Multitrack Music Transformer

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Overview

Generate orchestral music

- of diverse instruments
- using a new compact representation
- with a multi-dimensional transformer

Demo

(Source: Vienna Mozart Orchestra)

Related Work (Transformers for Music Generation)

Model	Multitrack	Instrument control	Compound tokens	Generative modeling
REMI [5]				✓
MMM [10]	✓			✓
CP [6]			✓	✓
MusicBERT [15]	✓		✓	
FIGARO [11]	✓			✓
MMT (ours)	✓	✓	✓	✓

Huang and Yang, "Pop Music Transformer: Beat-based Modeling and Generation of Expressive Pop Piano Compositions," *Proc. MM*, 2020.
Ens and Pasquier, "MMM : Exploring Conditional Multi-Track Music Generation with the Transformer," *arXiv preprint arXiv:2008.06048*, 2020.
Hsiao et al., "Compound Word Transformer: Learning to Compose Full-Song Music over Dynamic Directed Hypergraphs," *Proc. AAAI*, 2023.
Zeng et al., "MusicBERT: Symbolic Music Understanding with Large-Scale Pre-Training," *Proc. Findings of ACL*, 2021.
von Rütte et al., "FIGARO: Controllable Music Generation using Learned and Expert Features," *Proc. ICLR*, 2023.

Representation

- We represent a music piece as a sequence of events

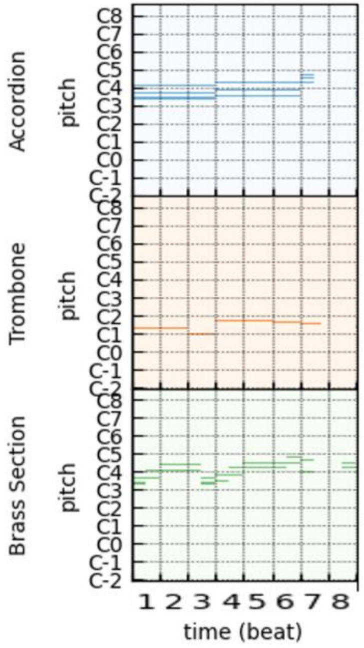
$$\mathbf{x} = (\mathbf{x}_1, \ldots, \mathbf{x}_n)$$

- Each event $\mathbf{x}_i$ is encoded as

$$\mathbf{x}_i = (\underbrace{x_i^{type}}_{\text{5 event types}}, \underbrace{x_i^{beat}, x_i^{position}, x_i^{pitch}, x_i^{duration}, x_i^{instrument}}_{\text{Specify note \& instrument information}})$$

5 event types
- Structural
  - Start of song
  - Start of notes
  - End of song
- Data
  - Instrument
  - Note

Representation (An Example)



