Shimon

An Intelligent Music-Playing Robot Capable of Improvising with Humans

Once upon a time...

Shimon: An intelligent music-playing robot capable of improvising with humans

A "player piano"

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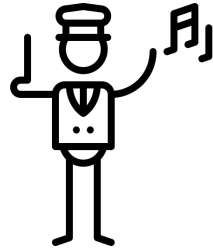
Topics for today

- Why musical robots?
- Introduction to Shimon
- Physical architecture
- Algorithms for Musicianship
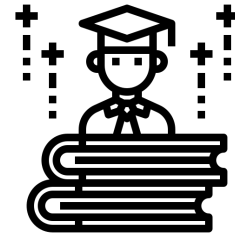- Related work and outlook

Why musical robots?

Motivation: Why musical robots?

Overcome **human shortcomings** in music

Play in **band settings** but with full musical control

Interdisciplinary education

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Introduction to Shimon

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What is Shimon?

An intelligent music-playing robot

Developed by Guy Hoffmann and Gil Weinberg
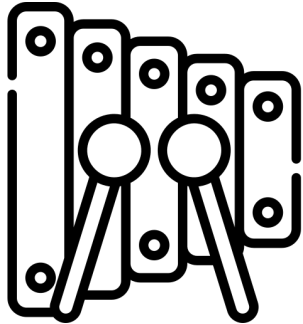
Plays full range of marimba using four arms

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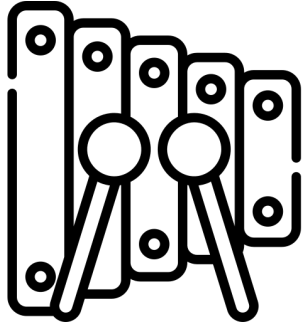
What can Shimon do?

Play set melodies alone

Shimon playing a simple melody

Vincent Rolfs

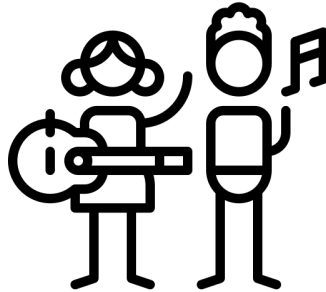*Shimon: An intelligent music-playing robot capable of improvising with humans*

What can Shimon do?

Play set melodies alone

Play set melodies with others in a call-and-response fashion

Shimon playing call-and response (slow)

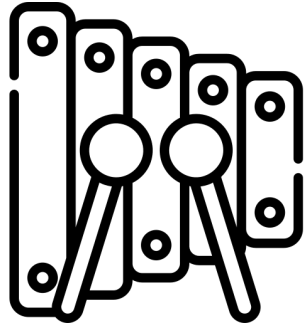*Vincent Rolfs*

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Shimon playing call-and response (fast)

Vincent Rolfs

Shimon: An intelligent music-playing robot capable of improvising with humans
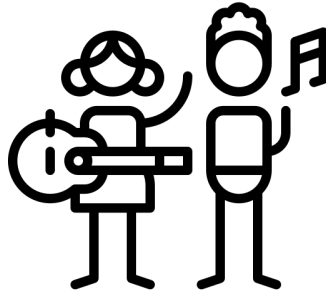
What can Shimon do?

Play set melodies alone

Play set melodies with others
in a call-and-response fashion

Play improvisation together
with other actors

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Shimon improvising

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Physical Architecture

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Physical architecture: Goals

