The NITech text-to-speech system for the Blizzard Challenge 2016

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Background

- Text-to-speech (TTS) systems
  - TTS systems are used in various applications
    - In-car navigation, smartphones, spoken dialogue systems, etc.
  - Demand for TTS systems is increasing
    - High speech quality, speaking styles, multilingual language, etc.
- TTS system based on big data
  - Quality of synthesized speech is improved by using big data
  - Speech data recorded with less noise and under same conditions are suitable for training
  - Recording a large amount of speech data requires a huge cost
- TTS system based on audiobooks
  - Audiobooks can be relatively easily used as a large amount of speech data and text pairs

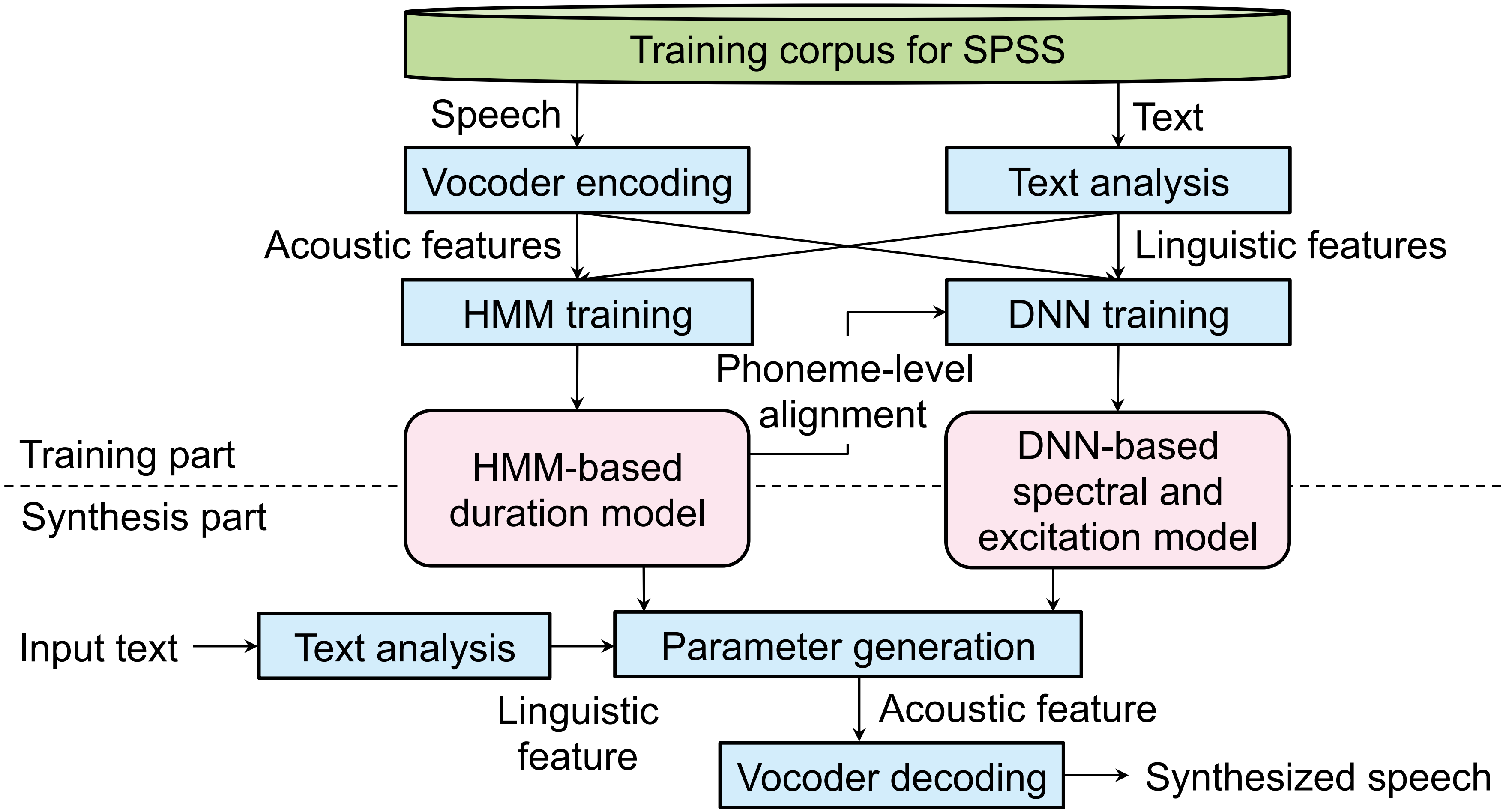
Blizzard Challenge 2016 task

- Blizzard Challenge [Black, *et al.*; ’05]
  - Blizzard Challenge was started in order to better understand and compare research techniques
- Blizzard Challenge 2016
  - Task is to construct a TTS system from children’s audiobooks
  - Five-hours speech data and text pairs are provided
  - All 50 books were recorded by one English female speaker
  - Speech data includes various speaking styles, emotions, characters, etc.
  - Example of provided data

"I'm king of the jungle," roared Lion.
"I'm going to eat you all up."
"No!" cried the jungle animals.

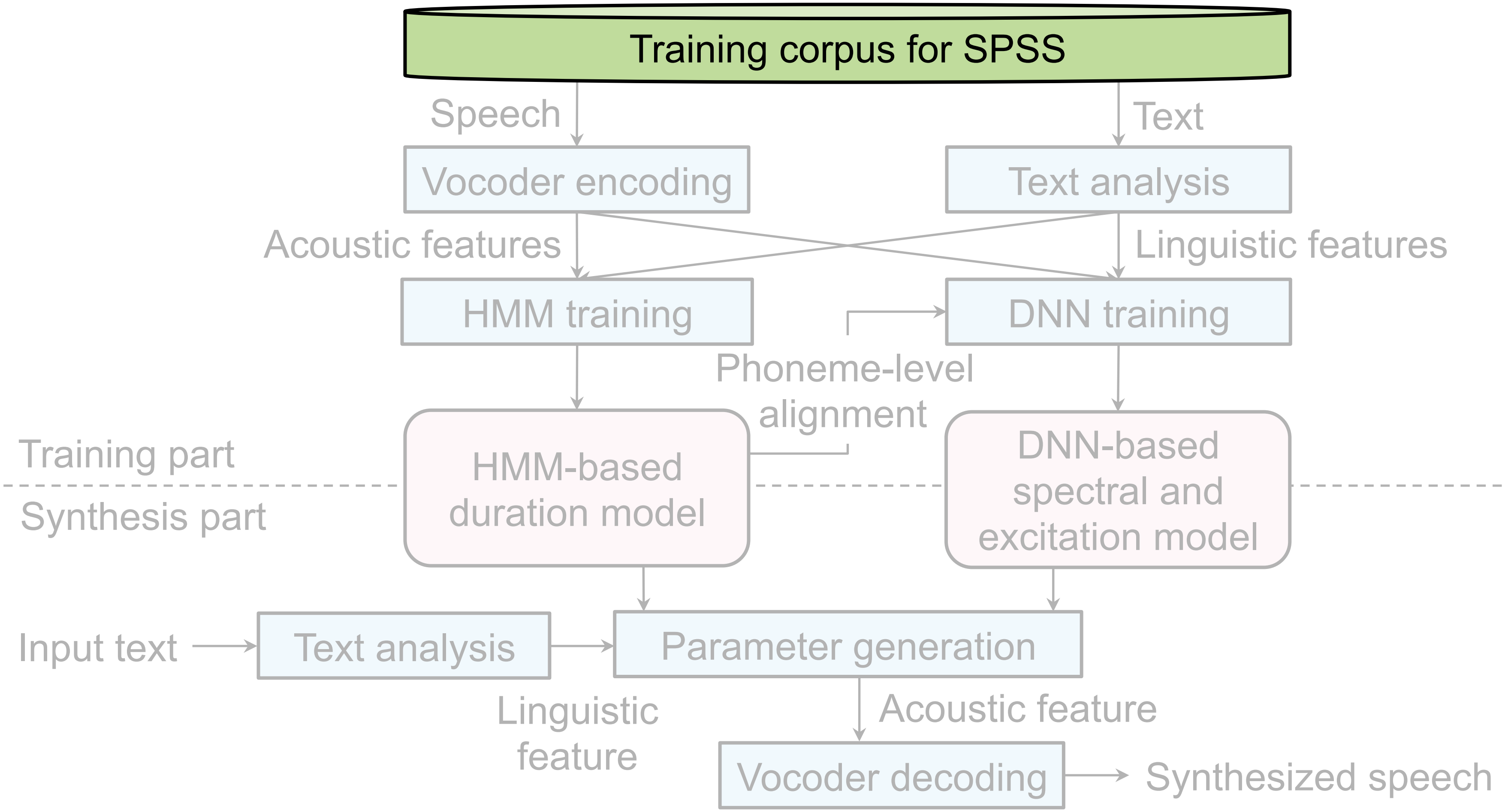
Character1
Character2
Descriptive part

NITech system



- Automatic construction of training corpus from audiobooks
- Design of linguistic features for SPSS based on audiobooks
- DNN-based SPSS

