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Automatic Descriptive Transcription of Carnatic Music

Presented at his Ph.D. Defense by

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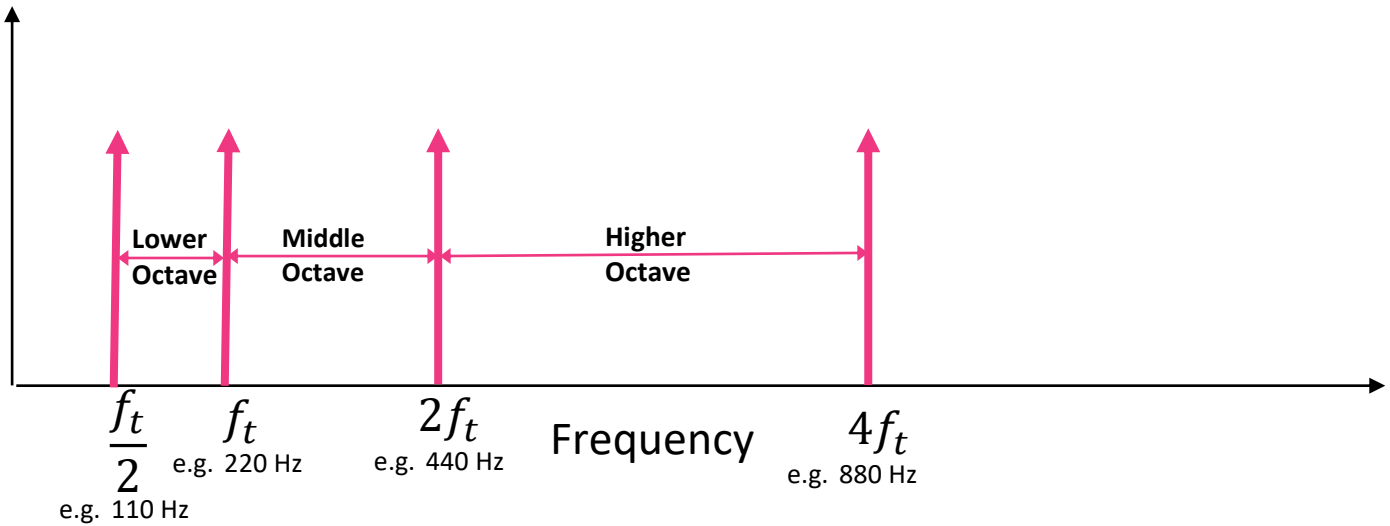
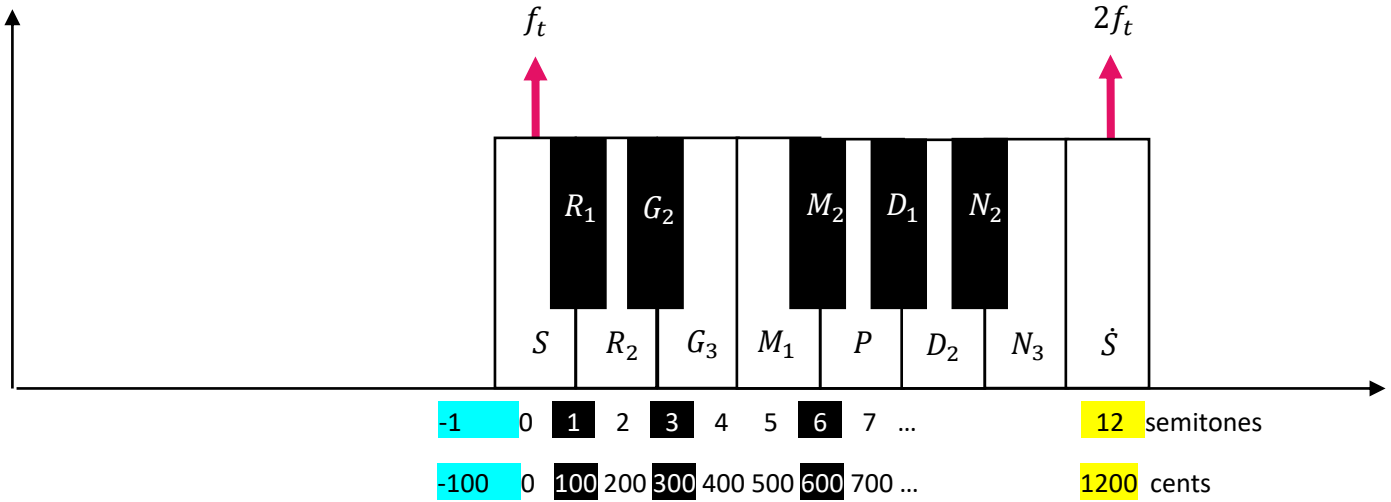
Pitch, Tonic, and Octave

- We use ‘pitch’ to signify ‘measured fundamental frequency’
- All melodies in Indian music are aligned to a *tonic note*
- If f_t is the pitch of the tonic note in Hz, range of pitch values $[f_t, 2f_t)$ is an **octave**



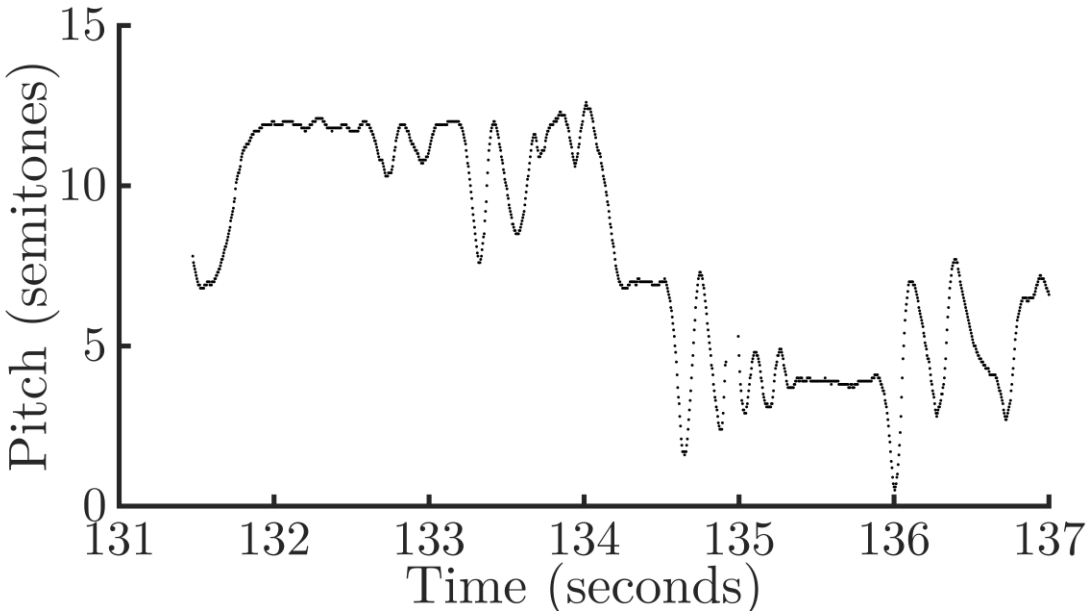
Twelve notes per octave

- Twelve notes per octave are used in several music systems
- Pitch f in Hz is converted to semitones $s = 12 \log_2 \frac{f}{f_t}$, for a *tonic* note of pitch f_t Hz