Large movements for visibility

Fast movements for virtuosity

Wide range of note combinations

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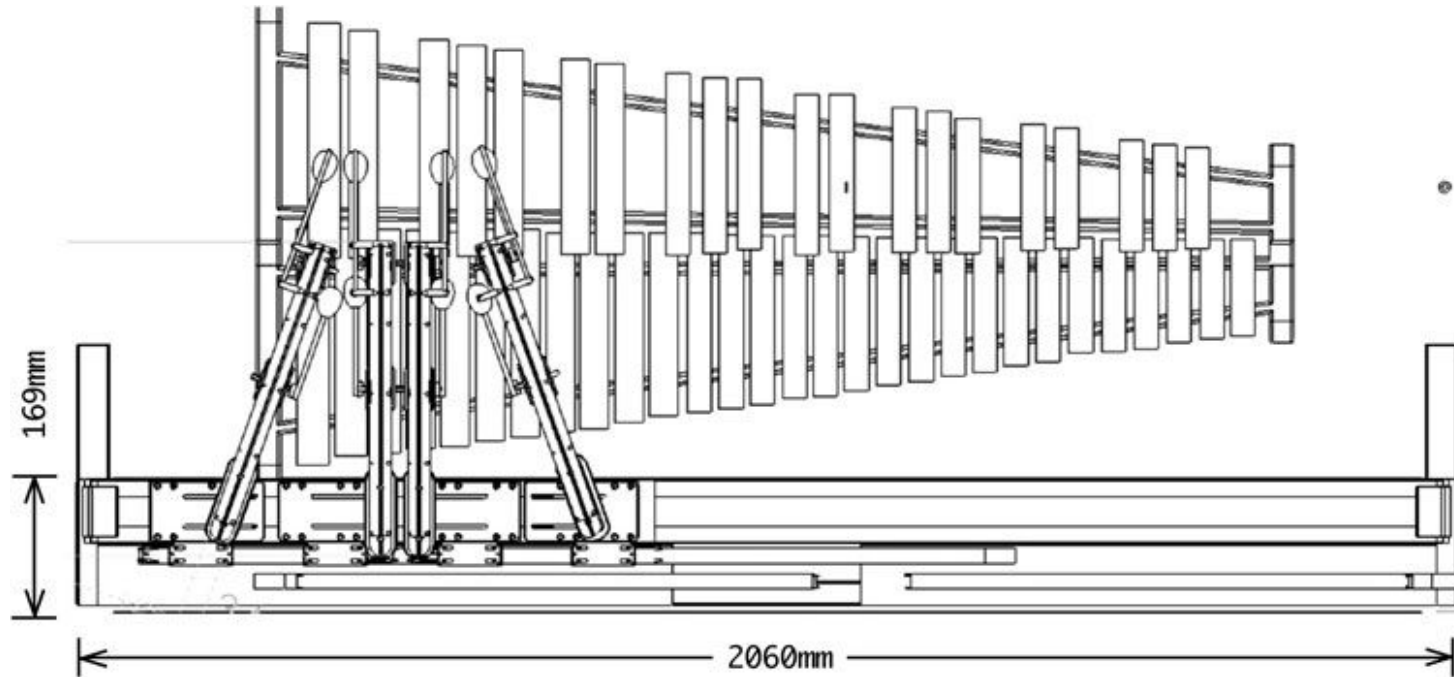
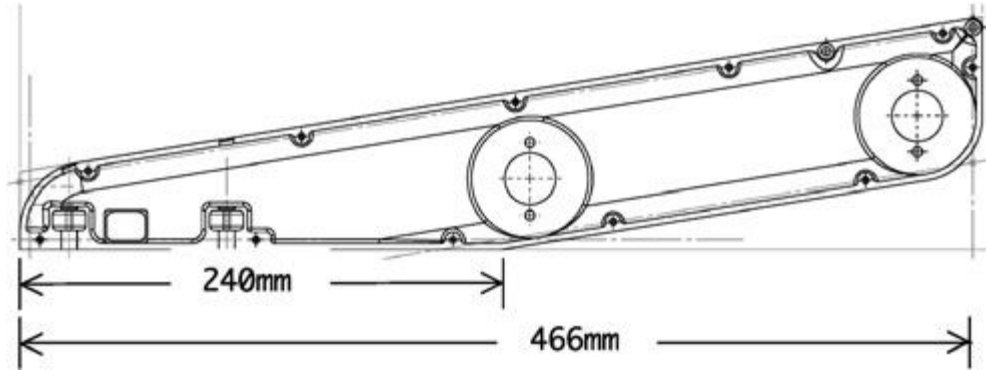# Physical architecture: High-level view

- **Four arms**, running along a shared rail using linear actuators

- Each arm can reach an **acceleration of up to 3g** (105 km/h per second)