Structural events

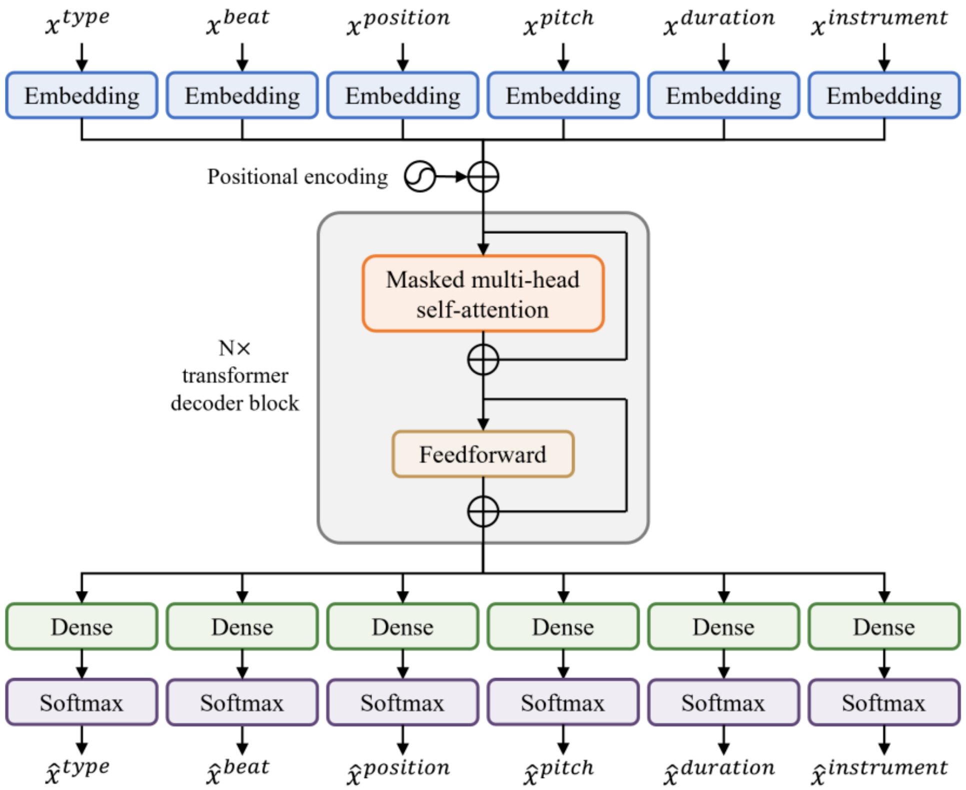
Instrument events

Note events

(0, 0, 0, 0, 0, 0)	Start of song
(1, 0, 0, 0, 0, 15)	Instrument: accordion
(1, 0, 0, 0, 0, 36)	Instrument: trombone
(1, 0, 0, 0, 0, 39)	Instrument: brasses
(2, 0, 0, 0, 0, 0)	Start of notes
(3, 1, 1, 41, 15, 36)	Note: beat=1, position=1, pitch=E2, duration=48, instrument=trombone
(3, 1, 1, 65, 4, 39)	Note: beat=1, position=1, pitch=E4, duration=12, instrument=brasses
(3, 1, 1, 65, 17, 15)	Note: beat=1, position=1, pitch=E4, duration=72, instrument=accordion
(3, 1, 1, 68, 4, 39)	Note: beat=1, position=1, pitch=G4, duration=12, instrument=brasses
(3, 1, 1, 68, 17, 15)	Note: beat=1, position=1, pitch=G4, duration=72, instrument=accordion
(3, 1, 1, 73, 17, 15)	Note: beat=1, position=1, pitch=C5, duration=72, instrument=accordion
(3, 1, 13, 68, 4, 39)	Note: beat=1, position=13, pitch=G4, duration=12, instrument=brasses
(3, 1, 13, 73, 4, 39)	Note: beat=1, position=13, pitch=C5, duration=12, instrument=brasses
(3, 2, 1, 73, 12, 39)	Note: beat=2, position=1, pitch=C5, duration=36, instrument=brasses
(3, 2, 1, 77, 12, 39)	Note: beat=2, position=1, pitch=E5, duration=36, instrument=brasses
...	...
(4, 0, 0, 0, 0, 0)	End of song

Multitrack Music Transformer

- A multi-dimensional decoder-only transformer model
  - Predict six fields *at the same time*
- Trained autoregressively
  - Predict the next event given past events
- At inference time, illegal values are assigned zero probabilities
  - Violate the ordering of structural events
  - Violate the hierarchical sorting of events



Three Sampling Modes

Unconditional generation

Input

```
(0, 0,  0,  0,  0,  0)  Start of song
(1, 0,  0,  0,  0, 15)  Instrument: accordion
(1, 0,  0,  0,  0, 36)  Instrument: trombone
(1, 0,  0,  0,  0, 39)  Instrument: brasses
(2, 0,  0,  0,  0,  0)  Start of notes
(3, 1,  1, 41, 15, 36)  Note: beat=1, position=1,  pitch=E2, duration=48, instrument=trombone
(3, 1,  1, 65,  4, 39)  Note: beat=1, position=1,  pitch=E4, duration=12, instrument=brasses
(3, 1,  1, 65, 17, 15)  Note: beat=1, position=1,  pitch=E4, duration=72, instrument=accordion
(3, 1,  1, 68,  4, 39)  Note: beat=1, position=1,  pitch=G4, duration=12, instrument=brasses
(3, 1,  1, 68, 17, 15)  Note: beat=1, position=1,  pitch=G4, duration=72, instrument=accordion
(3, 1,  1, 73, 17, 15)  Note: beat=1, position=1,  pitch=C5, duration=72, instrument=accordion
(3, 1, 13, 68,  4, 39)  Note: beat=1, position=13, pitch=G4, duration=12, instrument=brasses
(3, 1, 13, 73,  4, 39)  Note: beat=1, position=13, pitch=C5, duration=12, instrument=brasses
(3, 2,  1, 73, 12, 39)  Note: beat=2, position=1,  pitch=C5, duration=36, instrument=brasses
(3, 2,  1, 77, 12, 39)  Note: beat=2, position=1,  pitch=E5, duration=36, instrument=brasses
          ...           ...
(4, 0,  0,  0,  0,  0)  End of song
```

Only need to train ONE model!