Carnatic Music (CM) Pitch curve example

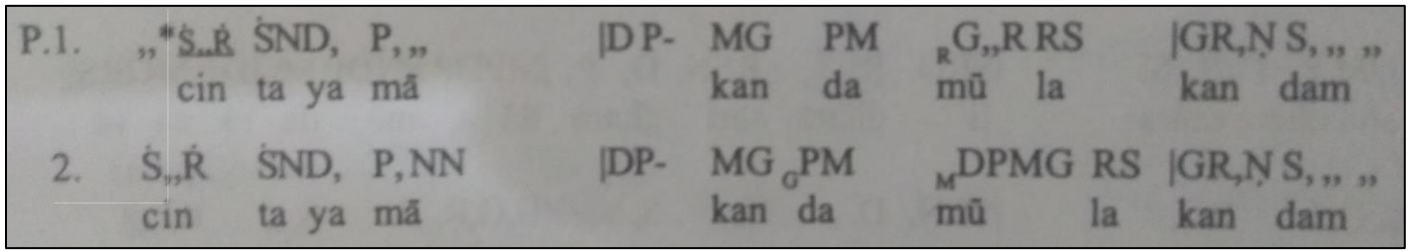
- CM uses *gamakas*, which are continuous movements of pitch between notes
- Pitch is tracked as a function of time (every $T_0 \approx 4.44$ ms), $s[n] = 1200 \log_2 \frac{f[n]}{f_t}$ cents



Challenges in Transcription of *gamakas*

- *Gamakas* are mandatory in CM
- … but are not captured in extant notation

T K Govinda Rao



- Synthesizing[1] by following the notation faithfully is clearly insufficient
- Challenge: Detailed transcription of *gamakas* is complex

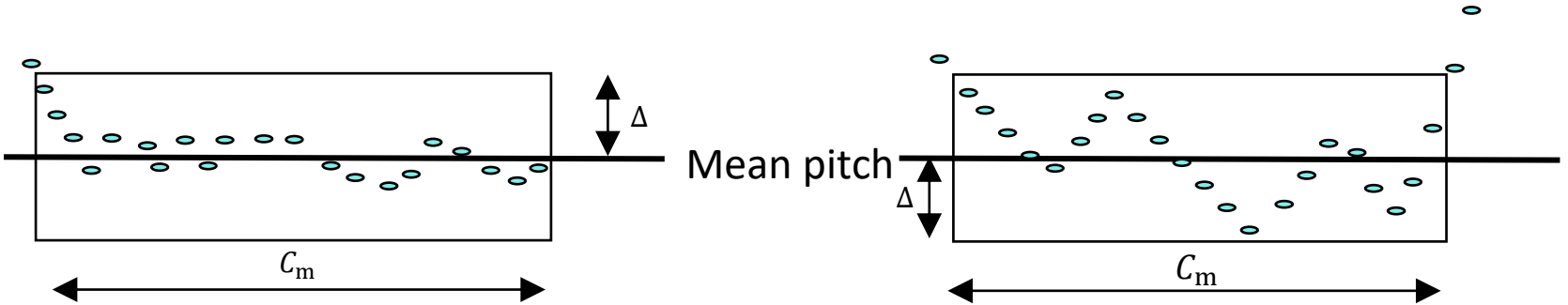
1. Kaustuv Kanti Ganguli and Preeti Rao, “Discrimination of melodic patterns in Indian classical music,” NCC 2015

Components of a CM pitch curve

- Our observation is that pitch curves in CM can be thought of as being made up of
  - **Constant-Pitch Note**s (or **CPN**s) and **Transient**s.
- Since the extent of *gamaka*/continuous pitch movements is important, we focus on
  - **Stationary Point**s (**STA**s), which are the maxima and minima of transients

