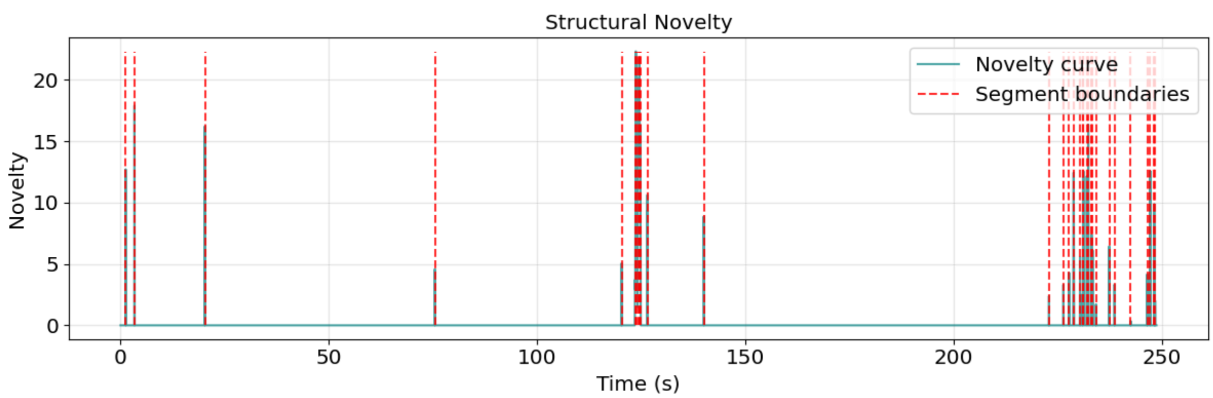


In [61]:
```python
def get_segments_baseline(y, sr, hop_length=512):
    """
    Compute structural novelty curve and segment boundaries (baseline versic
    """
    # Step 1: Compute chroma
    chroma = librosa.feature.chroma_cqt(y=y, sr=sr, hop_length=hop_length)

    # 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
```

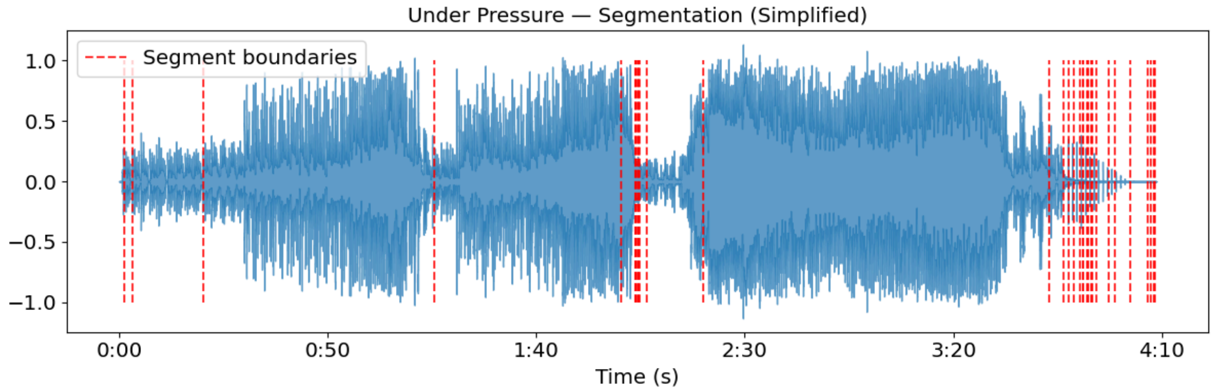
In [62]:
```
def plot_segments(novelty, boundaries, sr, hop_length=512, title="Structural
    """
    Plot structural novelty curve and segment boundaries.
    """
    times = librosa.frames_to_time(np.arange(len(novelty)), sr=sr, hop_lengt

    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 [63]:
```
boundaries, novelty = get_segments_baseline(y_under_pressure, sr)
plot_segments(novelty, boundaries, sr)
```



In [64]:
```
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 [65]:
```
plot_segments_over_waveform(y_under_pressure, sr, boundaries, title="Under P
```