NITech system



- Automatic construction of training corpus from audiobooks
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Automatic construction of training corpus

- Mismatches are present in speech data and text
  - Substitution: misreading text
  - Deletion: unrecording text
  - Insertion: recording additional information, i.e., onomatopoeia

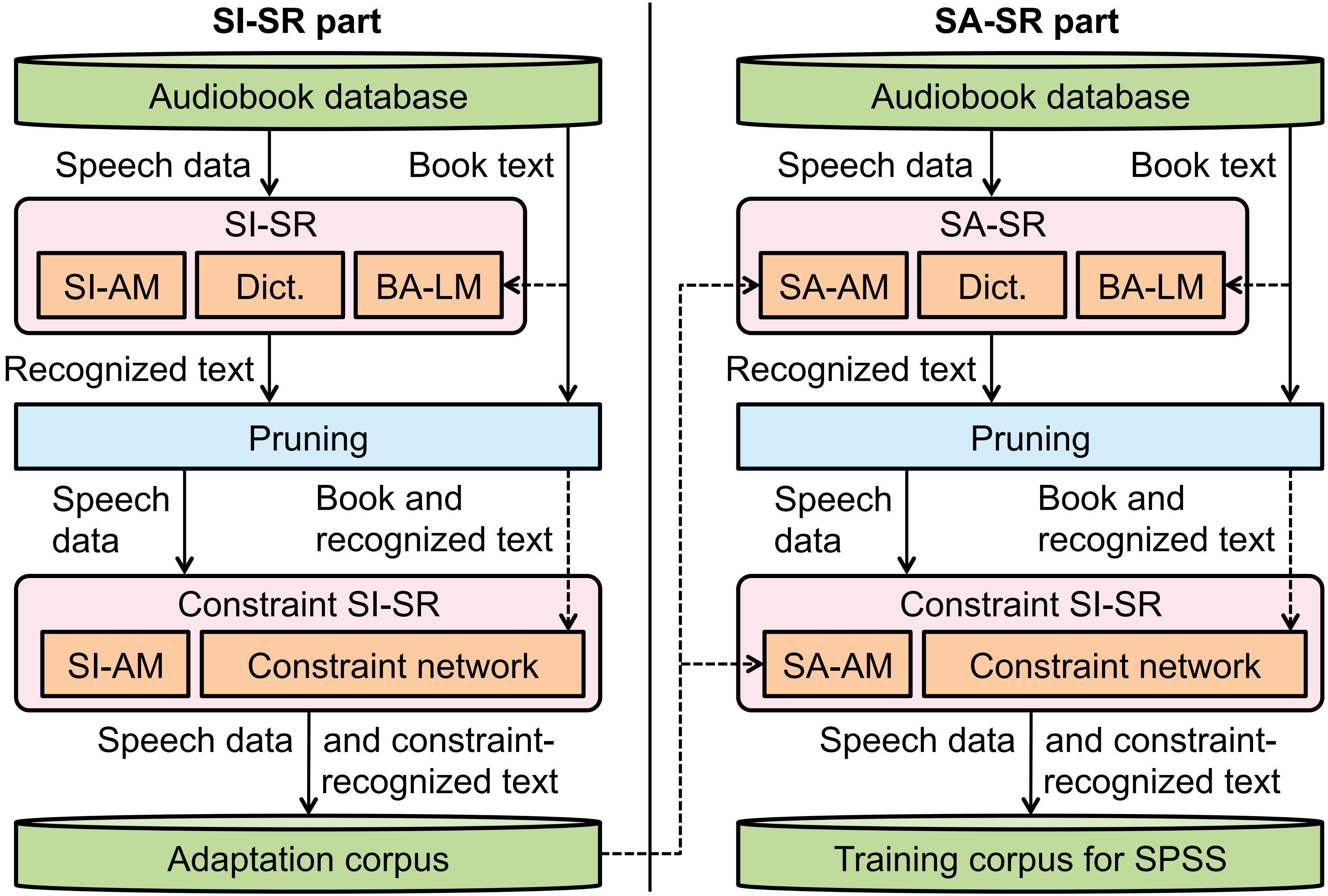
⇒ This will negatively affect an acoustic model of SPSS

- Training corpus construction using speech recognizer
  - Texts are estimated from speech data [Braunschweiler, *et al.*; ’10]
  - Texts may include speech recognition errors

Speech data	🔊
Correct text	he came to a cottage knock knock
Book text	he came to a cottage ________
Recognized text	she came to a cottage knock knock

Speech recognition using a constrained word network is conducted

Overview of training corpus construction



SI: speaker-independent, SA: speaker-adapted, BA, book adapted,
SR: speech recognize, AM: acoustic model, LM: language model

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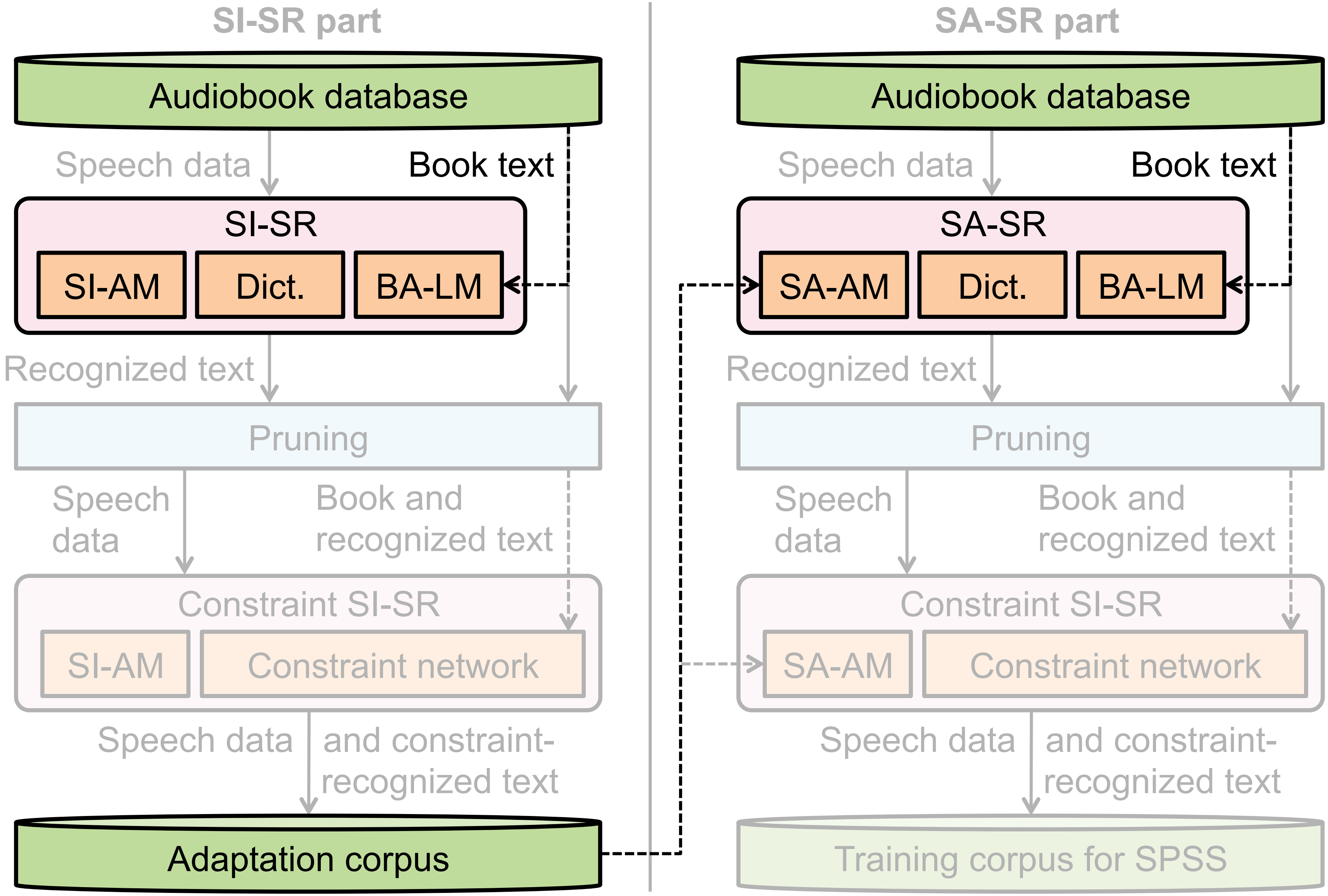