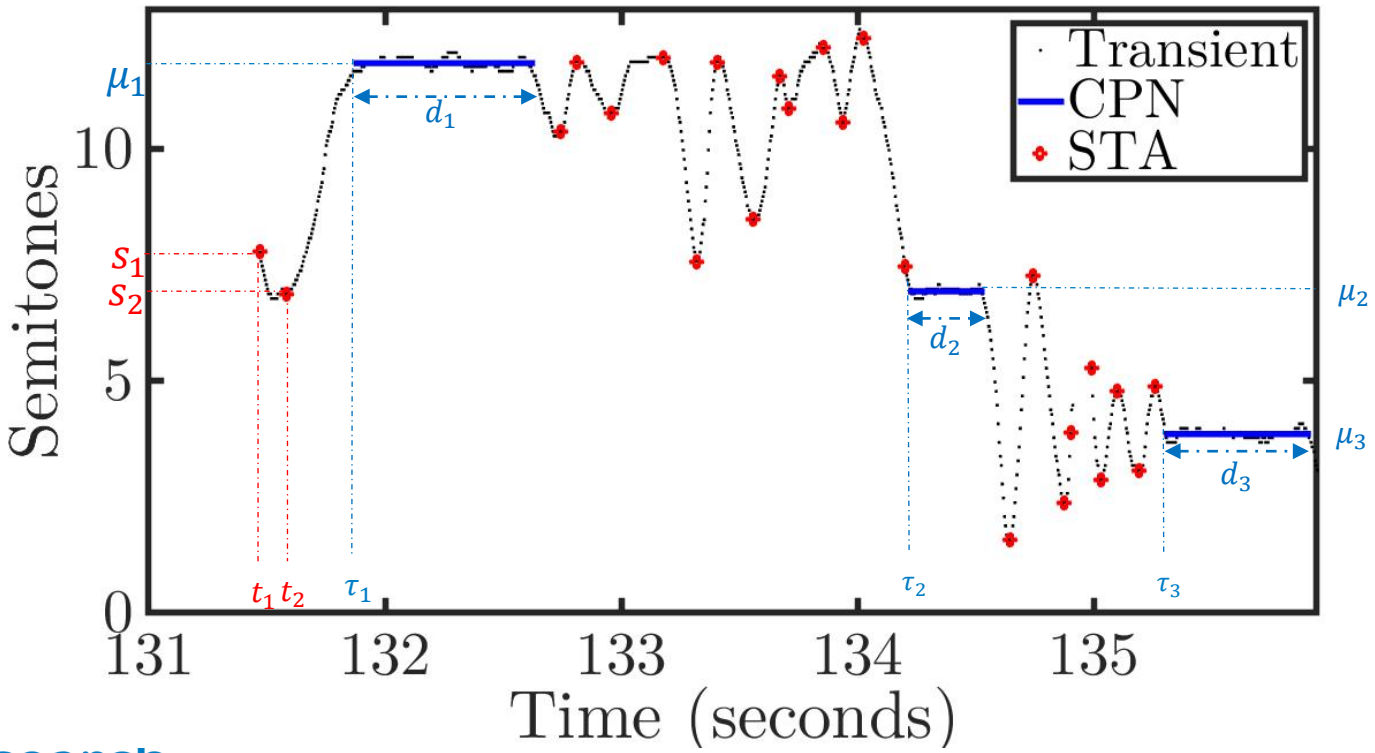
Definitions: CPN, transient, STA

- **Constant-Pitch Note (CPN):** Segment whose pitch does not vary from its mean pitch by more than $\Delta = 35$ cents and lasts for at least $C_{\mathrm{m}} = 80$ ms

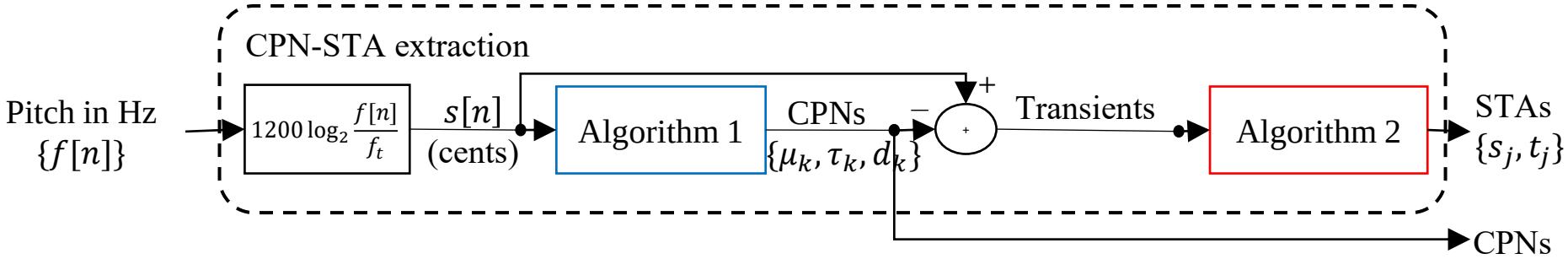


- **Transient**: Any pitch curve outside CPNs.
- **Stationary point (STA)**: Local maximum or minimum of transients

Extracted CPNs and STAs: Example



Extraction of CPNs, transients and STAs



Visualization by analogy to projectile motion

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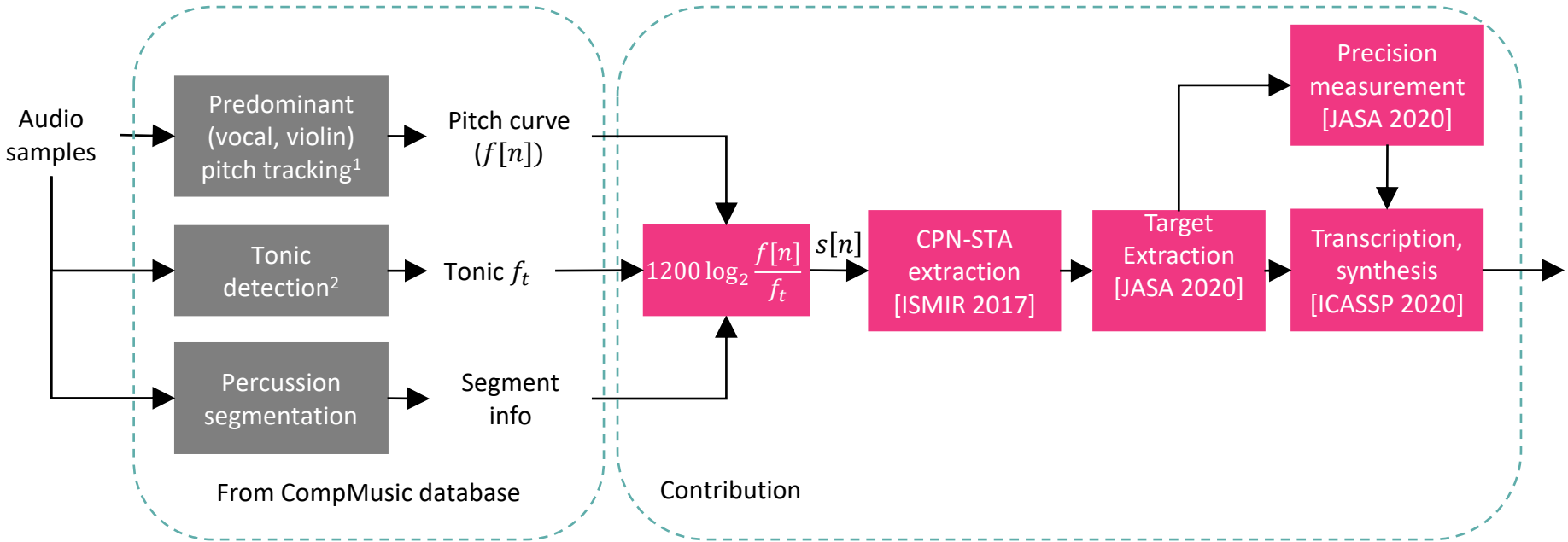
- CPNs and STAs are mapped to ledges and reflectors[1]

1. Visualization was done with the assistance of Rahul Gavas, TCS; presented at SMM19, Vienna

CompMusic: Dunya Corpus, Carnatic subset ("database")