- Each arm can **cover a full octave in 0.25 seconds**

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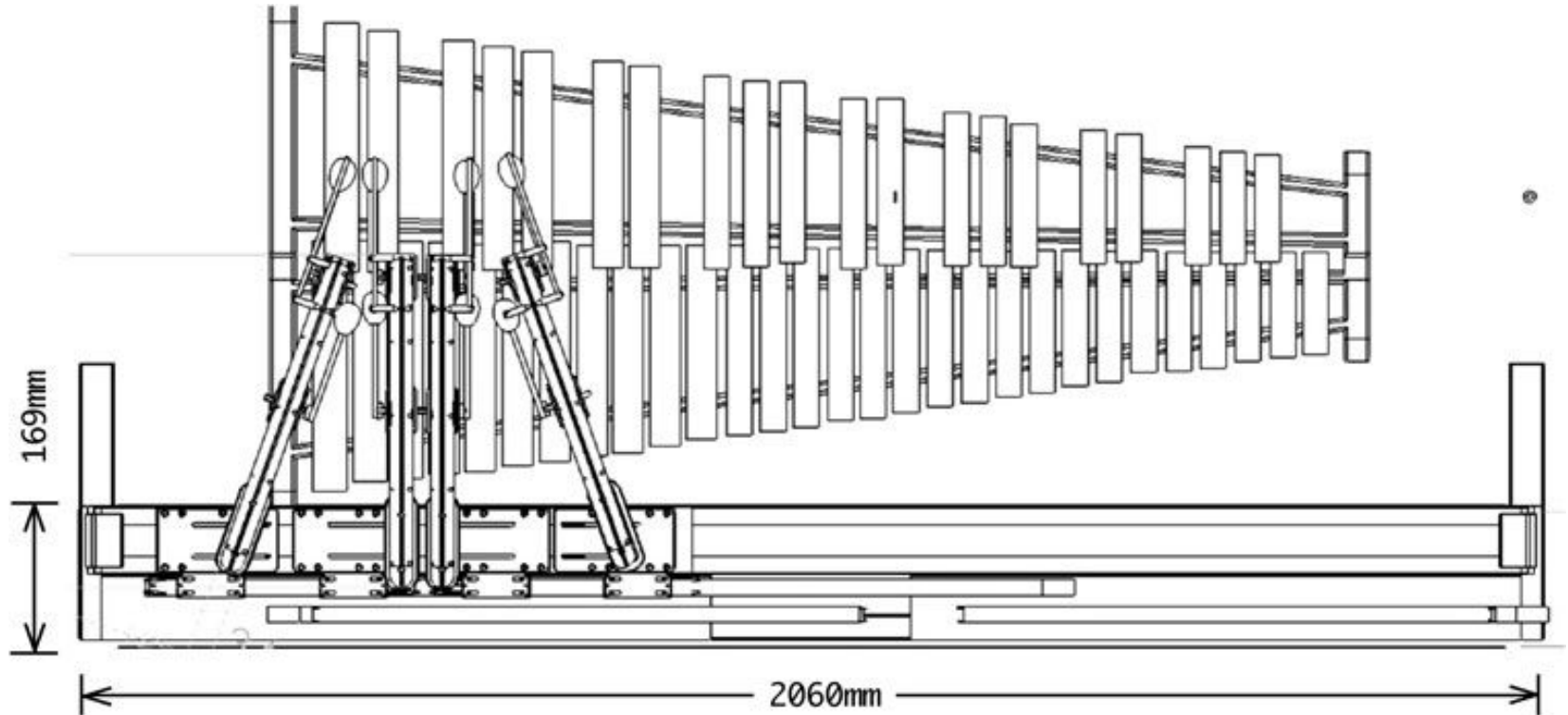# Physical architecture: Arms in detail

- **Each arm contains two mallets**, one for "black", one for "white" keys

- Both mallets are controlled by an **ON/OFF rotary solenoid**

- These actuators are positioned at the crosshairs in the figure

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Problem: Collision avoidance
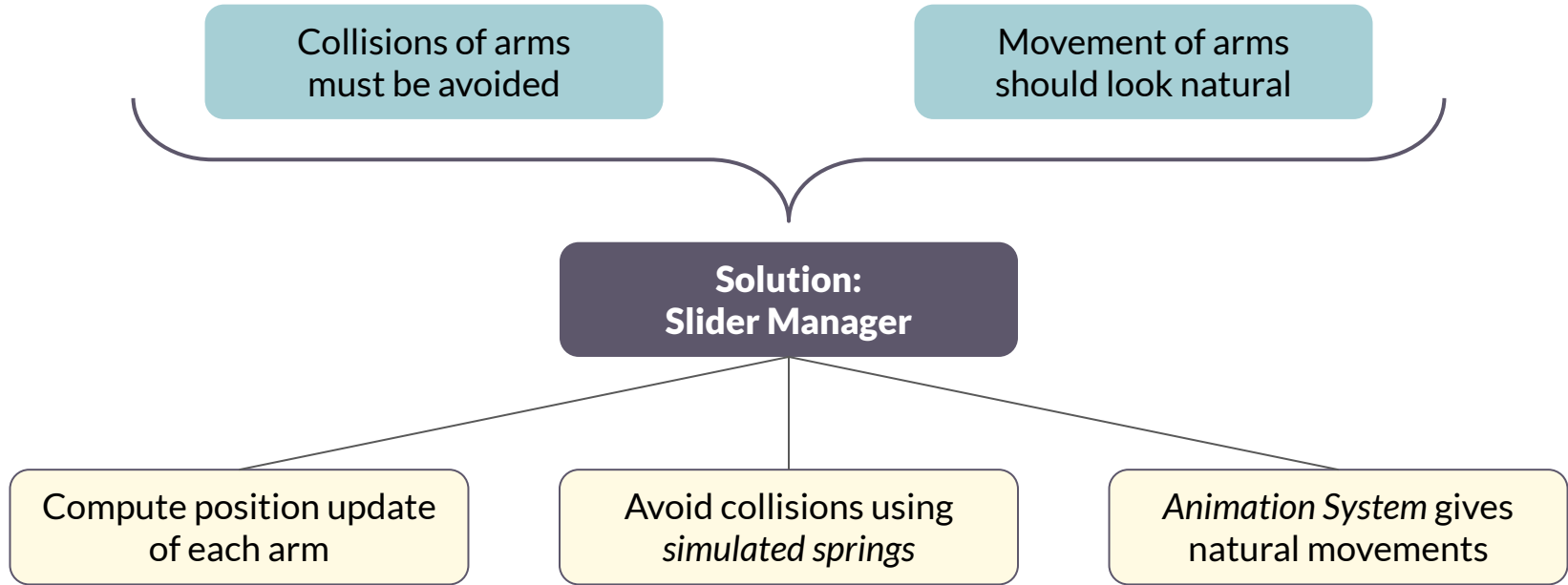
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Controlling of the arm motors