Instrument-informed generation

Input

```
(0, 0,  0,  0,  0,  0)  Start of song
(1, 0,  0,  0,  0, 15)  Instrument: accordion
(1, 0,  0,  0,  0, 36)  Instrument: trombone
(1, 0,  0,  0,  0, 39)  Instrument: brasses
(2, 0,  0,  0,  0,  0)  Start of notes
(3, 1,  1, 41, 15, 36)  Note: beat=1, position=1,  pitch=E2, duration=48, instrument=trombone
(3, 1,  1, 65,  4, 39)  Note: beat=1, position=1,  pitch=E4, duration=12, instrument=brasses
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(3, 1, 13, 73,  4, 39)  Note: beat=1, position=13, pitch=C5, duration=12, instrument=brasses
(3, 2,  1, 73, 12, 39)  Note: beat=2, position=1,  pitch=C5, duration=36, instrument=brasses
(3, 2,  1, 77, 12, 39)  Note: beat=2, position=1,  pitch=E5, duration=36, instrument=brasses
          ...           ...
(4, 0,  0,  0,  0,  0)  End of song
```

N-beat continuation

Input

```
(0, 0,  0,  0,  0,  0)  Start of song
(1, 0,  0,  0,  0, 15)  Instrument: accordion
(1, 0,  0,  0,  0, 36)  Instrument: trombone
(1, 0,  0,  0,  0, 39)  Instrument: brasses
(2, 0,  0,  0,  0,  0)  Start of notes
(3, 1,  1, 41, 15, 36)  Note: beat=1, position=1,  pitch=E2, duration=48, instrument=trombone
(3, 1,  1, 65,  4, 39)  Note: beat=1, position=1,  pitch=E4, duration=12, instrument=brasses
(3, 1,  1, 65, 17, 15)  Note: beat=1, position=1,  pitch=E4, duration=72, instrument=accordion
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(3, 2,  1, 73, 12, 39)  Note: beat=2, position=1,  pitch=C5, duration=36, instrument=brasses
(3, 2,  1, 77, 12, 39)  Note: beat=2, position=1,  pitch=E5, duration=36, instrument=brasses
          ...           ...
(4, 0,  0,  0,  0,  0)  End of song
```

Experimental Setup

Data

- Symbolic Orchestral Database (SOD) (Crestel et al., 2017)
  - 5,743 songs, 357 hours
- Temporal resolution: 12 time steps per quarter note
- 80% training, 10% validation, 10% test
- Data augmentation
  - Randomly shift for -5~6 semitones
  - Randomly select a starting beat

Model & Training

- 6 transformer decoder blocks
- 8 attention heads
- Model dimension: 512
- Sequence length: 1024
- Maximum number of beats: 256
- Maximum training steps: 200,000

Crestel et al., "A database linking piano and orchestral MIDI scores with application to automatic projective orchestration," *Proc. ISMIR*, 2017.

Example Results

Unconditional generation

Instrument-informed generation

church-organ, viola, contrabass, strings, voices, horn, oboe

4-beat continuation

Wolfgang Amadeus Mozart's Eine kleine Nachtmusik

More audio samples

salu133445.github.io/mmt/

OttoPilot33, "Eine Kleine Nachtmusik - By My MIDI Virtual Orchestra." https://youtu.be/_g8iCdY34jc

Subjective Listening Test Results

	Number of parameters	Average sample length (sec)	Inference speed (notes per second)	Subjective listening test results			
				Coherence	Richness	Arrangement	Overall
MMM [10]	19.81 M	38.69	5.66	3.48 ± 0.35	3.05 ± 0.38	3.28 ± 0.37	3.17 ± 0.43
REMI+ [11]	20.72 M	28.69	3.58	$\mathbf{3.90 \pm 0.52}$	$\mathbf{3.74 \pm 0.21}$	$\mathbf{3.74 \pm 0.44}$	$\mathbf{3.77 \pm 0.41}$
MMT (ours)	19.94 M	**100.42**	**11.79**	3.55 ± 0.46	3.53 ± 0.35	3.40 ± 0.44	3.33 ± 0.47

2.6x/3.5x longer
generated samples
(within the same sequence length)

2.1x/3.3x faster
inference speed

Higher quality than MMM
Lower quality than REMI+

Ens and Pasquier, "MMM : Exploring Conditional Multi-Track Music Generation with the Transformer," *arXiv preprint arXiv:2008.06048*, 2020.
von Rütte et al., "FIGARO: Controllable Music Generation using Learned and Expert Features," *Proc. ICLR*, 2023.