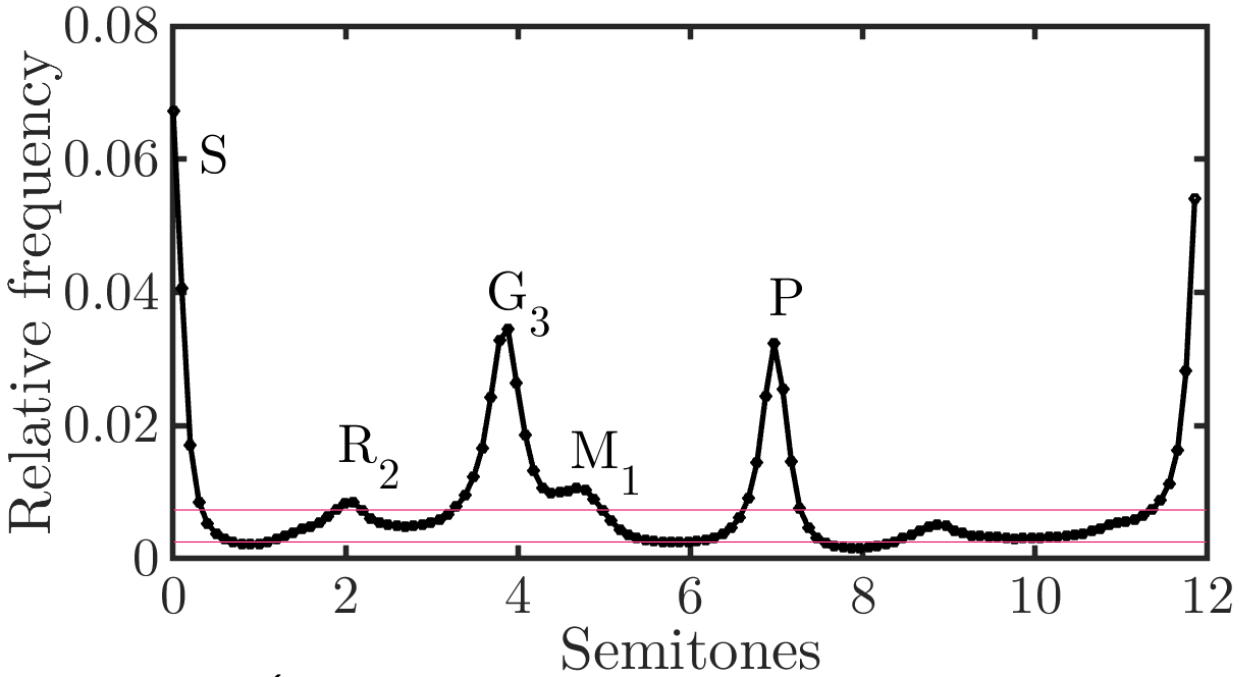
Database has 480 concert renditions in 40 *rāga*s by 64 professional musicians

- More than 200 minutes for each of 7 major ragas
- Nearly 100,000 CPNs and millions of STAs

1. Salamon and Gomez, IEEE TASLP 2015
2. Salamon, Gulati and Serra, ISMIR 2012

Histograms of pitch-values

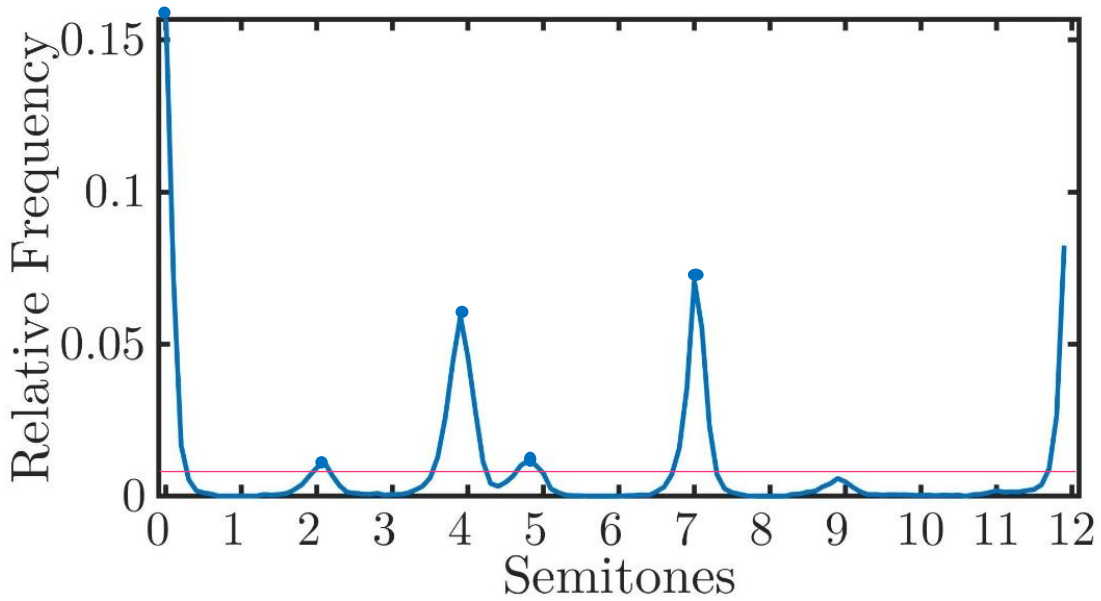
- Histogram counts the number of occurrences of pitch-values
- Wrapped around(or folded) to one octave; 120 bins of size 10 cents each



Rāga: *Śankarābharaṇam* (entire pitch curve in 12 renditions)

