Applying Syntax–Prosody Mapping Hypothesis and Prosodic Well-Formedness Constraints to Neural Sequence-to-Sequence Speech Synthesis

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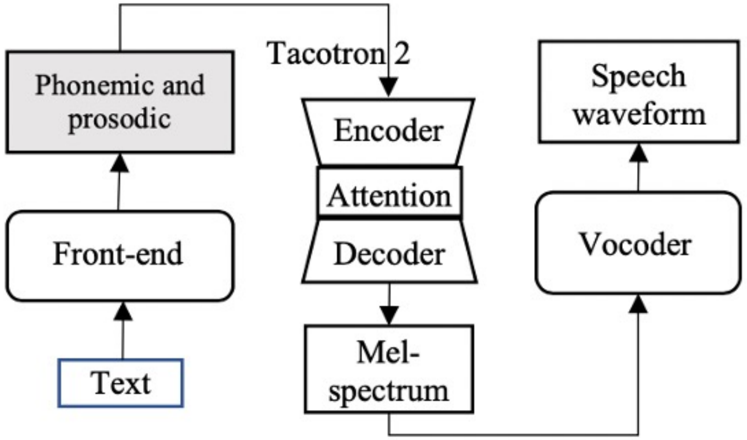
Backgrounds of TTS

- Advances of End-to-end text-to-speech synthesis (TTS) [1]
- Japanese has a huge number of characters, and the reading of each character is not consistent
- The introduction of phoneme sequences and accent symbols as inputs of TTS improves the naturalness of speech synthesis [2, 3, 4]



cited from Kaiki et al. 2021

[1] Shen et al., 2018
[2] Yasuda et al., 2019
[3] Fujimoto et al., 2019
[4] Kurihara et al., 2021

Backgrounds of TTS

- Other studies:
  - Incorporated information of the post-lexical level, such as syntactic structure and syntactic dependency information [5, 6].
- However,
  - Not objectively examined whether they can reproduce pitch patterns of phonological phenomena

[5] Guo et al., 2019
[6] Kaiki et al., 2021

Motivation

- Reproduce speech sounds with syntactic and phonological phenomena by applying linguistic theories to neural sequence-to-sequence speech synthesis.

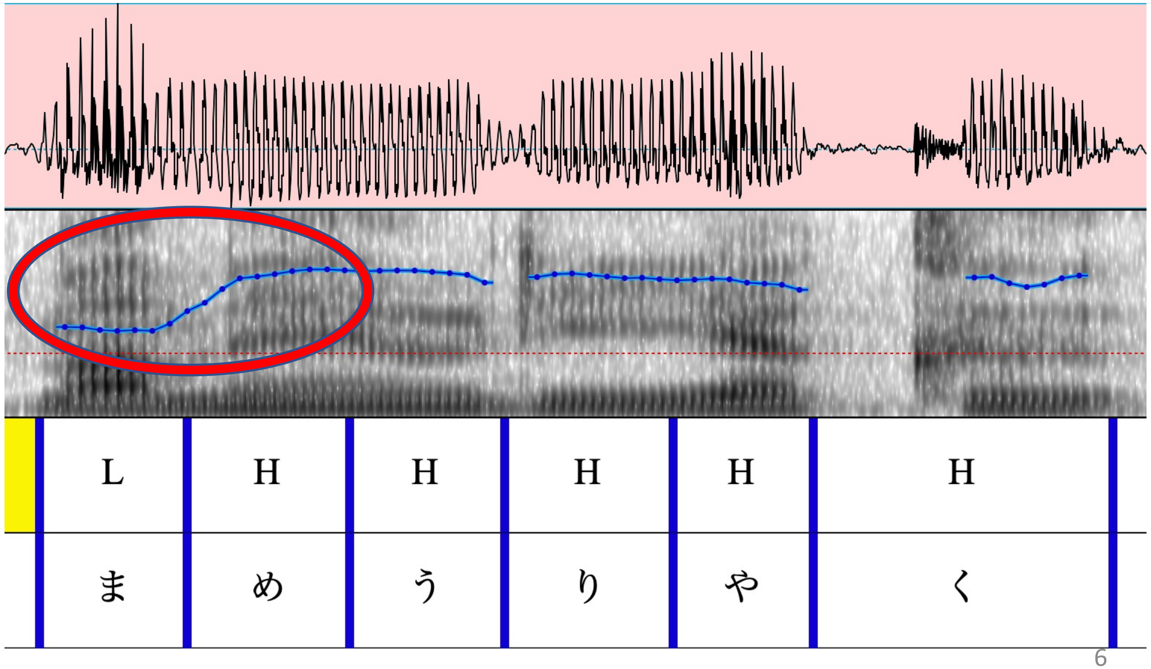
- Target Phenomena:
  - **Phenomenon 1. initial lowering**
  - **Phenomenon 2. rhythmic boost**

Outline of this talk

- Backgrounds and problems in current text-to-speech synthesis (TTS) systems: two phenomena
- **Phenomenon 1: the degree of initial lowering**
  - Proposed model 1: Syntax–Prosody Mapping Hypothesis
  - Experiment 1
- **Phenomenon 2: rhythmic boost**
  - Proposed model 2: Prosodic Well-Formedness Constraints
  - Experiment 2
- Discussions and Conclusion