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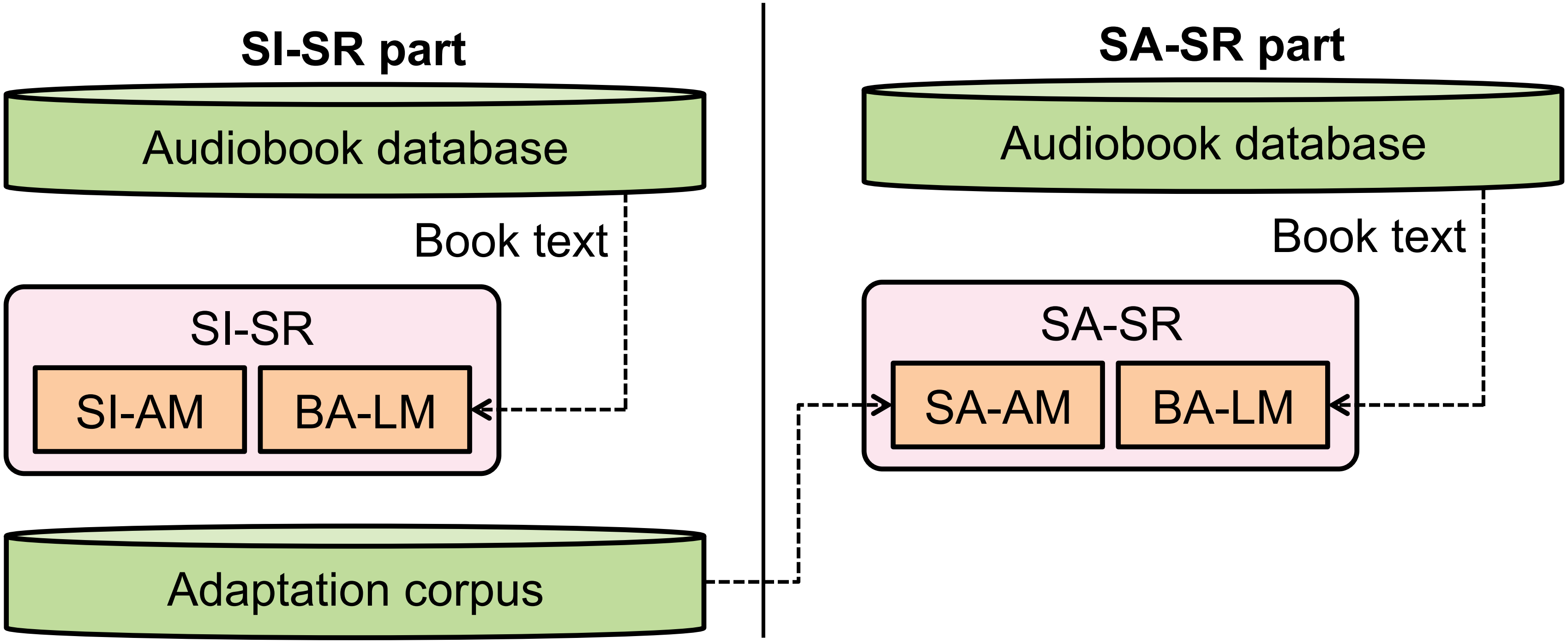
Adapted model

- Language model (LM)
  - Most book texts match speech data
  - LM based on book texts is useful for speech recognition
  - Book-adapted LM is used for speech recognition
- Acoustic model (AM)
  - Speaker-adapted AM is constructed by using SI-SR results



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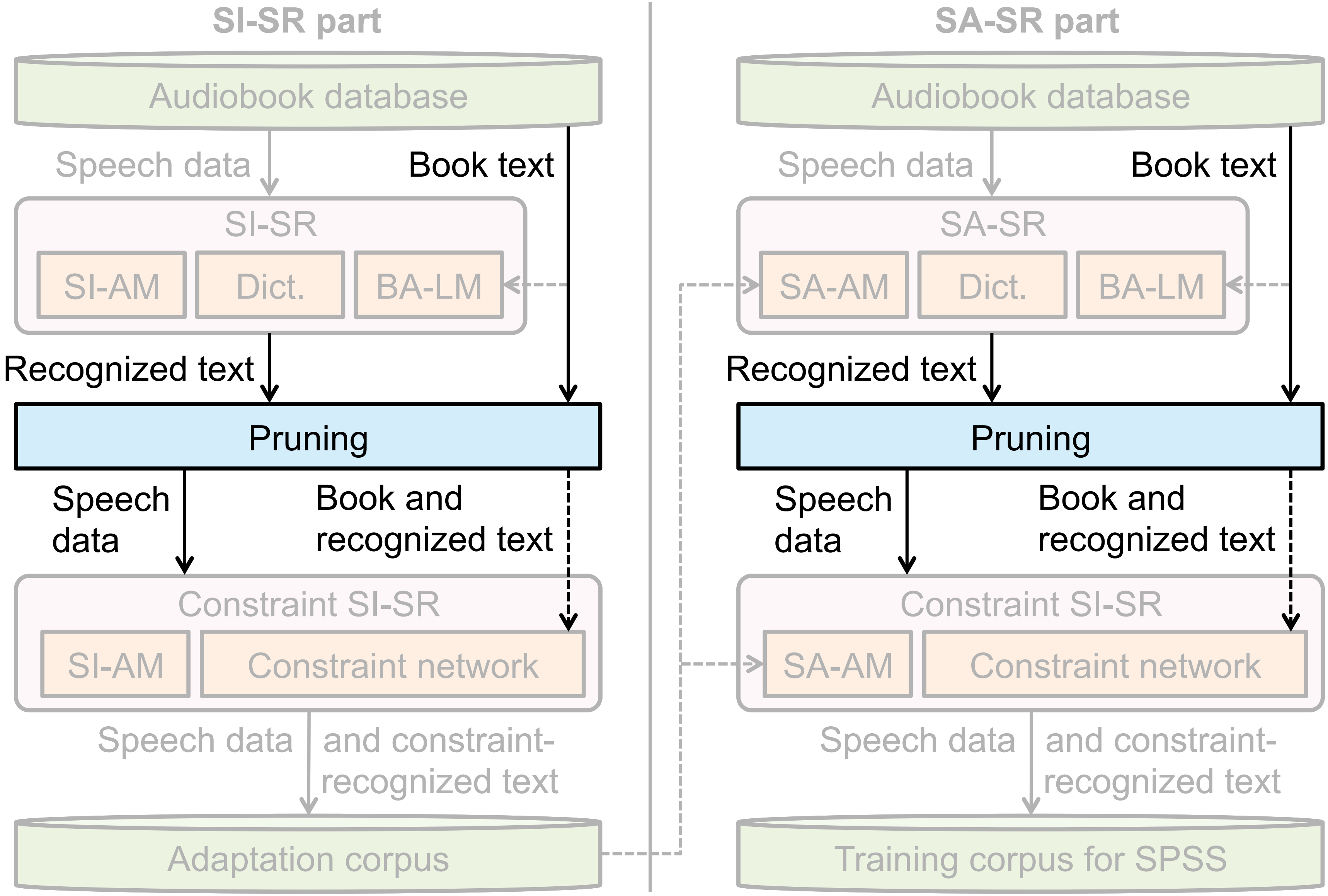