Detecting Raga-specific CPN Targets

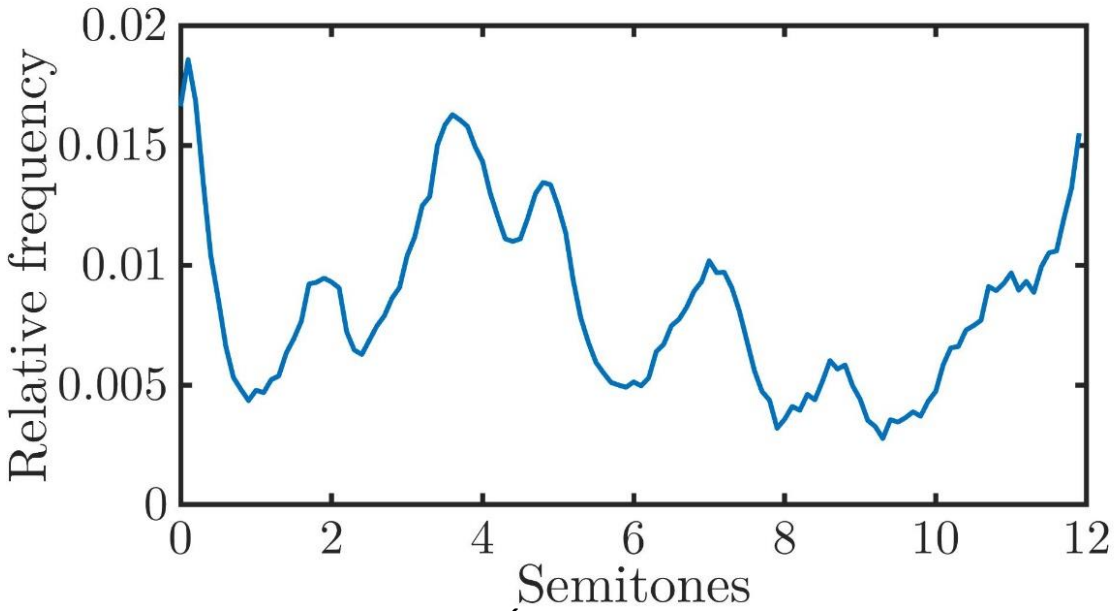
- For CPNs, detect peaks from the histogram of their mean pitch values $\{\mu_k\}$



Rāga: *Śankarābharaṇam*

Histograms of STAs

- Some peaks are visible, but are wider than in the CPN histogram
- Inconclusive about possible ‘hidden peaks’ between the visible peaks

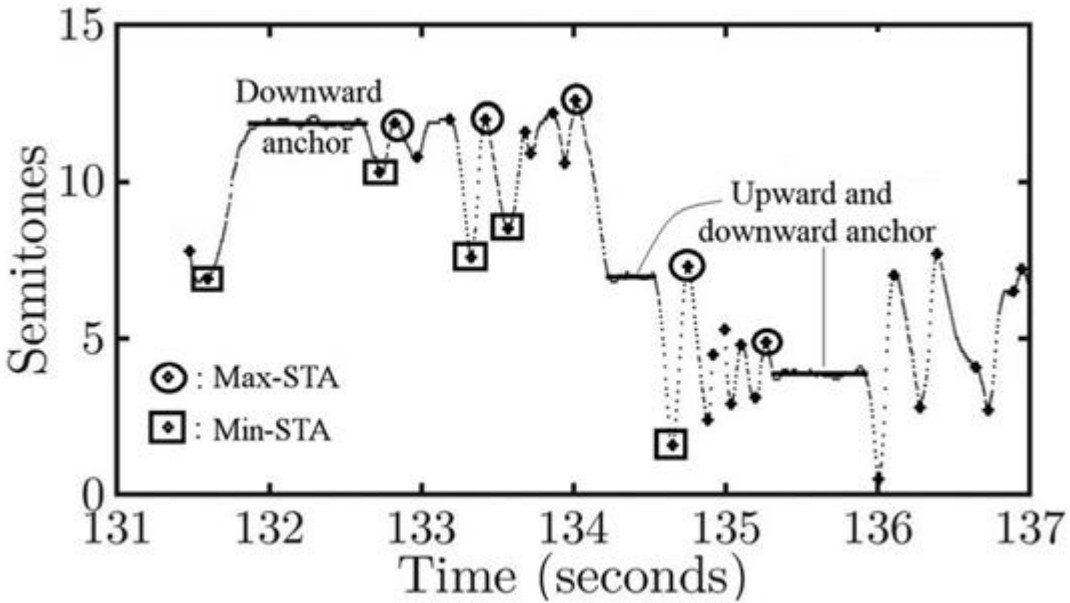


Rāga: *Śankarābharaṇam*

Anchors, Max-STAs, and Min-STAs

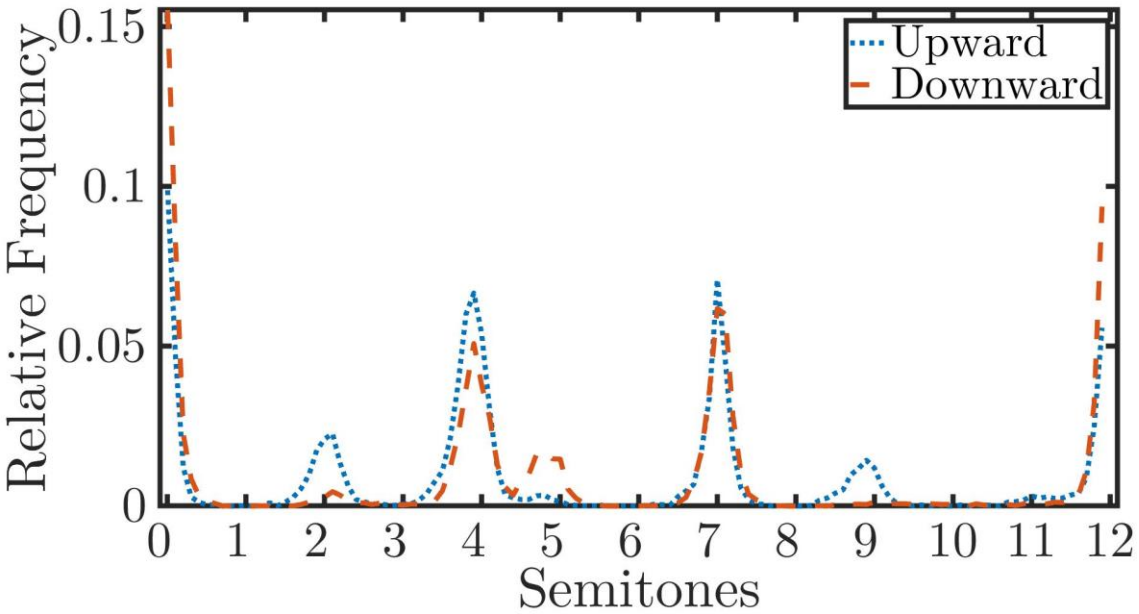
- **Anchor:** A CPN adjacent to a STA.
- An anchor can be an **upward anchor**, or a **downward anchor**, or *both*
- Each STA is *either* a **Max-STA** (local maximum) *or* a **Min-STA** (local minimum)

(Not all min-STAs & max-STAs are marked in the figure)