Phenomenon 1: the degree of initial lowering

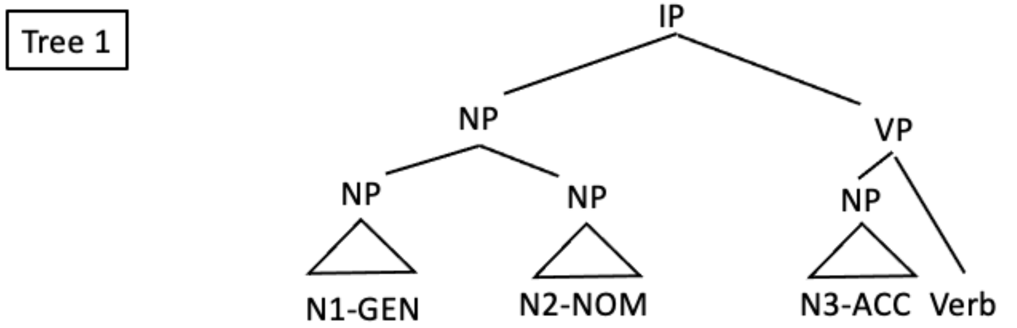
- The initial lowering is the F0 rise at the beginning of a PPhrase [7, 8]
- The degree of F0 rise in initial lowering varies in response to syntactic structure [9]



[7] Pierrehumbert &. Beckman, 1988
[8] Igarashi, 2015
[9] Selkirk et al., 2013

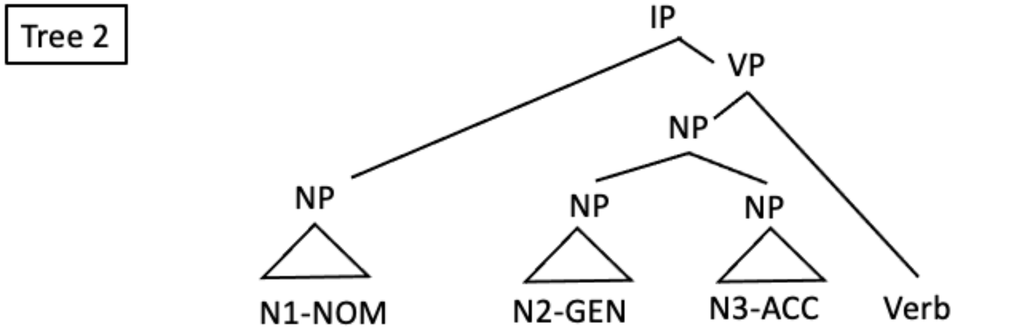
Phenomenon 1: the degree of initial lowering

- Initial lowering is greater at **position B than A in tree 1**, while the initial lowering is greater **at position A than B in tree 2** [9]
- The results can be explained via
  - Syntax–prosody mapping hypothesis [10]
  - Edge boost hypothesis (proposal)



a. Syntax: {$_{\text{IP}}$ [$_{\text{NP}}$ [$_{\text{NP}}$ N1-GEN] **A** [$_{\text{NP}}$ N2-NOM]] **B** [$_{\text{VP}}$ [$_{\text{NP}}$ N3-ACC] Verb]}

b. Phonology: {$_{\text{PC}}$ [$_{\text{PP}}$ [$_{\text{PP}}$ N1-GEN] **A** [$_{\text{PP}}$ N2-NOM]] **B** [$_{\text{PP}}$ [$_{\text{PP}}$ N3-ACC] Verb]}



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[9] Selkirk et al., 2013
[10] Selkirk, 2011

Phenomenon 1: the degree of initial lowering

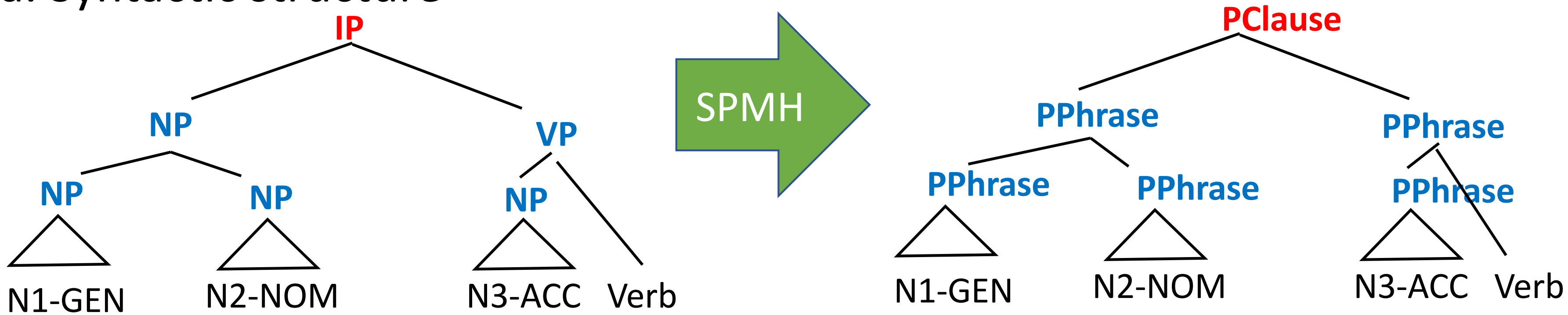
- Syntax–Prosody Mapping Hypothesis (SPMH) [10] require that syntactic categories be mapped to their corresponding phonological counterparts
  - **Syntactic clause → PClause**
  - **Syntactic phrase such as NP, VP → PPhrase**