In [66]:
```
"""
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,
```

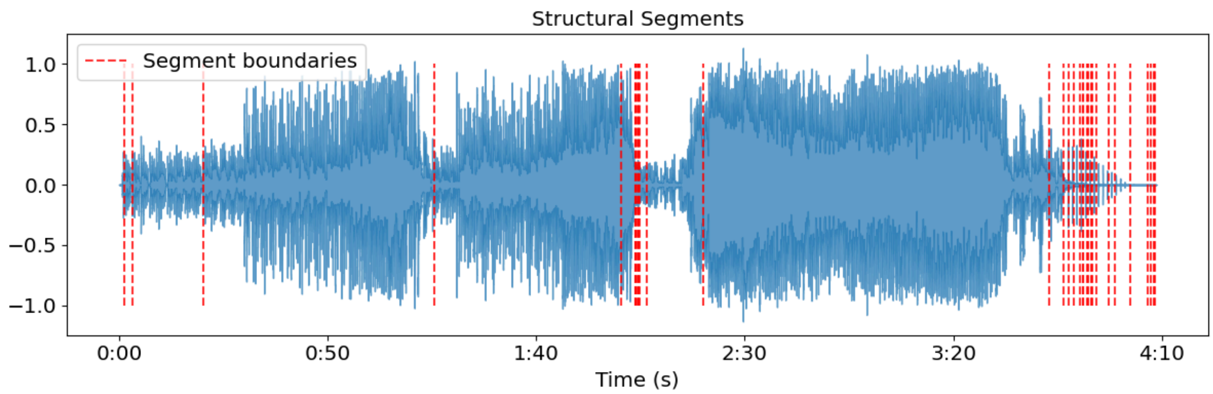
```python
        'beat_times': beat_times,
        'downbeat_times': downbeat_times,
        'key': key,
        'energy_values': energy_values,
        'energy_times': energy_times,
        'flux_values': flux_values,
        'flux_times': flux_times,
        'segment_boundaries': segment_boundaries,
        '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 [67]:

```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 [ ]:
```
"""

def local_tempo(y, sr, center_s, window_s=12.0):

    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 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))
    if b <= a:
        return float('nan')

    y_win = y[a:b]

    onset = librosa.onset.onset_strength(y=y_win, sr=sr)
    if onset is None or len(onset) < 4:
        t, _ = librosa.beat.beat_track(y=y_win, sr=sr)
        return float(t) if np.isfinite(t) and t > 0 else float('nan')

    tg = librosa.feature.tempogram(onset_envelope=onset, sr=sr)
    if tg.size == 0:
        return float('nan')

    tempi = librosa.tempo_frequencies(tg.shape[0], sr=sr)
    curve = tempi[np.argmax(tg, axis=0)]
```

```python
    val = float(np.median(curve))
    return val if np.isfinite(val) and val > 0 else float('nan')
```

In [69]:
```python
# 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])

# 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, sn
#     """
#     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, beat
#     """
#     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_bea
#       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)))
```

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

In [70]:
```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:
#     """
#     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.
#     """
#     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
#     B_ref = B_overlap[:ref_samples]  if len(B_overlap) >= ref_samples else

#     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, sr:
    n = min(len(A_overlap), len(B_overlap))
    if n == 0:
        return np.zeros(0, dtype=np.float32)

    a = A_overlap[:n].astype(np.float32, copy=False)
    b = B_overlap[:n].astype(np.float32, copy=False)

    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
    mixed = gA * a + gB * b

    def _rms(x): return float(np.sqrt(np.mean(x * x) + 1e-12))
    ref = max(int(0.25 * sr), min(int(0.5 * n), int(0.5 * sr)))
    A_end_rms   = _rms(a[-ref:]) if len(a) >= ref else _rms(a)
    B_start_rms = _rms(b[:ref])  if len(b) >= ref else _rms(b)

    target = A_end_rms + (B_start_rms - A_end_rms) * t
    headroom = 10 ** (-0.7 / 20.0)
    lo = min(A_end_rms, B_start_rms)
    hi = max(A_end_rms, B_start_rms)
    target = np.clip(target, lo, hi) * headroom

    win = max(1, int(0.045 * sr))
    if win > 1:
        hann = np.hanning(win).astype(np.float32); hann /= hann.sum()
        cur = np.sqrt(np.convolve(mixed * mixed, hann, mode="same") + 1e-12)
    else:
```

```python
        cur = np.full(n, _rms(mixed), dtype=np.float32)

    eps = 1e-9
    gain = target / np.maximum(cur, eps)
    gain = np.clip(gain, 0.70, 10 ** (0.8 / 20.0))

    alpha = 0.12
    g = np.empty_like(gain)
    acc = gain[0]
    for i in range(n):
        acc = alpha * gain[i] + (1 - alpha) * acc
        g[i] = acc
    acc = g[-1]
    for i in range(n - 1, -1, -1):
        acc = alpha * g[i] + (1 - alpha) * acc
        g[i] = acc

    return (mixed * g).astype(np.float32, copy=False)

# def energy_match_and_crossfade(A_overlap: np.ndarray, B_overlap: np.ndarra
#     gain_B = loudness_match_gain(A_overlap, B_overlap, sr)
#     B_matched = B_overlap * gain_B
#     return equal_power_crossfade(A_overlap, B_matched)
```