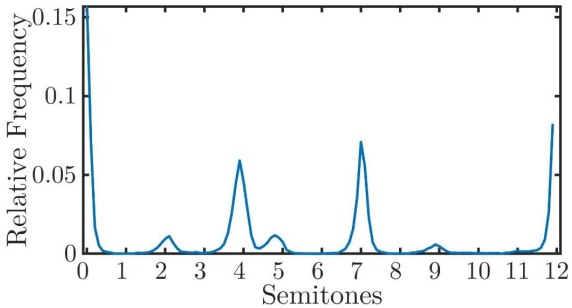


Histograms of Upward and Downward Anchors

- Peaks are as sharp as in the histogram of CPNs (reproduced on the right)
- Data-driven approach, does not use any specification in textbooks



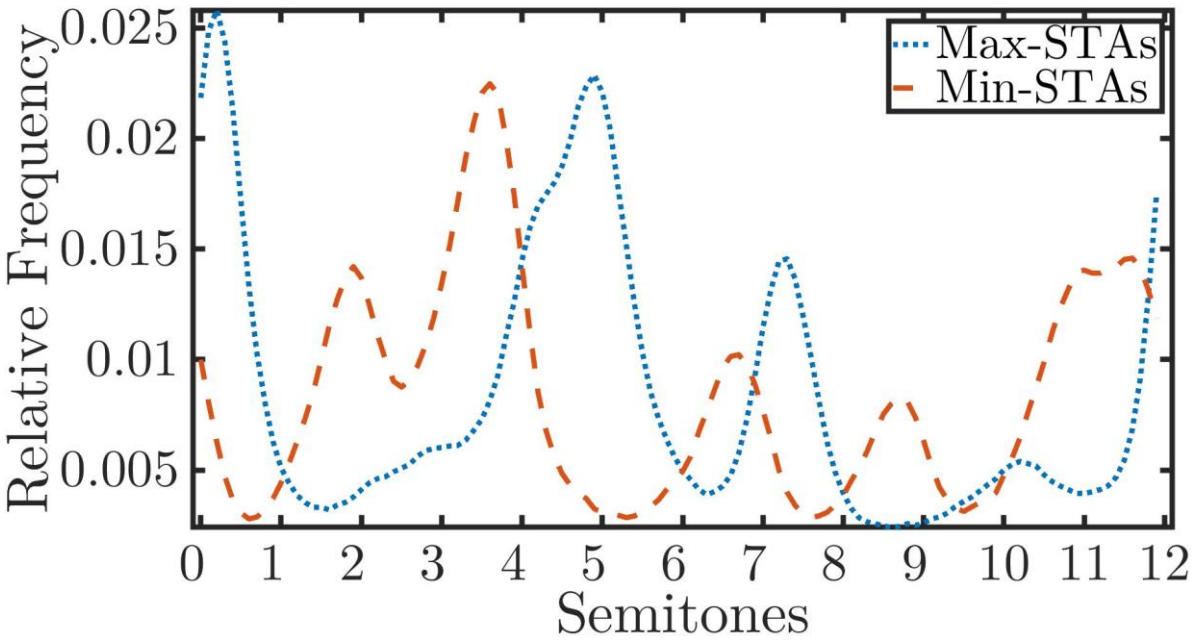
Compare: Histogram of CPNs



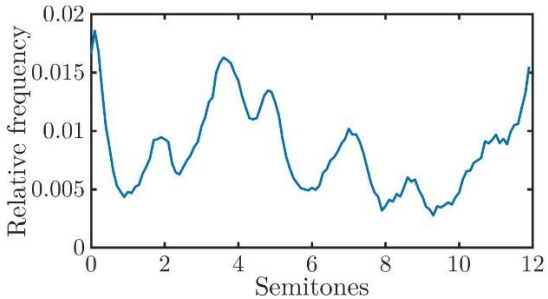
Rāga: *Śankarābharaṇam*

Detecting targets from histograms of Min-STAs and Max-STAs

- Peaks are sharper than in the histogram of all STAs, but not as sharp as for anchors
- Data-driven approach, does not use any specification in textbooks



Compare: Histogram of all STAs



Rāga: *Śankarābharaṇam*

Detecting targets for Max-STAs and Min-STAs

- Peaks are found one at a time in decreasing order of height
  - Locations of tall peaks (0.3 × max value) are always considered as targets.
  - Other peaks (0.15 × max value) farther than 110 cents from already detected targets are considered as targets
- Histogram is updated by removing detected peaks to detect smaller overlapping peaks
- Iterations halt the updated histogram has less than 10% of the original data.

Thresholds are chosen empirically, but outputs are relatively insensitive to them.

Detected Targets: Examples

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Śankarābharaṇam

- $\boldsymbol{\mathcal{A}_u} = \{0, 210, 390, 700, 890\}$ cents, which map to $\{S, R_2, G_3, P, D_2\}$;
- $\boldsymbol{\mathcal{A}_d} = \{0, 390, 480, 700\}$ cents, mapped to $\{S, G_3, M_1, P\}$.
- $\boldsymbol{S_{\max}} = \{20, \mathbf{250}, 370, 490, 730, \mathbf{1020}\}$ cents, mapped to $\{S, \mathbf{G_2}, G_3, M_1, P, \mathbf{N_2}\}$;
- $\boldsymbol{S_{\min}} = \{1160, 190, 360, 670, 870, \mathbf{1060}\}$ cents, mapped to $\{S, R_2, G_3, P, D_2, \mathbf{N_3}\}$