[10] Selkirk, 2011

Tree 1

a. Syntactic structure

b. Phonological structure



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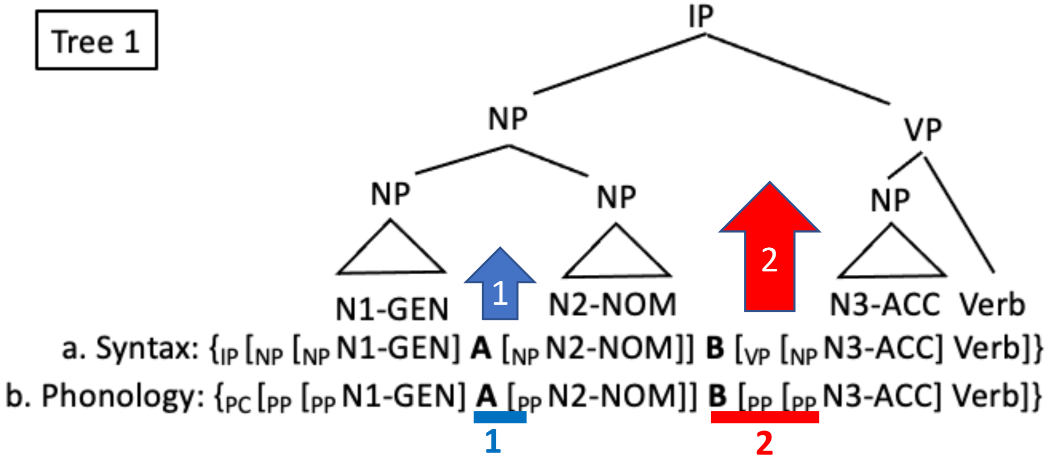
Phenomenon 1: the degree of initial lowering

- Initial lowering is greater at **position B than A in tree 1**, while the initial lowering is greater at **position A than B in tree 2** [9]
- Edge boost hypothesis (proposal)
  - the number of edges in the PPhrases is proportional to the degree of the pitch increase in the initial lowering

[9] Selkirk et al., 2013



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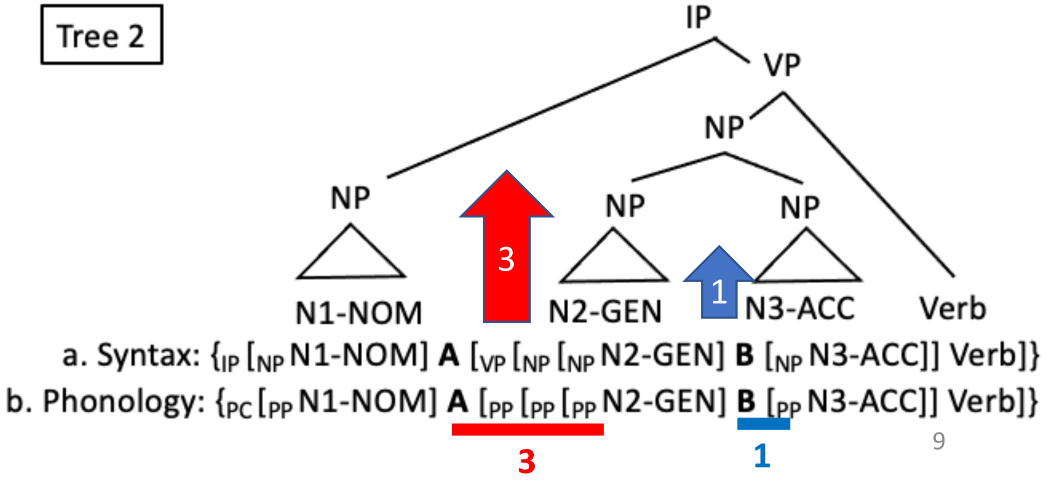

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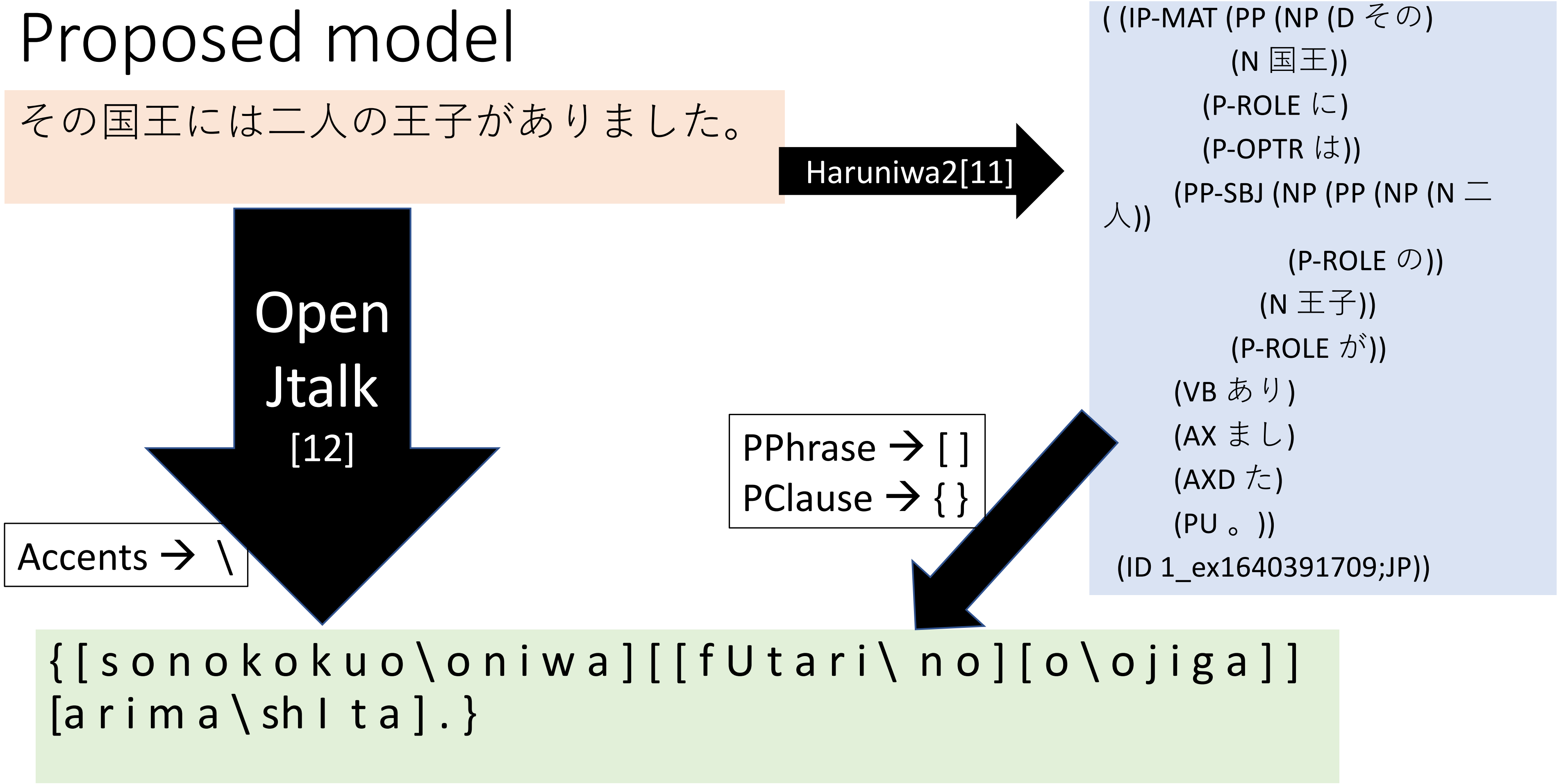
Proposed model