In [71]:
```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 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,
    prefer_same_mode: bool = True
):
    """
```

```python
    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 [ ]:

```python
def loudness_match_gain_A_to_B(A_overlap: np.ndarray, B_overlap: np.ndarray,
    """
    Compute a gain to scale **A** so its loudness near the seam matches **B*
    Uses the last window of A and the first window of B. B is left untouched
    """
    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))

    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

    try:
        rms_A = _rms(A_ref)
        rms_B = _rms(B_ref)
    except NameError:
        def _rms(x: np.ndarray) -> float:
            return float(np.sqrt(np.mean(np.square(x)) + 1e-12))
        rms_A = _rms(A_ref)
        rms_B = _rms(B_ref)

    return min(rms_B / max(rms_A, 1e-9), 1.0)


def pitch_shift_A_to_B(
    yA: np.ndarray, sr: int,
    keyA_tonic: int, keyA_mode: str,
    keyB_tonic: int, keyB_mode: str,
    max_semitones: int = 3,
    prefer_same_mode: bool = True
):
    n_steps = semitone_diff_to_match(keyA_tonic, keyA_mode, keyB_tonic, keyB
    if abs(n_steps) == 0 or abs(n_steps) > max_semitones:
        return yA, 0
```

```
    yA_shifted = librosa.effects.pitch_shift(yA, sr=sr, n_steps=float(n_step
    return yA_shifted, int(n_steps)
```

In [73]:
```
# 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 [74]:
```
# 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 [75]:
```
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 [76]:
```
def candidate_transitions(songA, songB, sr, overlap_beats=8, num_downbeats=5
    """
    Generate candidate transition positions between A and B.
    Prioritizes structural intros/outros if segmentation is available.
    Falls back to first/last N downbeats if structural segments are empty.

    Returns: List of tuples (tA_start, tB_start) of transition times
    """
    downbeats_A = songA['downbeat_times']
    downbeats_B = songB['downbeat_times']
```

```
    candidates_A = []
    candidates_B = []

    if 'segment_boundaries' in songA and len(songA['segment_boundaries']) >
        outro_start_time = songA['segment_boundaries'][-1]
        candidates_A = downbeats_A[downbeats_A >= outro_start_time]

    if 'segment_boundaries' in songB and len(songB['segment_boundaries']) >
        intro_end_time = songB['segment_boundaries'][0]
        candidates_B = downbeats_B[downbeats_B < intro_end_time]


    if len(candidates_A) == 0:
        print(f"Warning: No structural outro downbeats found for {songA['nam
        num_A = min(num_downbeats, len(downbeats_A))
        candidates_A = downbeats_A[-num_A:]


    if len(candidates_B) == 0:
        print(f"Warning: No structural intro downbeats found for {songB['nam
        num_B = min(num_downbeats, len(downbeats_B))
        candidates_B = downbeats_B[:num_B]

    candidates = []
    for tA in candidates_A:
        for tB in candidates_B:
            candidates.append((tA, tB))

    return candidates
```

In [77]:
```
def rate_transition(songA, songB, tA, tB, sr, overlap_beats=16, silence_thre
    """
    Rates a transition based on key, energy, and rhythmic similarity (DTW).
    """
    beatsA = songA['beat_times']
    beatsB = songB['beat_times']

    tA_idx = np.argmin(abs(beatsA - tA))
    tB_idx = np.argmin(abs(beatsB - tB))

    if songA['key'] == songB['key']:
      key_diff = 0
    else:
      key_diff = 1

    # Find the end of the overlap window
    tA_end_idx = min(tA_idx + overlap_beats, len(beatsA) - 1)
    tB_end_idx = min(tB_idx + overlap_beats, len(beatsB) - 1)

    # Get the ODF (flux) times
    flux_times_A = songA['flux_times']
    flux_times_B = songB['flux_times']

    # Find the start/end times of the overlap in seconds
    tA_start_s = beatsA[tA_idx]
    tA_end_s   = beatsA[tA_end_idx]
```

```
    tB_start_s = beatsB[tB_idx]
    tB_end_s   = beatsB[tB_end_idx]

    # Find the ODF values within that time window
    odf_A_indices = (flux_times_A >= tA_start_s) & (flux_times_A < tA_end_s)
    odf_B_indices = (flux_times_B >= tB_start_s) & (flux_times_B < tB_end_s)

    odf_A_segment = songA['flux_values'][odf_A_indices]
    odf_B_segment = songB['flux_values'][odf_B_indices]

    if len(odf_A_segment) == 0 or len(odf_B_segment) == 0:
        return float('inf')

    # Normalize the ODF segments
    odf_A_norm = (odf_A_segment - np.mean(odf_A_segment)) / np.std(odf_A_seg
    odf_B_norm = (odf_B_segment - np.mean(odf_B_segment)) / np.std(odf_B_seg

    # Calculate rhythmic distance using DTW
    D, wp = librosa.sequence.dtw(X=odf_A_norm, Y=odf_B_norm, metric='euclide
    rhythmic_diff = D[wp[-1, 0], wp[-1, 1]] / len(wp)

    # Final Weighted Score
    score = (key_diff * 2) + (rhythmic_diff * 1.0)

    return score
```