Collisions of arms
must be avoided

Movement of arms
should look natural

Solution:
Slider Manager

Compute position update
of each arm

Avoid collisions using
simulated springs

Animation System gives
natural movements

Algorithms for Musicianship

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The three types of interaction modules

Call-and-response

Opportunistic overlay

Rhythmic phrase-matching improvisation

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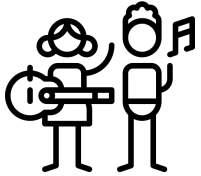
The three types of interaction modules
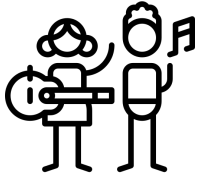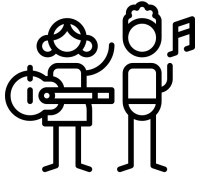
Call-and-response

Opportunistic overlay

Rhythmic phrase-matching improvisation

- Plays a **set melody** in response to a musical sequence played at an **arbitrary tempo**
- **Beat-matched and synchronized**, starting on time, without delay

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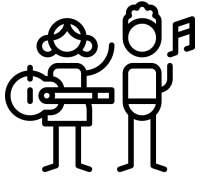# The three types of interaction modules

Call-and-response

Opportunistic overlay

- Focuses on **choreographic** movement
- Plays a sparse **improvisation** that is beat-matched, synchronized and **chord-adaptive**

Rhythmic phrase-matching improvisation

Shimon using the opportunistic overlay module

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The three types of interaction modules

Call-and-response

Opportunistic overlay

Rhythmic phrase-matching improvisation

- Beat-matched and chord-synchronized improvisation
- Tries to match style and density of human player

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Shimon using the improvisation module

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The improvisation algorithm: Finding probabilities

1   Quantize the bar into 16 beats and **declare probabilities** $p_{i,k}$ for arm i to strike at beat k.

2   **Listen to one bar of human play** and quantize the playing into 16 beats.

3   For each of the 16 beats, **cluster the notes played** in that beat into 4 bins (one of for each arm) by pitch.

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The improvisation algorithm: Finding probabilities

k bins   here: $k=16$

here: $m=4$

m clusters

0 1 16

0

1

2   h^2_1

4

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The improvisation algorithm: Finding probabilities