その国王には二人の王子がありました。

Haruniwa2[11]

```
( (IP-MAT (PP (NP (D その)
              (N 国王))
           (P-ROLE に)
           (P-OPTR は))
       (PP-SBJ (NP (PP (NP (N 二人))
                     (P-ROLE の))
                  (N 王子))
               (P-ROLE が))
       (VB あり)
       (AX まし)
       (AXD た)
       (PU 。))
  (ID 1_ex1640391709;JP))
```

Open Jtalk [12]

Accents → \

PPhrase → [ ]
PClause → { }

{[sonokokuo\oniwa][[fUtari\ no][o\ojiga]] [arima\shI ta].}

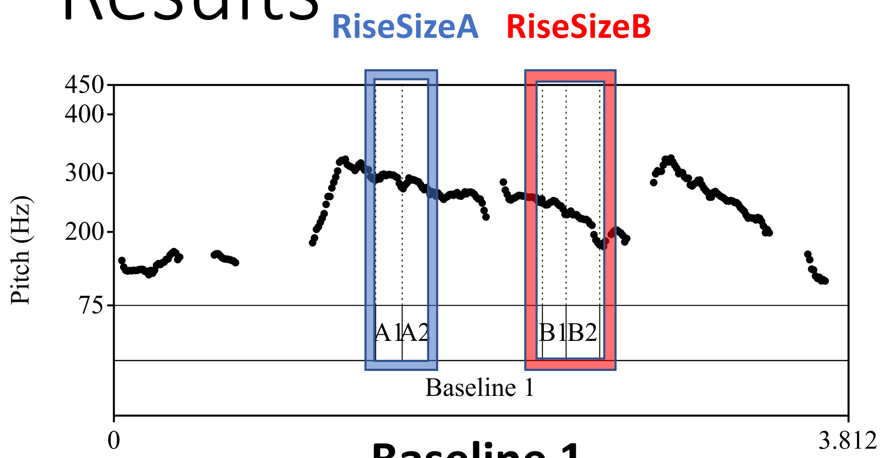
5,453 sentences were used for training, and 250 each were used for validation and testing.

Proposed model

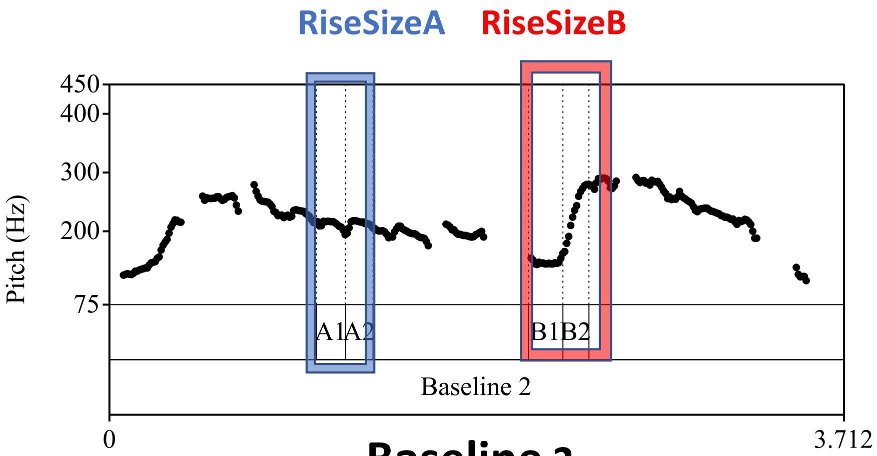
- The database consists of an oral transcription of the Arabian Nights and its reading voice by a single speaker [13].
- Japanese Tacotron 2 [14] generated a mel-spectrum, which is converted to waveforms via Griffin-Lim in ESPNet2 [15].
- 5,453 sentences were used for training, and 250 each were used for validation and testing.