Analyzing Self-attention

- *Mean relative attention* for a field d:

$$\gamma_k^{(d)} = \frac{\sum_{x\in\mathcal{D}}\sum_{s>t} \underbrace{\boxed{a_{s,t}(\mathbf{x})}}_{\text{Attention weight}} \underbrace{\boxed{1_{x_t^{(d)} - x_s^{(d)} = k}}}_{\text{Whether the field value is of difference } k}}{\sum_{x\in\mathcal{D}}\sum_{s>t} a_{s,t}(\mathbf{x})}$$

```
(0, 0,  0,  0,  0,  0)  Start of song
(1, 0,  0,  0,  0, 15)  Instrument: accordion
(1, 0,  0,  0,  0, 36)  Instrument: trombone
(1, 0,  0,  0,  0, 39)  Instrument: brasses
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```

$\gamma_{-8}^{(pitch)}$ $\gamma_{-5}^{(pitch)}$

Analyzing Self-attention

- *Mean relative attention* for a field d:

$$\gamma_k^{(d)} = \frac{\sum_{x \in \mathcal{D}} \sum_{s>t} a_{s,t}(\mathbf{x}) \, 1_{x_t^{(d)} - x_s^{(d)} = k}}{\sum_{x \in \mathcal{D}} \sum_{s>t} a_{s,t}(\mathbf{x})}$$

Biased towards difference that occurred more frequently!

- *Mean relative attention gain* for a field d:

$$\tilde{\gamma}_k^{(d)} = \gamma_k^{(d)} - \frac{\sum_{x \in \mathcal{D}} \sum_{s>t} 1_{x_t^{(d)} - x_s^{(d)} = k}}{\sum_{x \in \mathcal{D}} \sum_{s>t} \boxed{1}}$$