1 Quantize the bar into 16 beats and **declare probabilities** $p_{i,k}$ for arm i to strike at beat k.
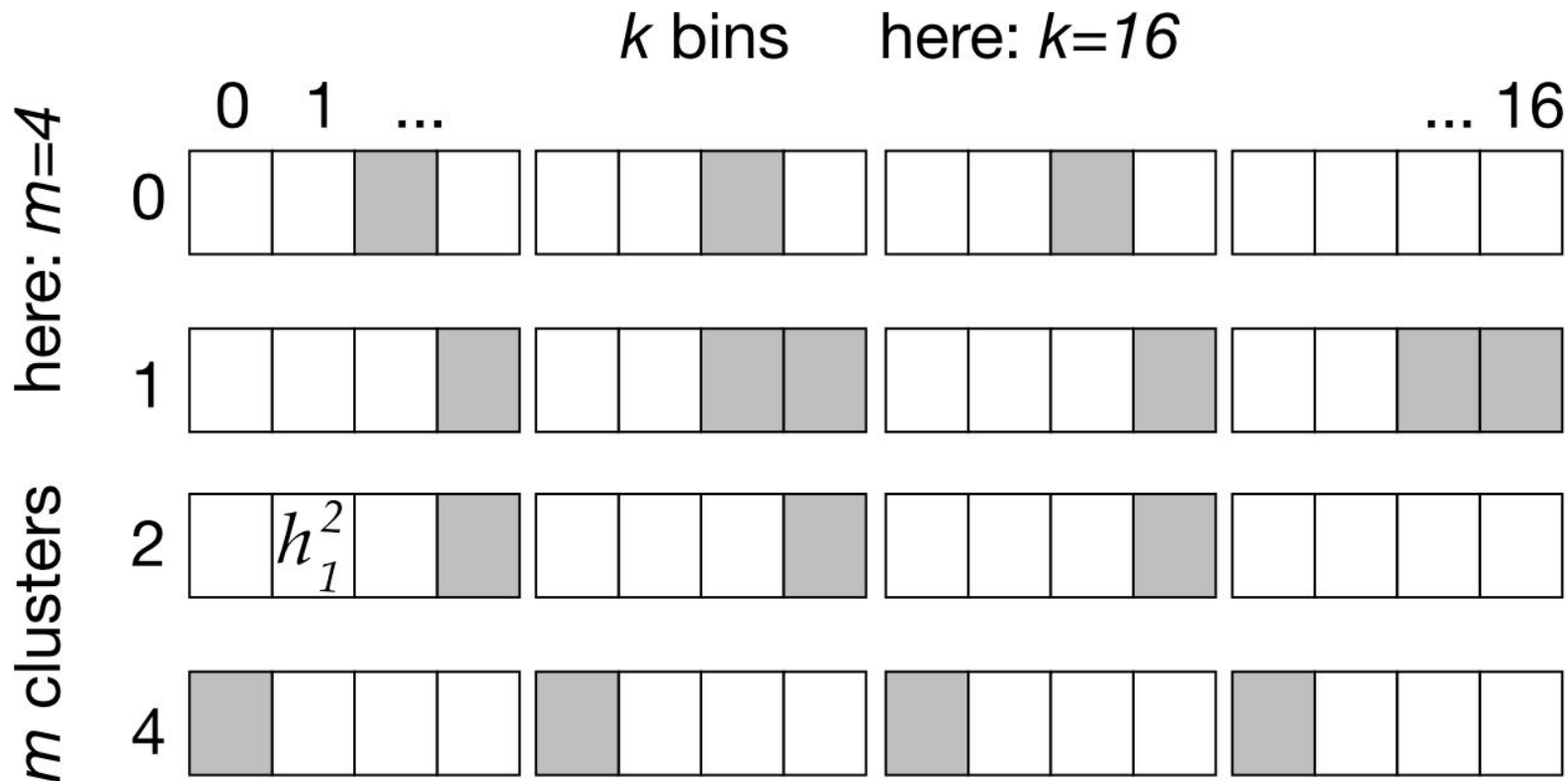
2 **Listen to one bar of human play** and quantize the playing into 16 beats.

3 For each of the 16 beats, **cluster the notes played** in that beat into 4 bins (one of for each arm) by pitch.

4 Declare $h_{i,k}$ as 1 if the human played a note in bin i at beat k, and 0 otherwise. Then apply
$$p_{i,k} \leftarrow \lambda h_{i,k} + (1 - \lambda) p_{i,k}.$$

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The improvisation algorithm: Playing

1   **Detect the current chord played** by comparing human play to all chords in the piece.

2   **Position the arms** according to the detected chord. Each arm now targets one key.