[13] Takehazuchi
[14] Wang et al., 2017
[15] Watanabe et al., 2018

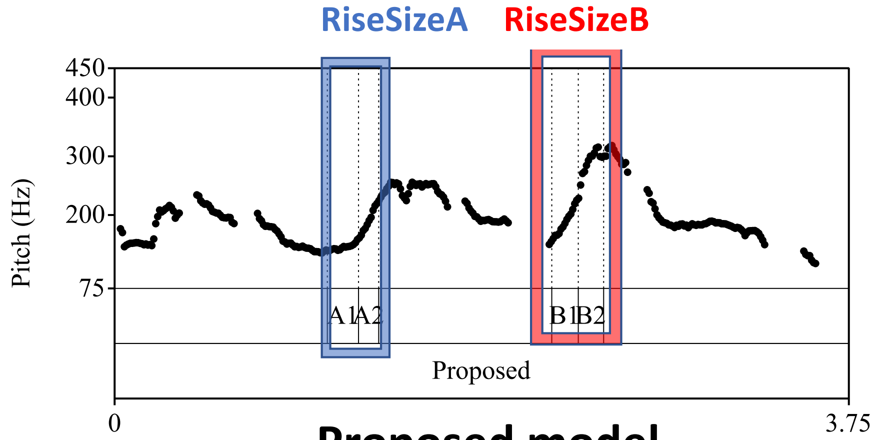
Results



Baseline 1



Baseline 2



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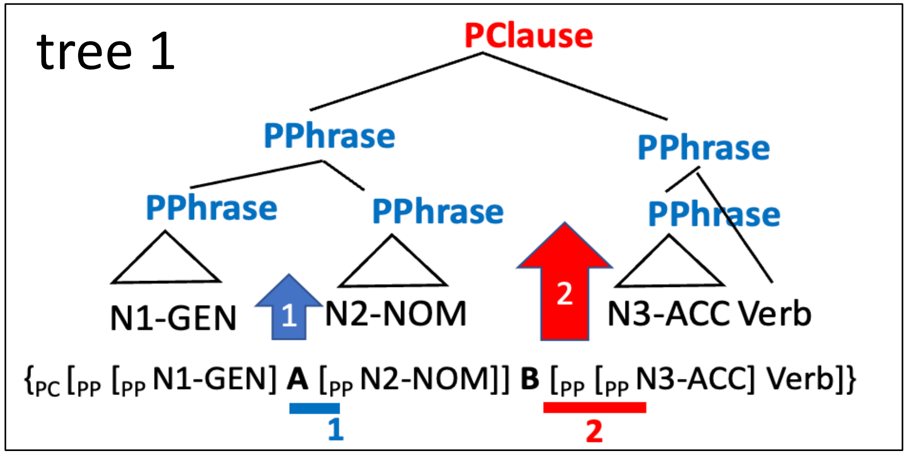


Results

- In natural prosody, RiseSizeB is greater than RiseSizeA in tree 1, while RiseSizeA is greater than RiseSizeB in tree 2 [9]
- The proposed model and Baseline 2 showed the same pattern as the natural prosody reported earlier [9]

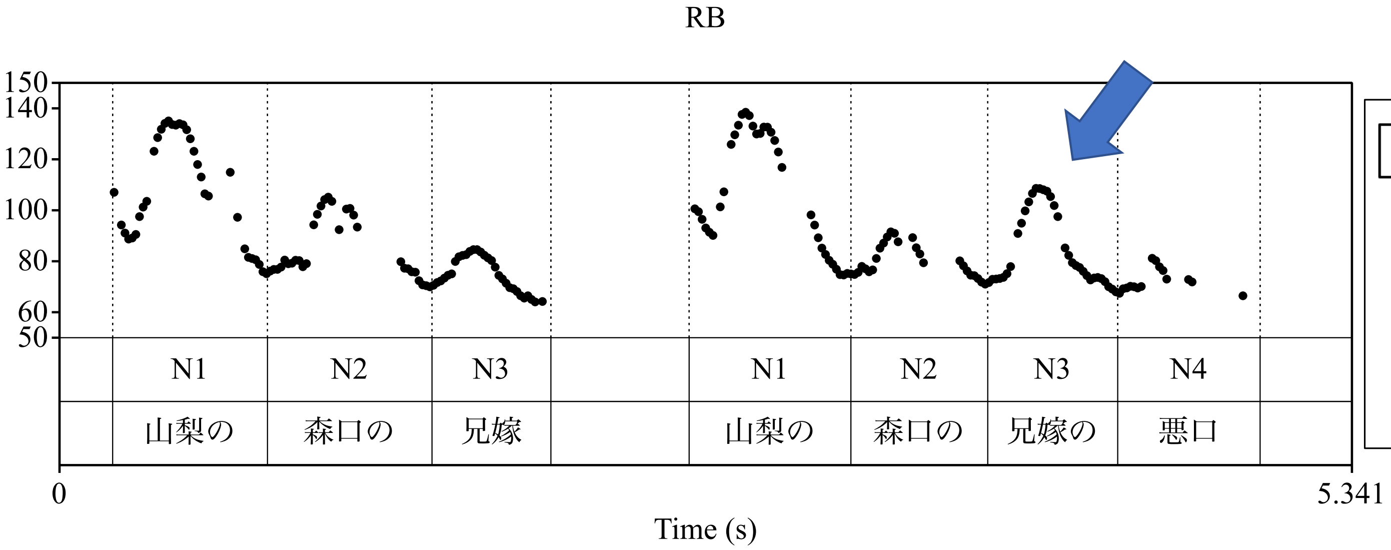
model	sentence	cond	RiseSizeA	RiseSizeB	Same pattern as natural prosody?
baseline 1	1	tree 1	0.68	-0.26	No
baseline 2	1	tree 1	1.75	12.12	Yes
proposed	1	tree 1	8.17	11.84	Yes
baseline 1	1	tree 2	0.72	0.51	Yes
baseline 2	1	tree 2	14.17	3.50	Yes
proposed	1	tree 2	11.96	1.56	Yes
baseline 1	2	tree 1	2.17	8.06	Yes
baseline 2	2	tree 1	4.32	10.58	Yes
proposed	2	tree 1	6.12	9.39	Yes
baseline 1	2	tree 2	0.50	-2.27	No
baseline 2	2	tree 2	12.35	2.71	Yes
proposed	2	tree 2	9.30	9.07	Yes