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Pruning

- Word-match accuracy
  - Concordance rate of book text and recognized text

Book text	he came to a cottage
Recognized text	she came to a cottage knock knock

word-match accuracy
= 57%

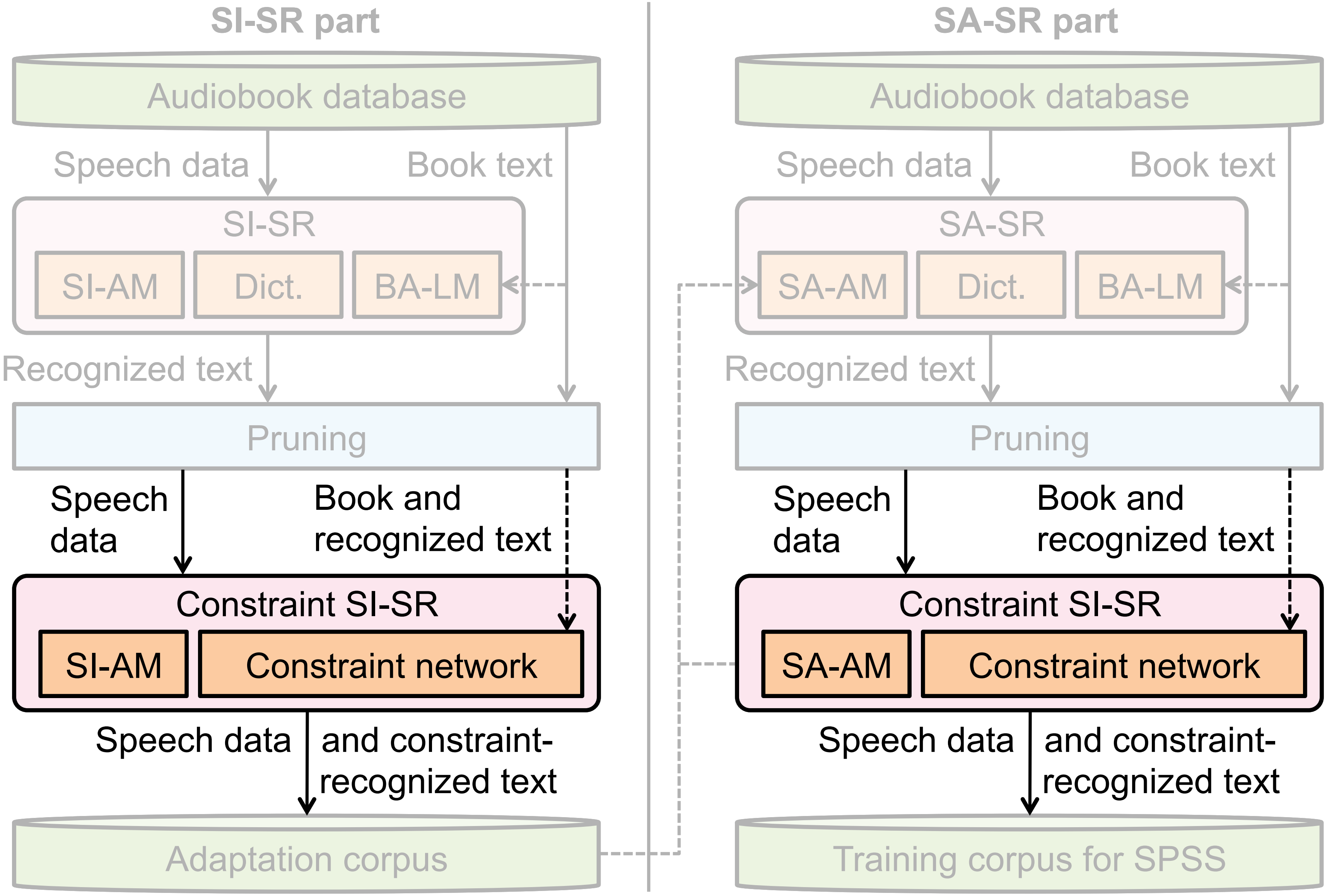
  - Low word-match accuracy

    ⇒ Reliability of text is lower

- Pruning of low word match accuracy
  - If word-match accuracy is not more than threshold, speech data and text pair is pruned from training corpus
  - Relation between quantity and quality of corpus is trade-off

Threshold	Large	Small
Quantity of corpus	Small	Large
Quality of corpus	High	Low

Overview of training corpus construction



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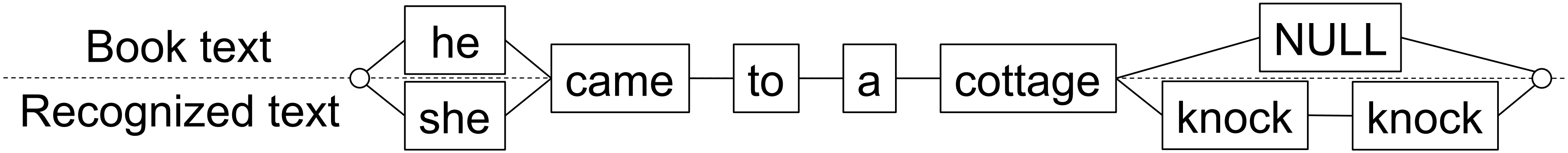
Constraint speech recognition