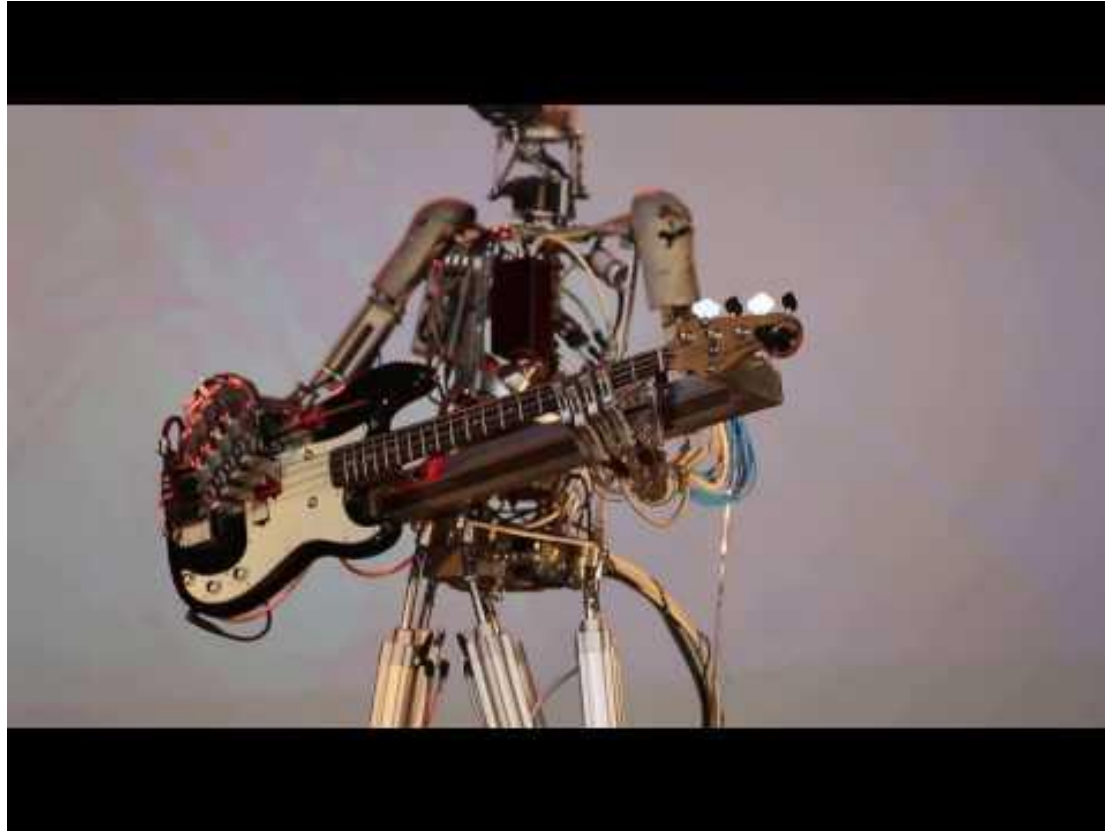**3**   **Strike** arm i at beat k with probability $p_{i, k}$.

4   **...Profit!**

Related work and outlook

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Compressorhead, a band consisting only of robots

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Haile, a robotic percussionist by Weinberg et al.

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A "hyperinstrument" by Kapur et al.

A "hyperinstrument" by Kapur et al.

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Strengths and weaknesses of Shimon

Can improvise in a variety of genres ⟷ Algorithms depend strongly on chord classification

Is able to play in sync with humans in a natural way ⟷ Tempo detection is very simplistic

Can improvise on the fly and invent new melodies ⟷ Improvisation does not improve over time

Shimon is continually improved ⟷ Many new advances are not published
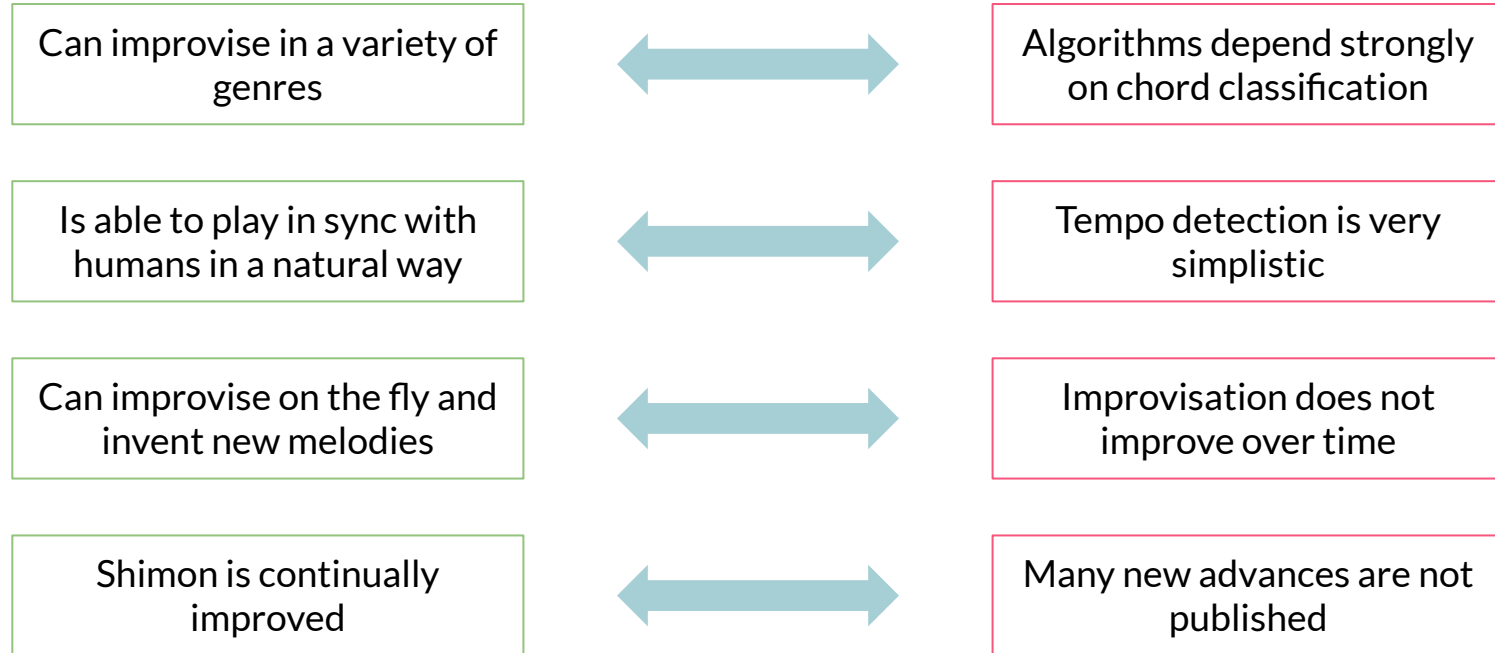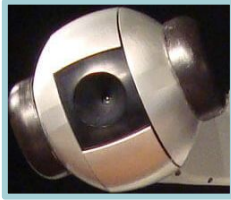
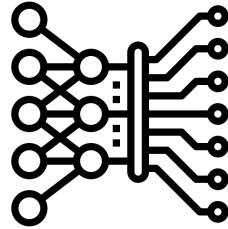# The future of Shimon