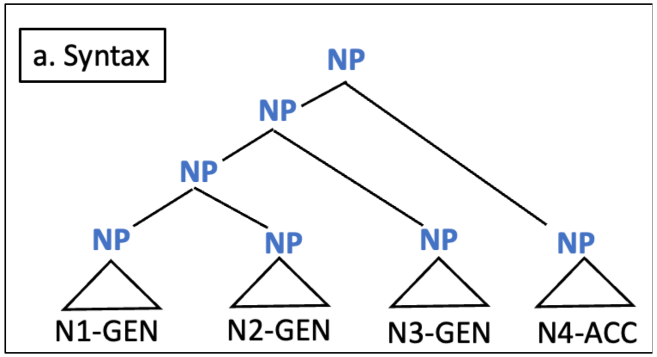
[9] Selkirk et al., 2013

Phenomenon 2: Rhythmic boost

- Rhythmic boost
  - F0 is boosted on the third word in four-word sequences
  - but not in three-word sequences [16, 17]

[16] Kubozono, 1989
[17] Shinya et al., 2004

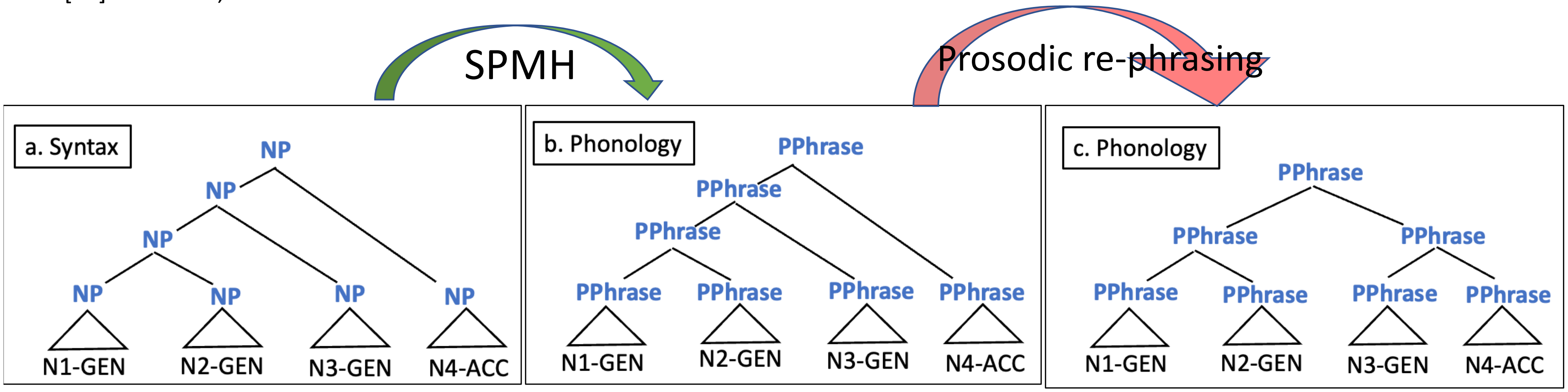




Phenomenon 2: Rhythmic boost

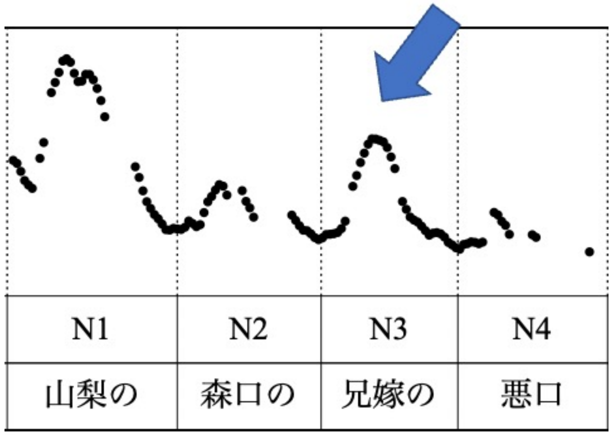
- Due to Syntax-Prosody Mapping Hypothesis, a left-branching phonological structure is predicted
- However, a prosodic well-formedness constarint triggers phonological re-phrasing [16]
- prosodically re-phrased as two intermediate PPhrases (MiPs) recursively dominating two minimal PPhrases (PPs) each