Assuming a uniform attention matrix

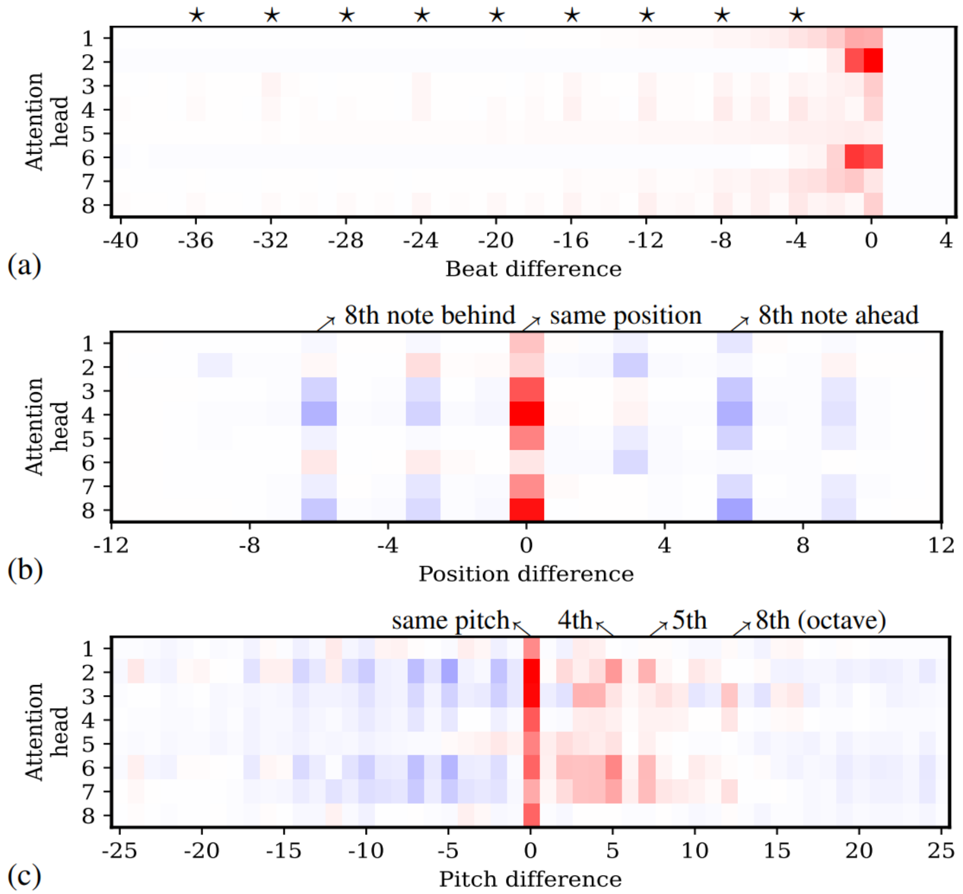
Musical Self-attention

The MMT model attends more to notes

- that are $4N$ beats away in the past
- that have the same position as the current note (A note on beat attends more to a note on beat; a note off beat attends more to a note off beat.)
- that has a pitch in an octave above which forms a consonant interval

→ MMT learns a relative self-attention for certain aspects of music, specifically, beat, position and pitch.

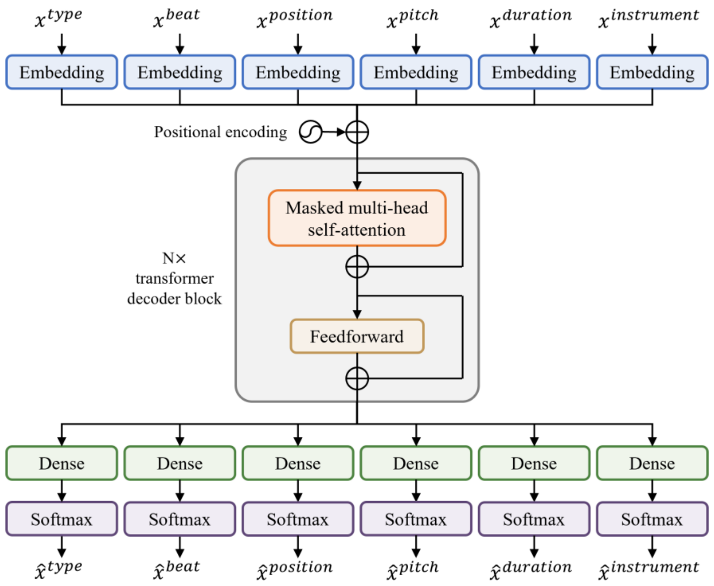
Positive and negative mean relative attention gain



Summary

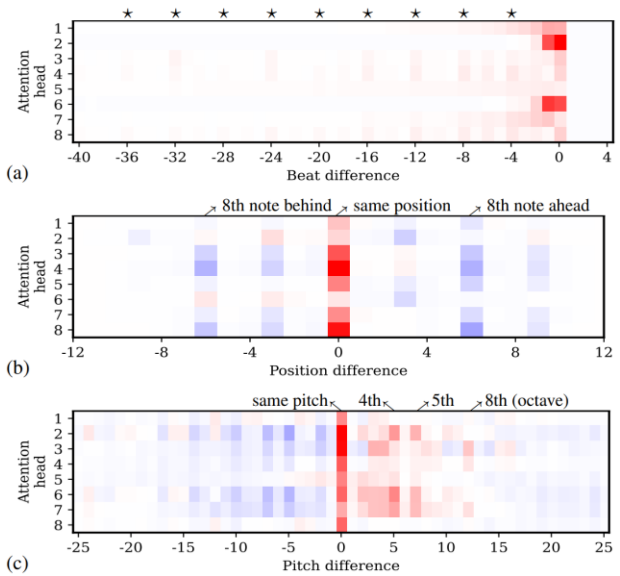
Multitrack Music Transformer

Proposed an efficient representation and model for multitrack music generation



Musical Self-attention

Presented the first systematic analysis of musical self-attention



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Thank you!

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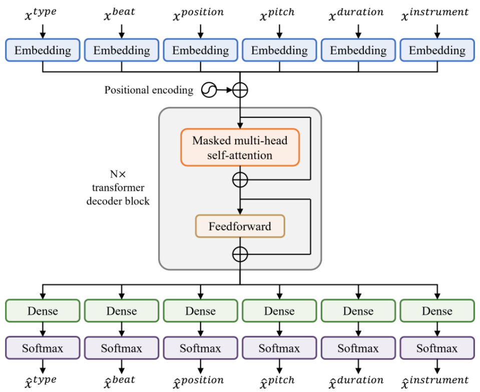
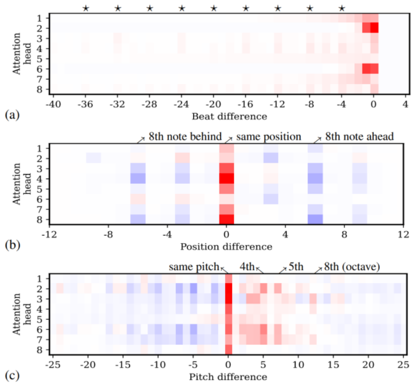


Musical Self-attention







Paper: arxiv.org/abs/2207.06983 Demo: salu133445.github.io/mmt/ Code: github.com/salu133445/mmt