Shimon's head:
Further research

DeepShimon:
Using neural networks
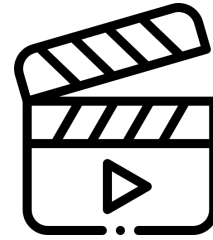
Shimon as a movie score
composer

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Thank you for your attention!

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References

References

[1] L. Mickey. RagTime Scott Joplin Pianola Autoleon Triumph Auto London 1924. URL: https://www.youtube.com/watch?v=4iymj0gZpj4 (visited on 01/12/2020).

[2] Shimon Robot. Gallery. URL: https://www.shimonrobot.com/gallery (visited on 01/12/2020).

[3] Georgia Tech Center for Music Technology. People. URL: https://gtcmt.gatech.edu/people (visited on 01/12/2020).

[4] G. Hoffmann. Bio. URL: http://guyhoffman.com/bio/ (visited on 01/12/2020).

[5] G. Hoffman and G. Weinberg. "Interactive improvisation with a robotic marimba player". In: Autonomous Robots 31.2 (Oct. 2011), pp. 133–153. issn: 1573-7527. doi: 10.1007/s10514-011-9237-0. URL: https : / /doi.org/10.1007/s10514-011-9237-0.

[6] gerbilsproductions. Shimon Robot plays True Romance Theme. URL: https://www.youtube.com/watch?v=PjWSiaMQn08 (visited on 01/12/2020).

[7] gerbilsproductions. Human-Robot Jazz Improvisation (Full Performance). URL: https://www.youtube.com/watch?v=qy02lwvGv3U (visited on 01/12/2020).

References

[8] vpro vrije geluiden. Robot Shimon and friends in Concert (VG Live). URL: https://www.youtube.com/watch?v=Rx-QSphvr20 (visited on 01/12/2020).

[9] S. Kanatyev. Compressorhead - Smells Like Teen Spirit (Nirvana Cover) (live in Moscow, Russia). URL: https://www.youtube.com/watch?v=TaY7vohLXK4 (visited on 01/12/2020).

[10] leech. Haile, the interactive robot drummer. URL: https://www.youtube.com/watch?v=veQS6tsogAA (visited on 01/12/2020).

[11] TEDx Talks. Composing, programming, and performing musical robots: Ajay Kapur at TEDxCalArts. URL: https://www.youtube.com/watch?v=GsqiJqMFcvM (visited on 01/12/2020).