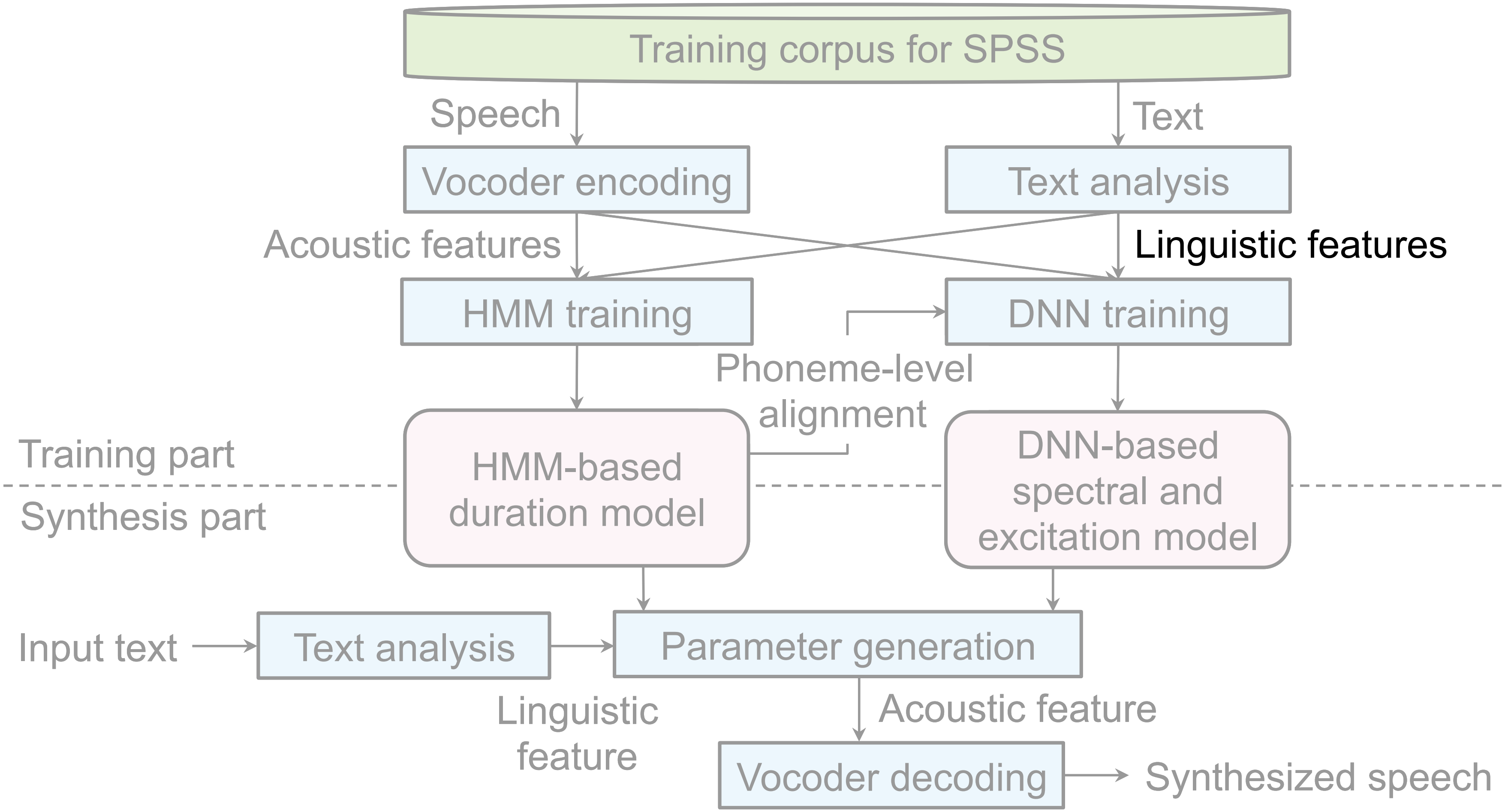
- Constraint-recognized text
  - Speech recognition using constrained word network consisting of book and recognized text
  - Path penalty
    - Book text is NULL: path penalty for book text
    - Otherwise: path penalty for recognized text
  - Speech recognizer with constrained word network without LM

Book text	he came to a cottage
Recognized text	she came to a cottage knock knock



- Contain text corresponding to additional speech information
- Reduce speech recognition errors

NITech system



- Automatic construction of training corpus from audiobooks
- Design of linguistic features for SPSS based on audiobooks
- DNN-based SPSS

Design of linguistic features (1/2)

- Linguistic features
  - Context-dependent model is used to capture contextual factors
  - Appropriate linguistic features design is needed to synthesize high-quality speech
  - Speech in conversational and descriptive parts of audiobook
    - Conversational part: emphatically, emotionally, etc.
    - Descriptive part: comparatively neutrally

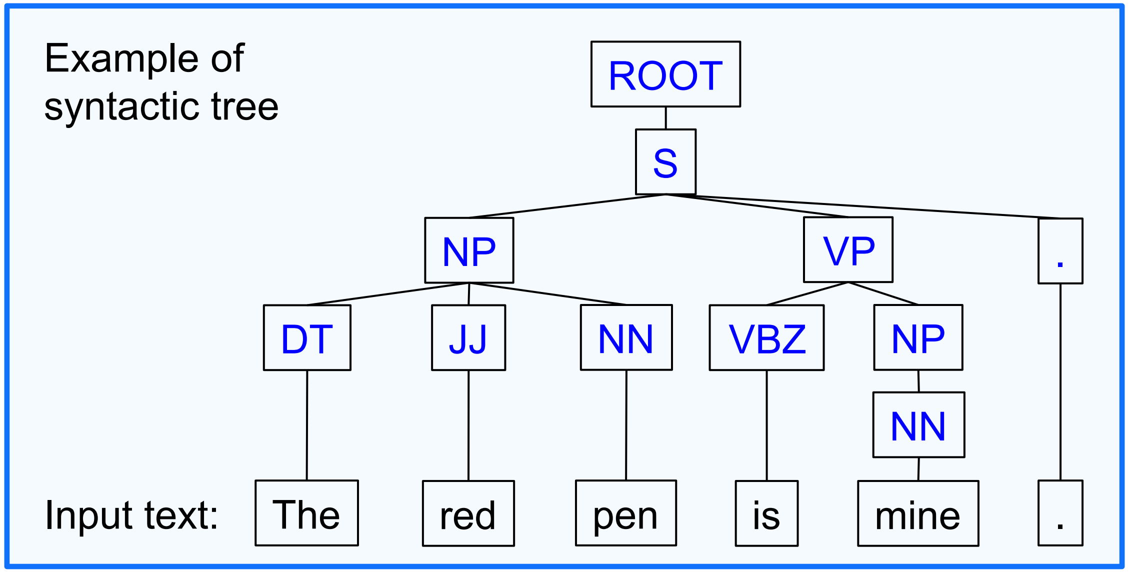
    ⇒ Double quotes are used to express conversational part
  - Prosodic information
    - Intonation, rhythm, etc.

    ⇒ Detailed parsing results are used to express prosodic information

- Linguistic feature using double quotes
  - Example of added linguistic features
    - Whether the current phoneme is enclosed by double quotes
    - The rate of word enclosed by double quotes in this page

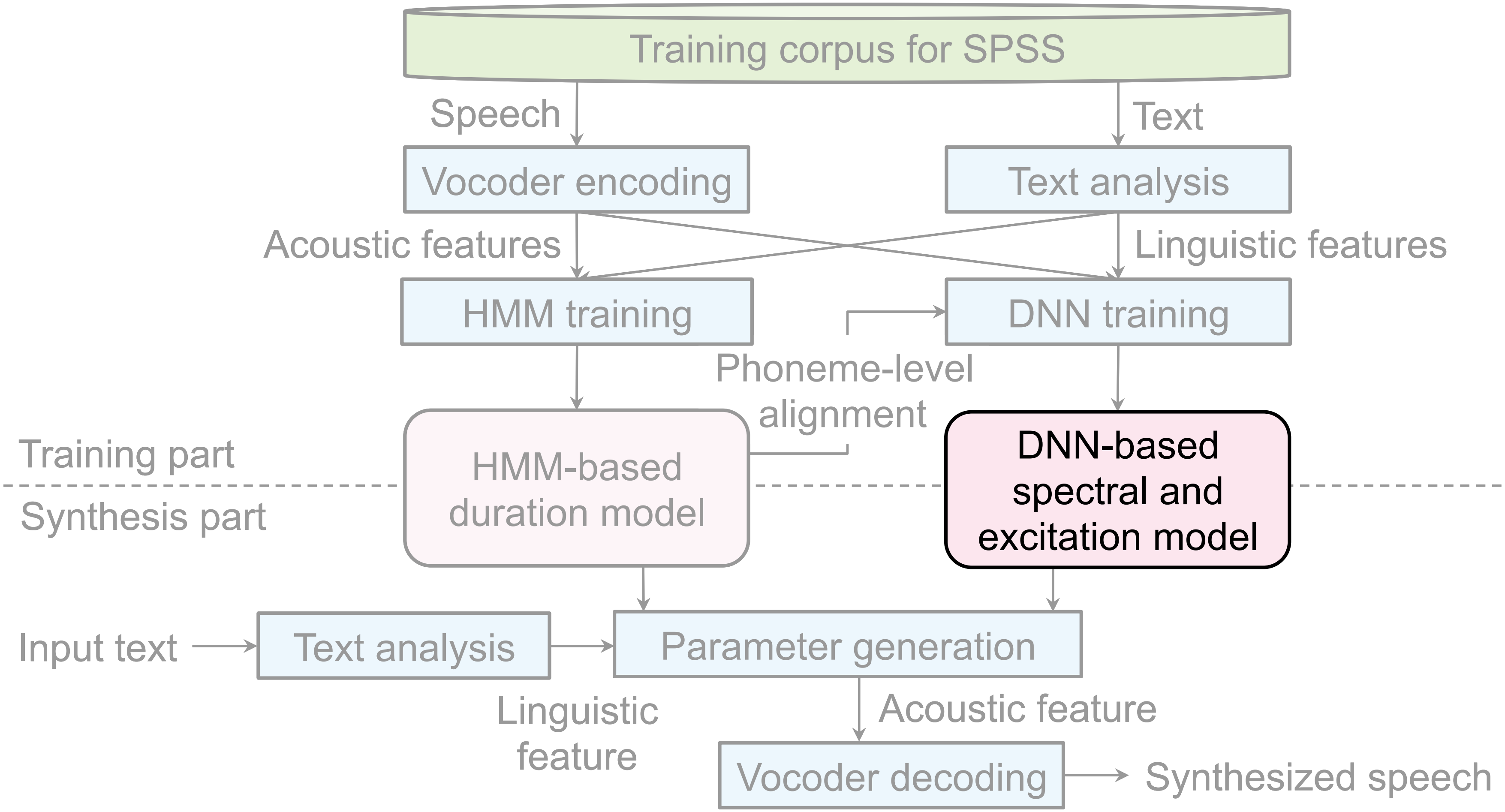
Design of linguistic features (2/2)