In [78]:
```
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 [79]:
```
def make_transition(songA, songB, sr, overlap_beats=8):
    print(f"Starting transition A to B: {songA['name']} → {songB['name']}")

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

    # 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")
```

```
    # Get beat times
    beatsA = songA['beat_times']
    beatsB = songB['beat_times']

    # A
    iA0 = int(np.searchsorted(beatsA, best_tA))
    iA1 = min(iA0 + overlap_beats, len(beatsA) - 1)
    tA0 = float(best_tA)
    tA1 = float(beatsA[iA1])

    # B
    iB0 = int(np.searchsorted(beatsB, best_tB))
    iB1 = min(iB0 + overlap_beats, len(beatsB) - 1)
    tB0 = float(best_tB)
    tB1 = float(beatsB[iB1])

    # Slice audio
    sA0, sA1 = int(round(tA0 * sr)), int(round(tA1 * sr))
    sB0, sB1 = int(round(tB0 * sr)), int(round(tB1 * sr))
    A_pre      = yA[:sA0]
    A_overlap0 = yA[sA0:sA1]
    B_overlap  = yB[sB0:sB1]

    if len(A_overlap0) == 0 or len(B_overlap) == 0:
        print("Warning: empty overlap window")
        return np.concatenate([A_pre, yB[sB0:]])

    # Tempo-match A's overlap to B's overlap
    dur_A = len(A_overlap0) / sr
    dur_B = len(B_overlap)  / sr

    rate = (dur_A / max(dur_B, 1e-9))
    A_overlap = librosa.effects.time_stretch(A_overlap0, rate=float(rate))

    # Trim or pad A_overlap to match B_overlap length
    n = len(B_overlap)
    if len(A_overlap) > n:
        A_overlap = A_overlap[:n]
    elif len(A_overlap) < n:
        A_overlap = np.pad(A_overlap, (0, n - len(A_overlap)))

    # Pitch-shift A toward B
    keyA_tonic, keyA_mode = parse_key_string(songA['key'])
    keyB_tonic, keyB_mode = parse_key_string(songB['key'])
    A_overlap, n_steps = pitch_shift_A_to_B(
        A_overlap, sr, keyA_tonic, keyA_mode, keyB_tonic, keyB_mode
    )
    if n_steps != 0:
        print(f"Pitch-shifted A by {n_steps:+d} semitones toward B during ov

    # Loudness-match A to B
    gain_A = loudness_match_gain_A_to_B(A_overlap, B_overlap, sr)
    A_overlap_matched = A_overlap * gain_A

    # Equal-power crossfade
    #mixed_overlap = equal_power_crossfade(A_overlap_matched, B_overlap)
```

```
    mixed_overlap = equal_power_crossfade(A_overlap_matched, B_overlap, sr)

    # Final assembly
    B_post = yB[sB1:]
    full_mix = np.concatenate([A_pre, mixed_overlap, B_post])

    # Normalize to avoid clipping
    peak = np.max(np.abs(full_mix))
    if peak > 0:
        full_mix = 0.98 * (full_mix / peak)

    print("Transition complete (A morphed into B; B unchanged outside overla
    return full_mix
```

In [ ]:

```
def save_mix(y, sr, filename="mix.wav"):
    peak = np.max(np.abs(y)) + 1e-12
    y = 0.89 * (y / peak)
    y16 = np.int16(y * 32767)
    # 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[1]
song_B = loaded_song_library[2]

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

```
Starting transition A to B: Billie Jean → Get Lucky
Found best anchor points: tA=169.89s, tB=0.79s
Transition complete (A morphed into B; B unchanged outside overlap).
Saved mix to final_output.wav
```

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

In [ ]:

```
```

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