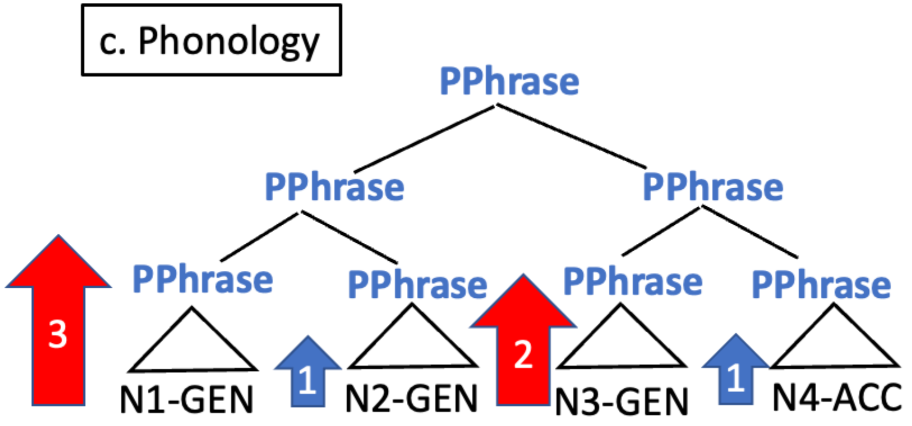
[16] Kubozono, 1989



Phenomenon 2: rhythmic boost

- F0 is boosted on the third word in four-word sequences [16, 17]
- The results can be explained via
  - syntax–prosody mapping hypothesis
  - phonological re-phrasing
  - Edge boost hypothesis (proposal): assuming that **<u>the number of edges</u>** in the PPhrases is proportional to the degree of the pitch increase in the initial lowering



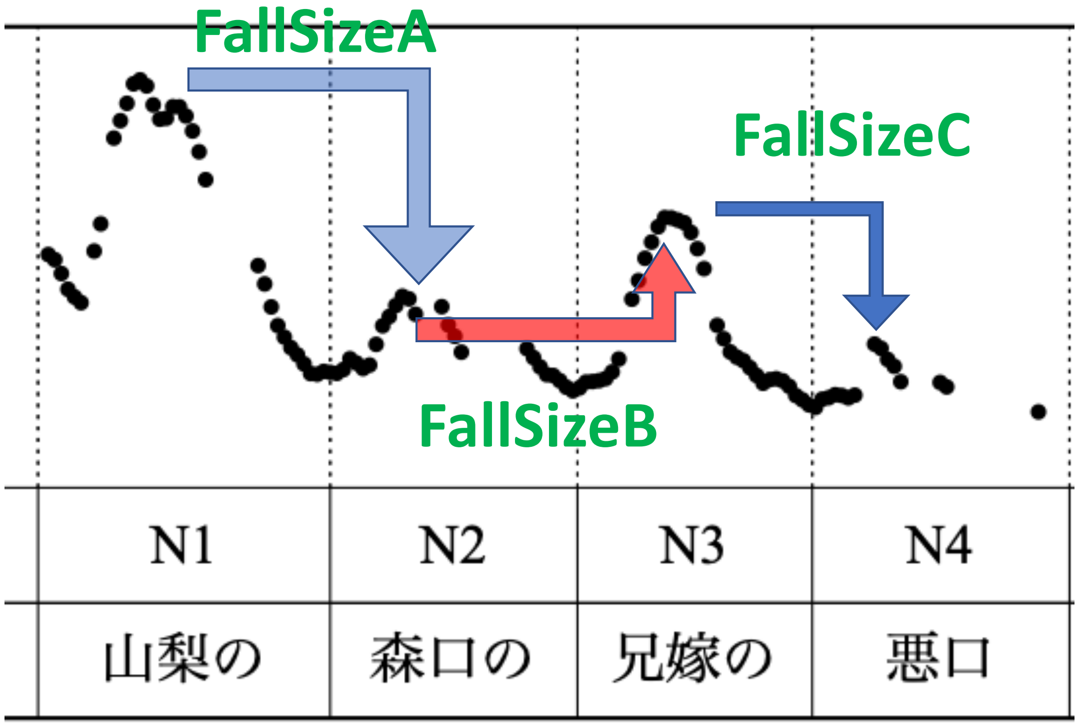


b. Phonology: [$_{\text{PP}}$ [$_{\text{PP}}$ [$_{\text{PP}}$ N1-GEN] [$_{\text{PP}}$ N2-GEN]] [$_{\text{PP}}$ [$_{\text{PP}}$ N3-GEN] [$_{\text{PP}}$ N4-ACC]]]

3 1 2 1

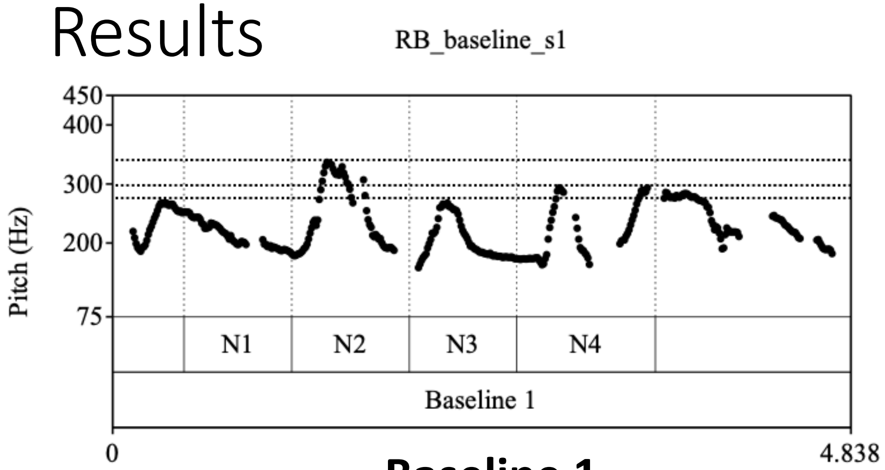
[16] Kubozono, 1989
[17] Shinya et al., 2004