[12] Purdue University. URL: https://www.purdue.edu/convocations/wp-content/uploads/2016/06/Shimon_1920x552.jpg (visited on 01/12/2020).
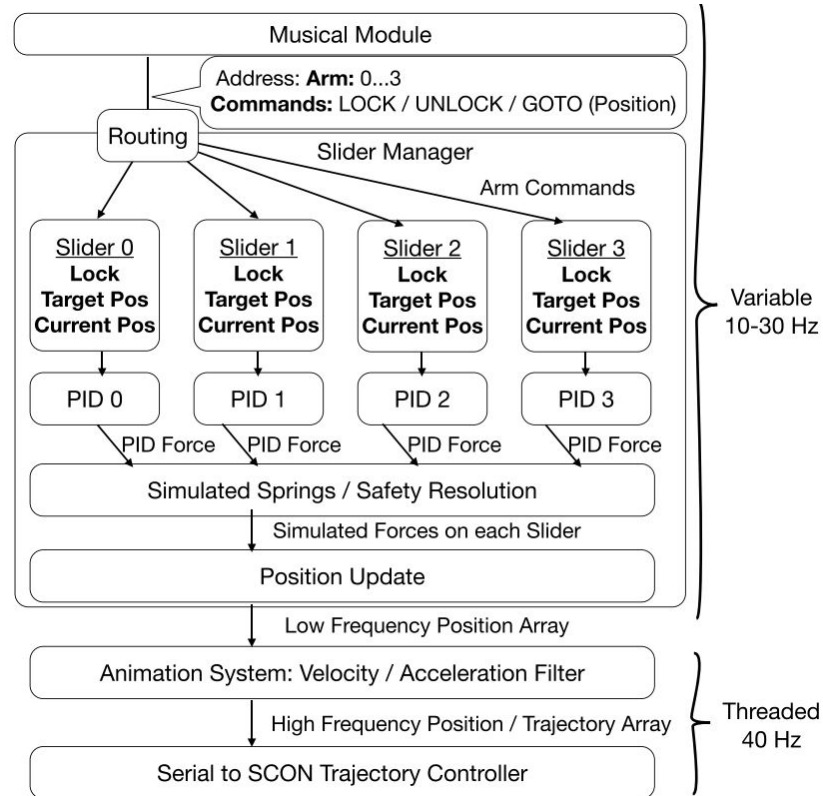
Icons designed by Freepic from Flaticon.

Appendix

Appendix

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Controlling of the arm motors

Shimon: An intelligent music-playing robot capable of improvising with humans
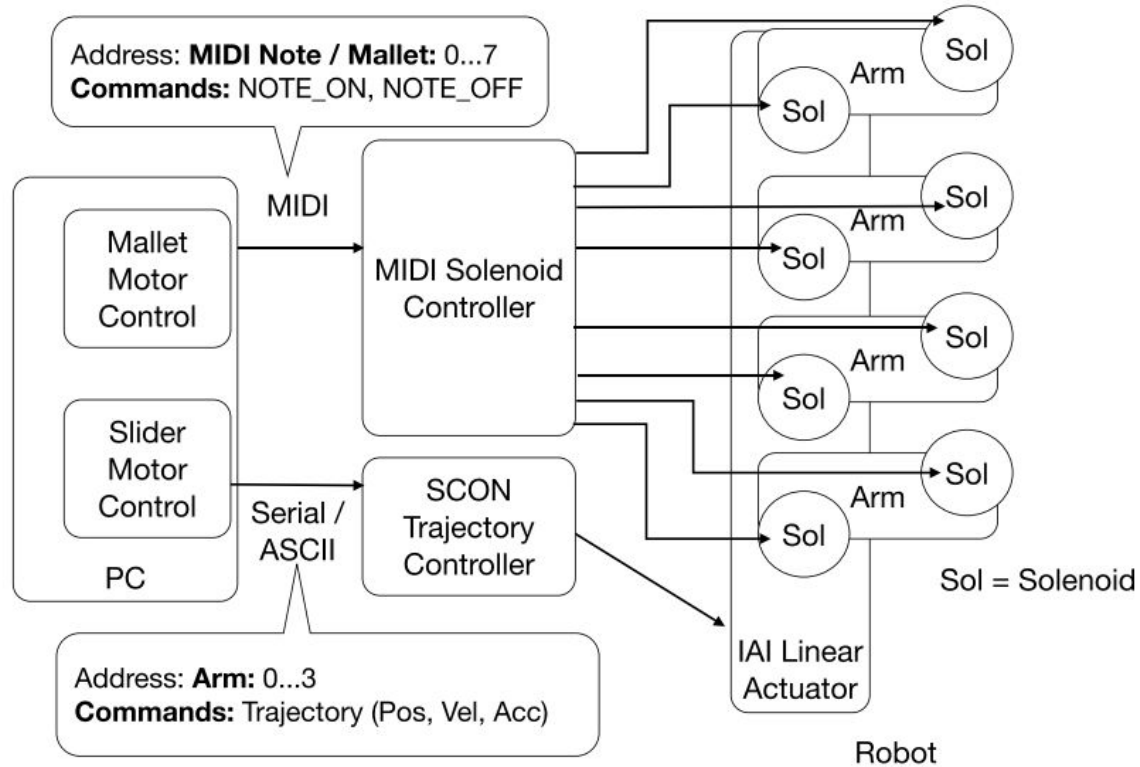
Controlling of the mallet motors

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