- Linguistic feature using detailed parsing results
  - Results of parsing is represented by syntactic tree



  - Example of added linguistic features
    - Guess part-of-speech of the parent of the current word
    - Distance on the syntactic tree between the current word and the previous word
    - Position of the current word in the parent of the current word
    - The number of phonemes in the parent of the current word

NITech system



- Automatic construction of training corpus from audiobooks
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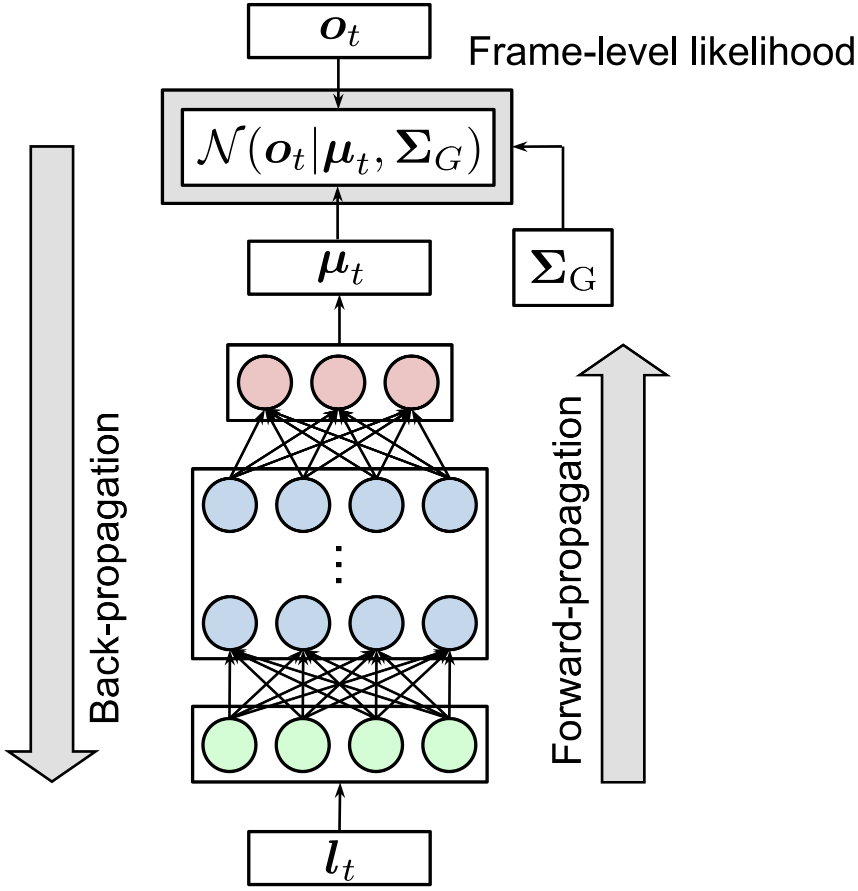
DNN-based SPSS

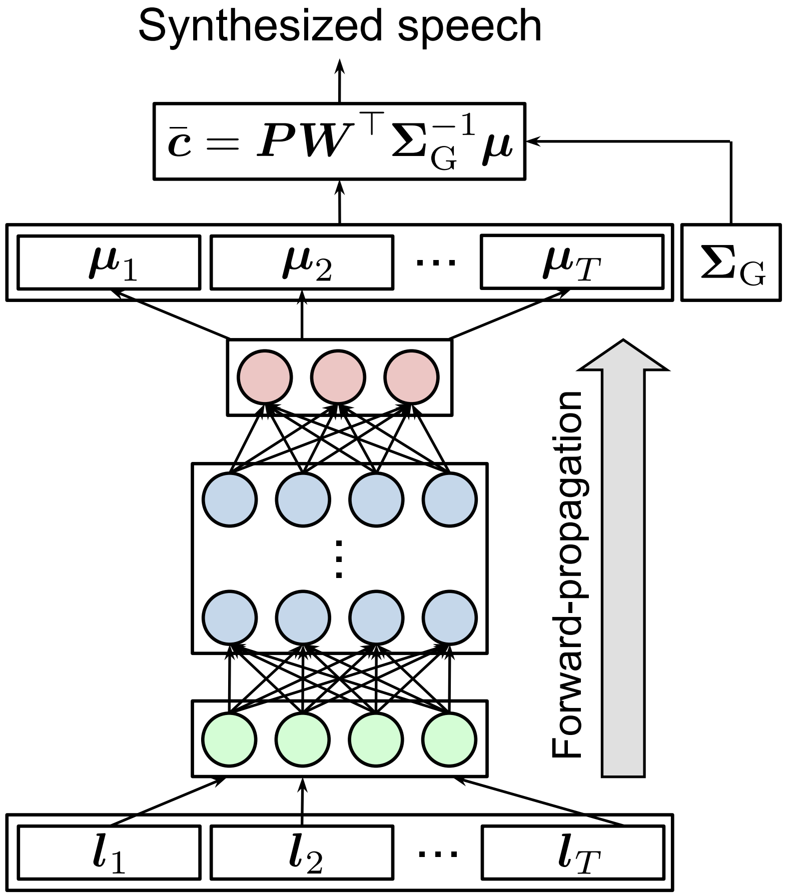
- DNN-based SPSS [Zen, *et al.*; ’12]
  - DNN is trained to represent a mapping function from linguistic features to acoustic features
  - DNN-based SPSS improves naturalness of synthesized speech
  - Inconsistency in training and synthesis criterion
  - Over-smoothing on speech parameter trajectories

Trajectory training considering global variance

DNN-based SPSS (1/3)