Measurements

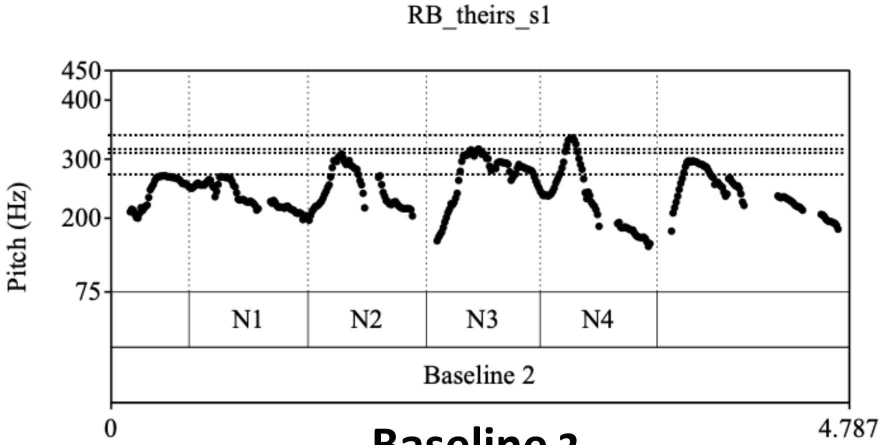


- Measurements (in semitones)
  - FallSizeA = maximum F0 of N2 minus maximum F0 of N1
  - FallSizeB = maximum F0 of N3 minus maximum F0 of N2
  - FallSizeC = maximum F0 of N4 minus maximum F0 of N3
- In natural speech,
  - FallSizeA becomes negative
  - FallSizeB approaches zero or becomes positive
  - FallSizeC becomes negative

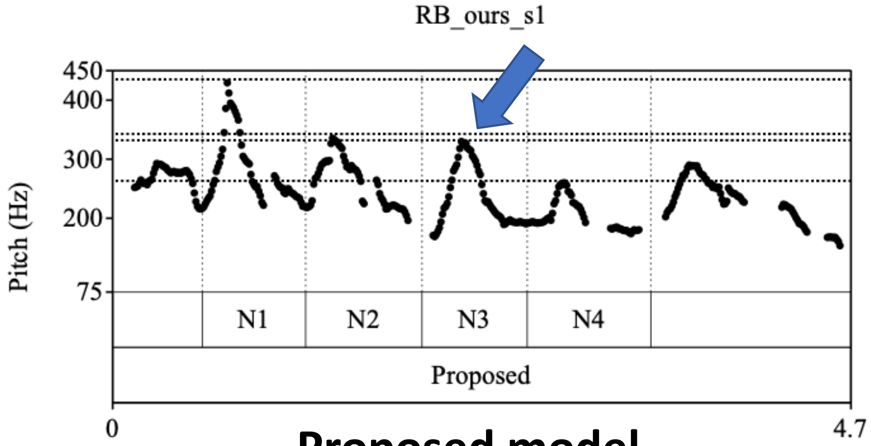
Results



Baseline 1

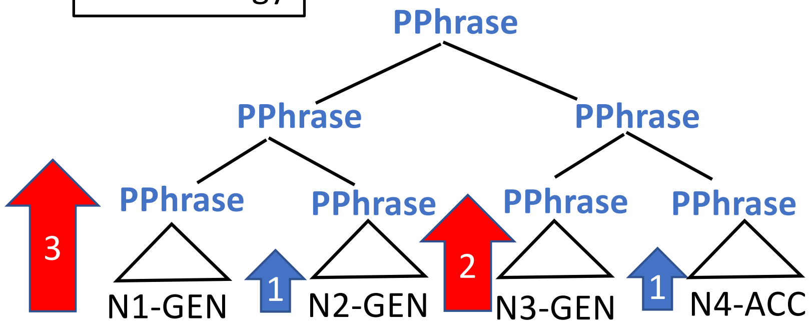


Baseline 2



Proposed model

c. Phonology



b. Phonology: [$_{PP}$ [$_{PP}$ [$_{PP}$ N1-GEN] [$_{PP}$ N2-GEN]] [$_{PP}$ [$_{PP}$ N3-GEN] [$_{PP}$ N4-ACC]]]

Results

- In natural speech,
  - FallSizeA becomes negative
  - FallSizeB approaches zero or becomes positive
  - FallSizeC becomes negative
- Only the proposed model showed the same patterns as those of natural language

model	sentence	FallSizeA	FallSizeB	FallSizeC	Same pattern as natural prosody?
baseline 1	1	4.95	-4.02	1.57	No
baseline 2	1	2.25	0.53	1.00	No
proposed	1	-3.79	-0.41	-3.98	Yes
baseline 1	2	1.29	-2.71	-2.24	No
baseline 2	2	0.62	2.60	-4.54	No
proposed	2	-2.84	1.94	-1.12	Yes

Discussions and conclusion

- We applied linguistic theories to TTS
- The proposed method was able to reproduce not only syntactic but also phonological phenomena
    - **Phenomenon 1. initial lowering**
    - **Phenomenon 2. rhythmic boost**
- The proposed method efficiently synthesizes phonological phenomena in the test data that were not explicitly included in the training data
- The proposed method is applicable to Japanese and other languages

Thank you

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