- Frame-level training





$\boldsymbol{l}$: linguistic feature vector

$\boldsymbol{\mu}$: mean vector

$\boldsymbol{\Sigma}_G$: globally tied covariance matrix

$\boldsymbol{o}$: speech parameter vector

$\boldsymbol{c}$: static-feature vector

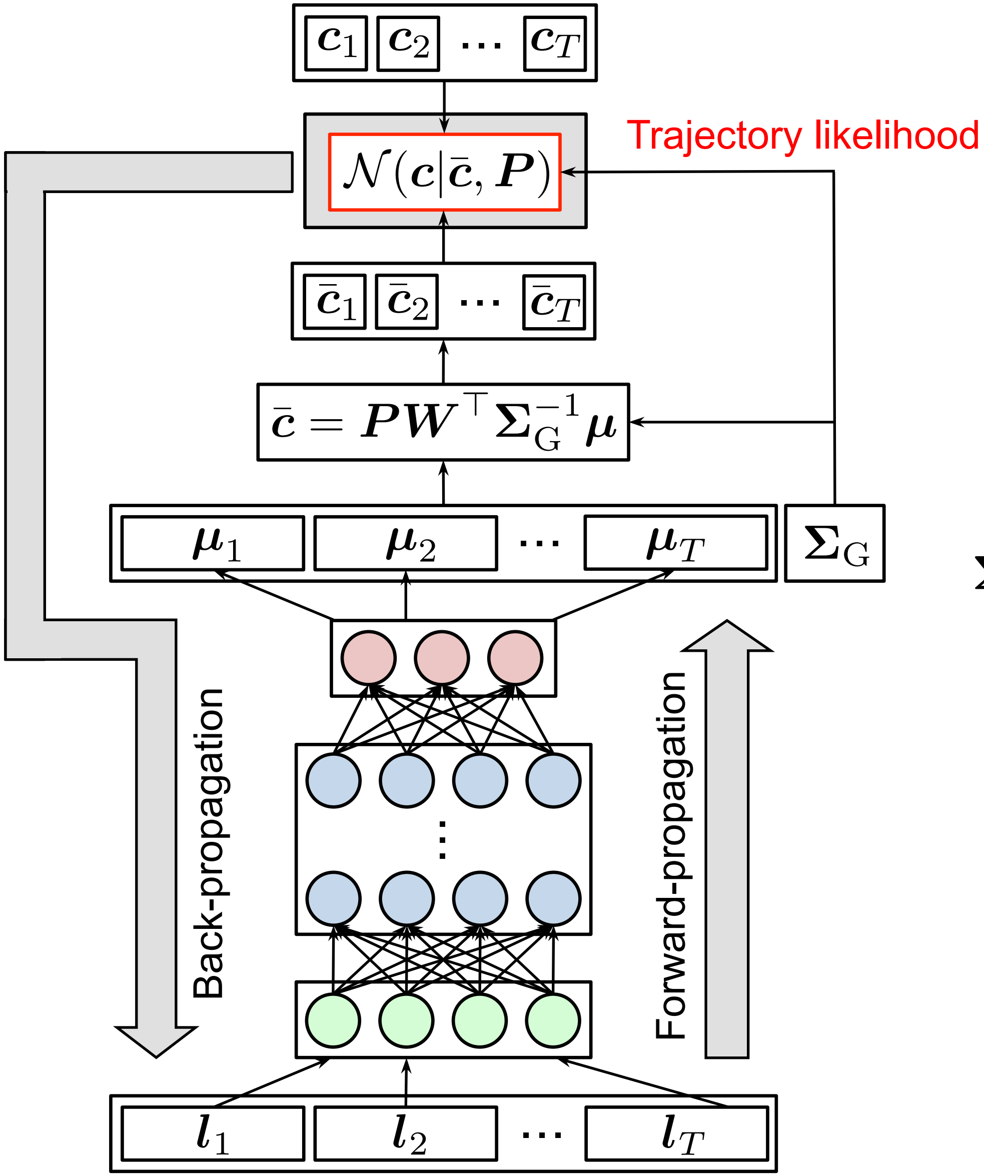
$\bar{\boldsymbol{c}}$: optimal static-feature vector

$$\boldsymbol{P} = \left(\boldsymbol{W}^\top\boldsymbol{\Sigma}_\mathrm{G}^{-1}\boldsymbol{W}\right)^{-1}$$

$\boldsymbol{W}$: window matrix

DNN-based SPSS (2/3)

- Trajectory training [Hashimoto, *et al.*; ’16]



c_1 c_2 … c_T
$\mathcal{N}(c|\bar{c}, P)$
Trajectory likelihood
$\bar{c}_1$ $\bar{c}_2$ … $\bar{c}_T$
$\bar{c} = PW^\top \Sigma_G^{-1} \mu$
μ_1 μ_2 … μ_T
Σ_G
Back-propagation
Forward-propagation
l_1 l_2 … l_T

$\boldsymbol{l}$: linguistic feature vector

$\boldsymbol{\mu}$: mean vector

$\boldsymbol{\Sigma}_G$: globally tied covariance matrix

$\boldsymbol{c}$: static-feature vector

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$$\boldsymbol{P} = \left(\boldsymbol{W}^\top \boldsymbol{\Sigma}_G^{-1} \boldsymbol{W}\right)^{-1}$$

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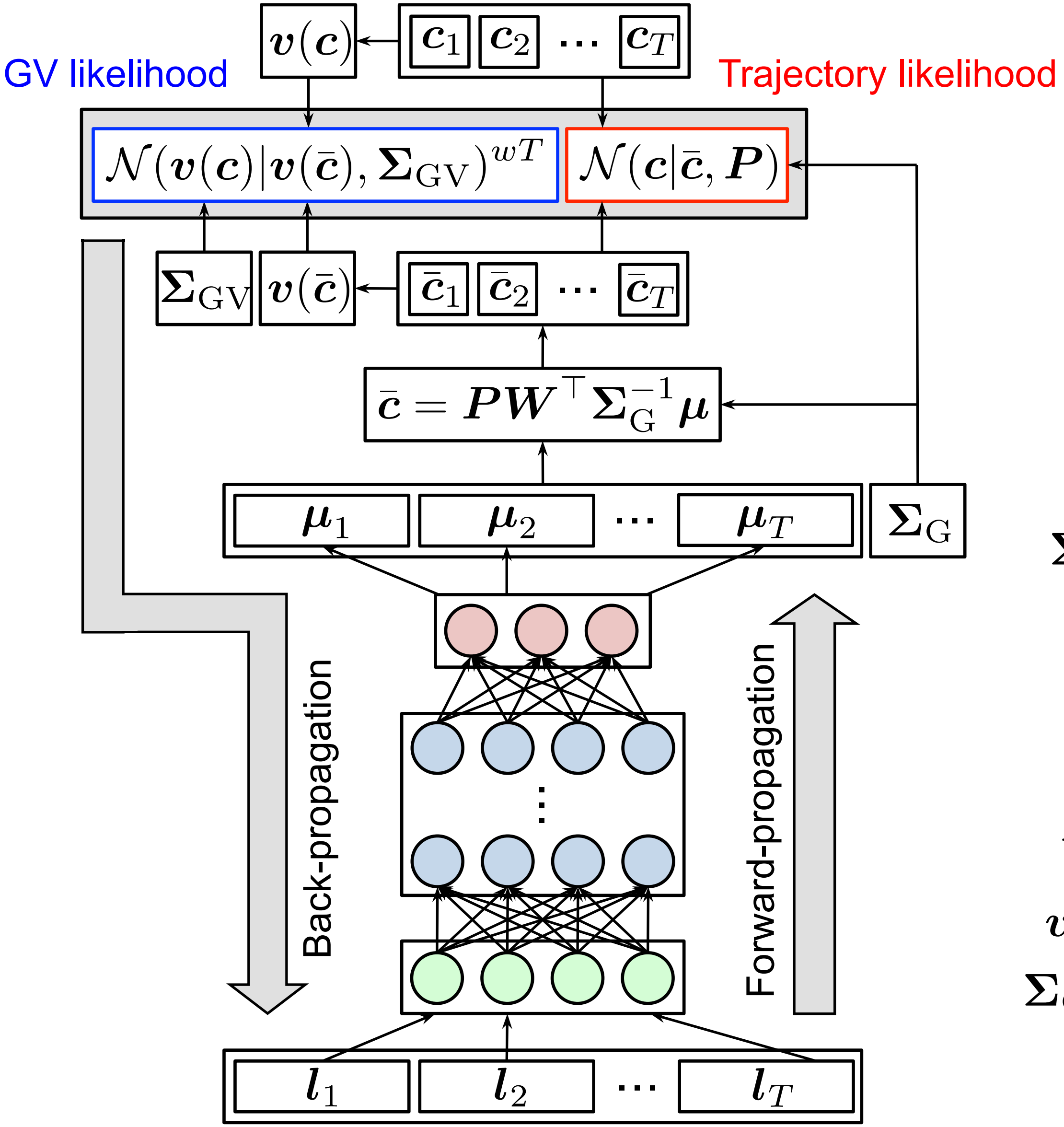
DNN-based SPSS (3/3)

- Trajectory training considering GV [Hashimoto, *et al.*; '16]



GV likelihood
Trajectory likelihood
$\boldsymbol{v}(\boldsymbol{c})$
$\boldsymbol{c}_1$ $\boldsymbol{c}_2$ $\cdots$ $\boldsymbol{c}_T$
$\mathcal{N}(\boldsymbol{v}(\boldsymbol{c})|\boldsymbol{v}(\bar{\boldsymbol{c}}), \boldsymbol{\Sigma}_{\mathrm{GV}})^{wT}$
$\mathcal{N}(\boldsymbol{c}|\bar{\boldsymbol{c}}, \boldsymbol{P})$
$\boldsymbol{\Sigma}_{\mathrm{GV}}$
$\boldsymbol{v}(\bar{\boldsymbol{c}})$
$\bar{\boldsymbol{c}}_1$ $\bar{\boldsymbol{c}}_2$ $\cdots$ $\bar{\boldsymbol{c}}_T$
$\bar{\boldsymbol{c}} = \boldsymbol{P}\boldsymbol{W}^\top\boldsymbol{\Sigma}_{\mathrm{G}}^{-1}\boldsymbol{\mu}$
$\boldsymbol{\mu}_1$ $\boldsymbol{\mu}_2$ $\cdots$ $\boldsymbol{\mu}_T$
$\boldsymbol{\Sigma}_{\mathrm{G}}$
Back-propagation
Forward-propagation
$\boldsymbol{l}_1$ $\boldsymbol{l}_2$ $\cdots$ $\boldsymbol{l}_T$

$\boldsymbol{l}$: linguistic feature vector

$\boldsymbol{\mu}$: mean vector

$\boldsymbol{\Sigma}_G$: globally tied covariance matrix

$\boldsymbol{c}$: static-feature vector

$\bar{\boldsymbol{c}}$: optimal static-feature vector

$$\boldsymbol{P} = \left(\boldsymbol{W}^\top\boldsymbol{\Sigma}_{\mathrm{G}}^{-1}\boldsymbol{W}\right)^{-1}$$

$\boldsymbol{W}$: window matrix

$\boldsymbol{v}(\cdot)$: GV vector

$\boldsymbol{\Sigma}_{\mathrm{GV}}$: GV covariance matrix

Training corpus construction conditions

Children’s audiobook	50 books, 1090 pages
SR training corpus	WSJ0, WSJ1, TIMIT
Sampling rage	16 kHz
Frame	window: Hamming, length: 25 ms, shift: 10 ms
Acoustic-feature	12-dimensional MFCC + Δ + $\Delta\Delta$
Acoustic model	3-state left-to-right GMM-HMM
Language model	tri-gram
Pruning threshold	word-match accuracy: 90%

TTS system conditions

Training corpus	825 pages (constraint-recognition text)
Sampling rage	44.1 kHz
Frame	window: F0-adapteve Gaussian, shift: 5 ms
Acoustic feature	229-dimensional acoustic features (49-dimensional STRAIGHT mel-cepstrum, 24-dimensional aperiodicity measure + Δ + ΔΔ, log F0, voiced/unvoiced features)
Linguistic feature	426-dimensional linguistic features (423-dimensional binary and numerical features, three duration features)
HMM structure	5-sate left-to-right MSD-HSMM
DNN structure	3 hidden layers with 2048 hidden units, activation function: sigmoid, dropout: 50%, GV weight: 0.001

Experimental conditions of listening test

Participant	paid participants (104 native speakers)
Page domain	7 criteria, 60-point MOS
Sentence domain	2 criteria, 5-point MOS
Intelligibility test	semantically unpredictable sentence (SUS), word error rate (WER)
System	17 systems (1 natural speech, 16 TTS systems)

Speech samples

- Automatic construction of training corpus from audiobooks

Text \ Threshold	80%	90%	100%
Book text	🔊 🔊	🔊 🔊	🔊 🔊
Recognized text	🔊 🔊	🔊 🔊	🔊 🔊
Constraint-recognized text	🔊 🔊	🔊 🔊	🔊 🔊

- Design of linguistic features for SPSS based on audiobooks

Base	DQ	Parser	DQ + Parser
🔊 🔊	🔊 🔊	🔊 🔊	🔊 🔊

- DNN-based SPSS

HMM	DNN	Trajectory DNN	Trajectory GV DNN
🔊 🔊	🔊 🔊	🔊 🔊	🔊 🔊

Experimental results

- Page domain (60-point MOS)

Criterion	Overall impression	Pleasant ness	Speech pause	Stress	Intonation	Emotion	Listening effort
MOS	24	23	30	29	27	27	27
Rank	6th	7th	3rd	3rd	4th	5th	4th

- Sentence domain (5-point MOS)

Criterion	Naturalness	Similarity
MOS	3.0	2.6
Rank	5th	6th

- Intelligibility test

WER	12%
Rank	1st

Experimental results

Page domain (60-point MOS)

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Sentence domain (5-point MOS)

Criterion	Naturalness	Similarity
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Intelligibility test

WER	12%
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Page-level training and synthesis
⇒ High MOS of speech pause

Experimental results

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Sentence domain (5-point MOS)

Criterion	Naturalness	Similarity
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Intelligibility test

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Linguistic features of parsing
and trajectory training
⇒ High MOS of stress and intonation

Experimental results

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WER	12%
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Training corpus include various speaking style, emotion, character, etc.
⇒ Modeling is difficult
⇒ Low MOS of similarity

Experimental results

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Criterion	Naturalness	Similarity
MOS	3.0	2.6
Rank	5th	6th

- Intelligibility test

WER	12%
Rank	1st

Linguistic features of double quotes
⇒ Can distinguish descriptive part
⇒ Intelligible synthesized speech

Conclusion

- TTS system developed for the Blizzard Challenge 2016
  - NITech team focused on:
    - Automatic construction of training corpus from audiobooks
    - Design of linguistic features for SPSS based on audiobooks
    - DNN-based SPSS
  - Large-scale subjective listening tests
    - Synthesized high natural and highest intelligible speech
    - Should improve speaker similarity
- Future work
  - Improving linguistic features
    - Adding linguistic features of book, page, sentence, etc. codes
  - Improving robustness of outliers
    - ε-contaminated Gaussian loss [Zen, *et al.*; ’16]

Page-level training and synthesis

- Explicit page-tuning sounds
  - Page-tuning sounds are not suited for training AM
  - GMM is trained to detect page-tuning sounds
  - Speech data are divided into page-by-page speech data
  - Page-level decoding, training, and synthesis are conducted

Design of linguistic features

- Linguistic feature using page information
  - The number of {phrases, sentences} in this page
  - position of the current sentence in this page
- Linguistic feature using double quotes
  - Whether the {previous, current, next} {phoneme, syllable, word, phrase} is enclosed by double quotes
  - The rate of {word, phrase} enclosed by double quotes in this page
- Linguistic feature using detailed parsing results
  - Guess part-of-speech of the parent of the current word
  - Distance on the syntactic tree between the current word and {the {previous, next} word, root of the syntactic tree, the {previous, next} content word}
  - Position of the current word in the parent of the current word
  - The number of {phonemes, syllables, words} in the parent of the current word

HTS benchmark system

- Text: INNOETICS + NII (shared)
- Speech: page-level speech data (shared)
- Differences from HTS STRAIGHT demo scripts
  - Page-level linguistic features (shared)
  - F0 extractor: RAPT, SWIPE’, PEAPER voting method
  - Flat start using DAEM algorithm without phoneme alignment
  - GV weight: 1.0 → 0.0001