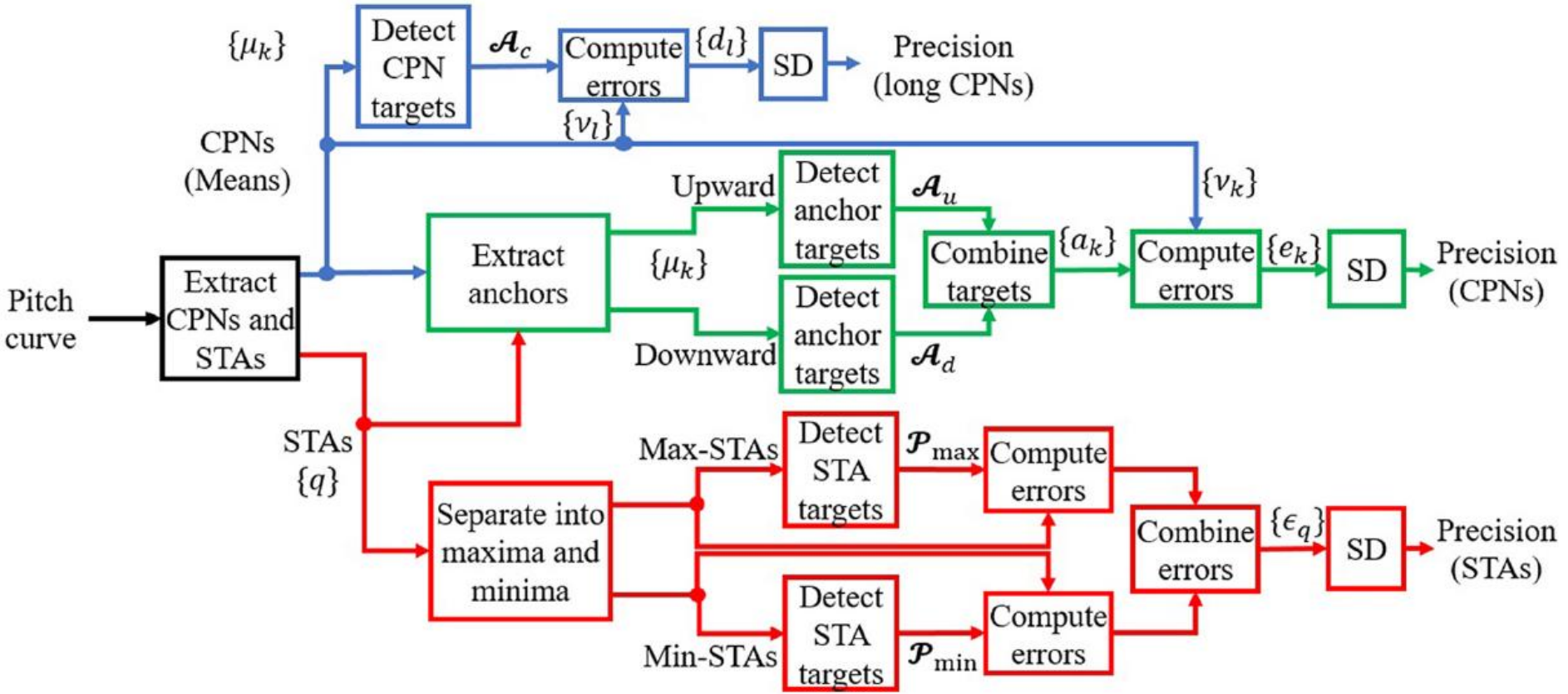
Tōḍī

- $\boldsymbol{\mathcal{A}_u} = \{0, 100, 180, 500, 700, 790, 880\}$ cents, which map to $\{S, R_1, R_2, M_1, P, D_1, D_2\}$;
- $\boldsymbol{\mathcal{A}_d} = \{0, 90, 500, 700, 790\}$ cents, mapped $\{S, R_1, M_1, P, D_1\}$.
- $\boldsymbol{S_{\max}} = \{20, 130, \mathbf{300}, 520, 700, 820, 940\}$ cents, mapped to $\{S, R_1, \mathbf{G_2}, M_1, P, D_1, D_2\}$;
- $\boldsymbol{S_{\min}} = \{1180, 170, 460, 690, 890\}$ cents, mapped to $\{S, R_2, M_1, P, D_2\}$

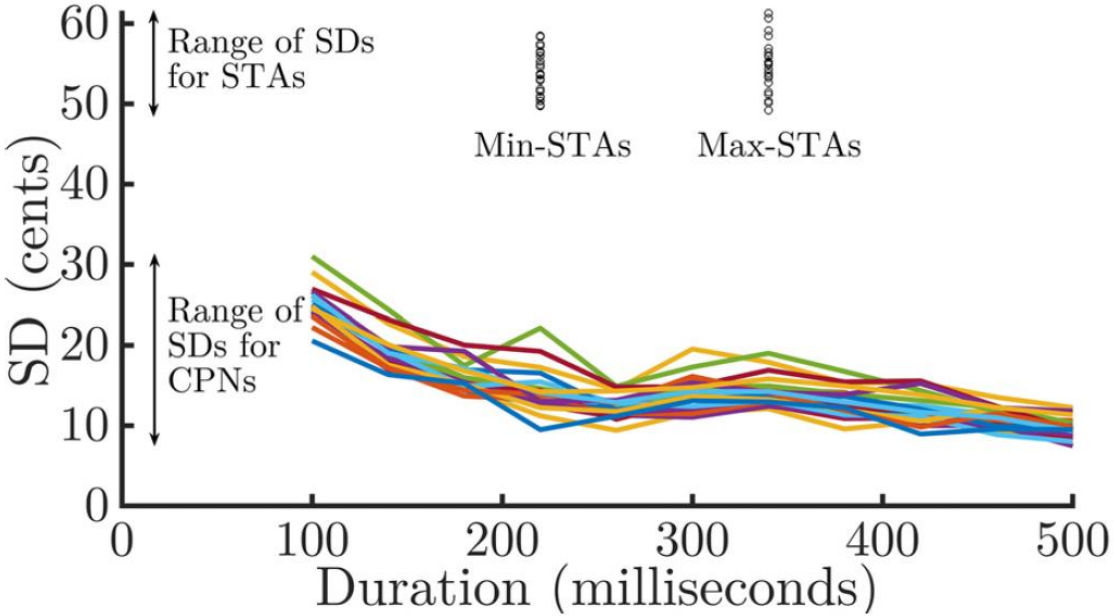
Precision Measurement

- Detected targets are quantized to integer semitones
- Precision is the standard deviation (SD) of errors with respect to the nearest target
- Measured precision guides transcription
- Precision is measured separately for CPNs, Min-STAs, and Max-STAs
- Errors with respect to targets are computed for each *rāga* separately

Precision Measurement Block Diagram



Measured Precision



Precision of professional musicians is in a range of:

~8 to ~15 cents for long CPNs

~50 to ~65 cents for STAs

Descriptive Transcription using CPNs and STAs

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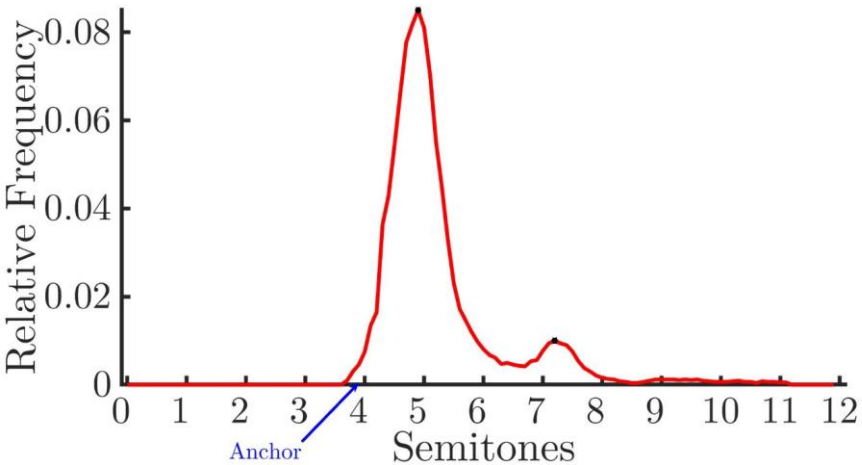
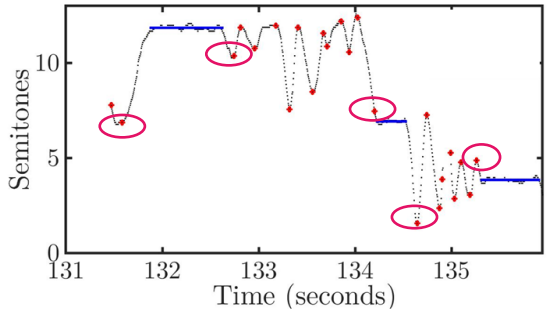
- Measured precision suggests that
  - CPNs may be quantized uniformly
  - Quantizing STAs is non-trivial
- CPNs and STAs constitute a descriptive transcription
  - Quantized pitch, location and duration of each CPN
  - Quantized pitch and location of each STA
  - Other points in a transient need not be quantized or even characterized

Anchor-specific Targets

- For each anchor $a \in \widetilde{\mathbf{A}}_u$ or $\widetilde{\mathbf{A}}_d$, obtain set of STA targets ($\tilde{\mathbf{S}}_{a,\max}, \tilde{\mathbf{S}}_{a,\min}$) from histograms of STAs adjacent to all instances of a

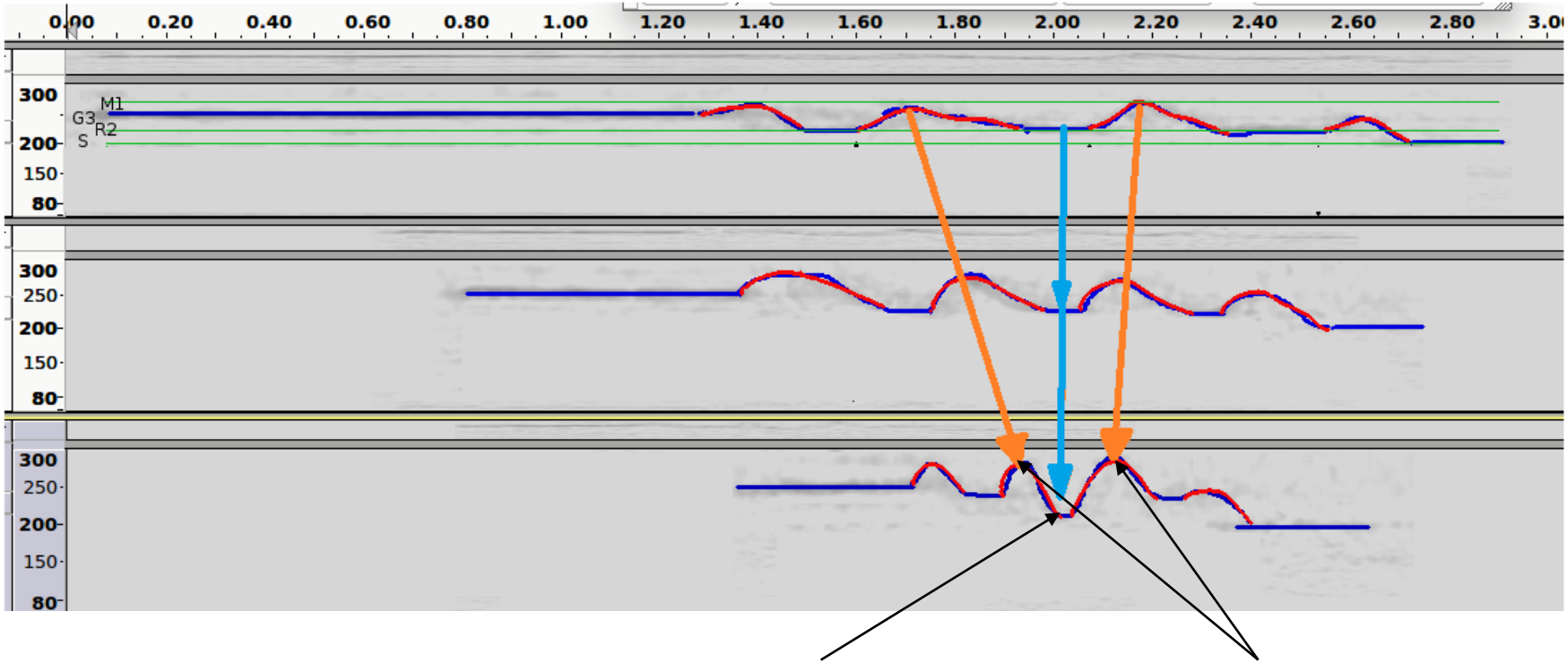


E.g., a = G_3 in *Śankarābharaṇam*



$\widetilde{\mathbf{A}}_u$	$\widetilde{\mathbf{S}}_{a,\max}$		$\widetilde{\mathbf{A}}_d$	$\widetilde{\mathbf{S}}_{a,\min}$	
S	G_2	M_1	$\dot{S}$	N_3	D_2
R_2	G_2	M_1	-		
G_3	M_1	P	G_3	R_2	
-			M_1	G_3	R_2
P	N_2	$\dot{S}$	P	G_3	R_2
D_2	N_2	$\dot{S}$	-		

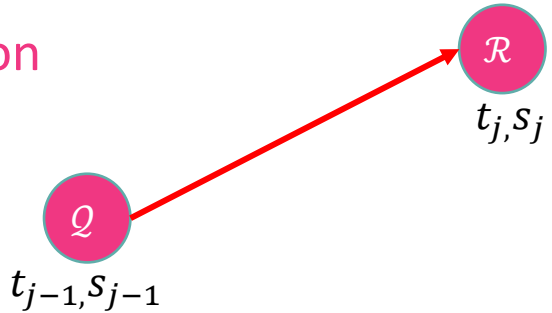
Introducing states based on properties of CPNs and STAs



STA in anchor state
$\mathcal{A}_t$ or ${}_t\mathcal{A}$

STA in transient state
${}_a\mathcal{T}$ or $\mathcal{T}_a$

Mathematical Formulation

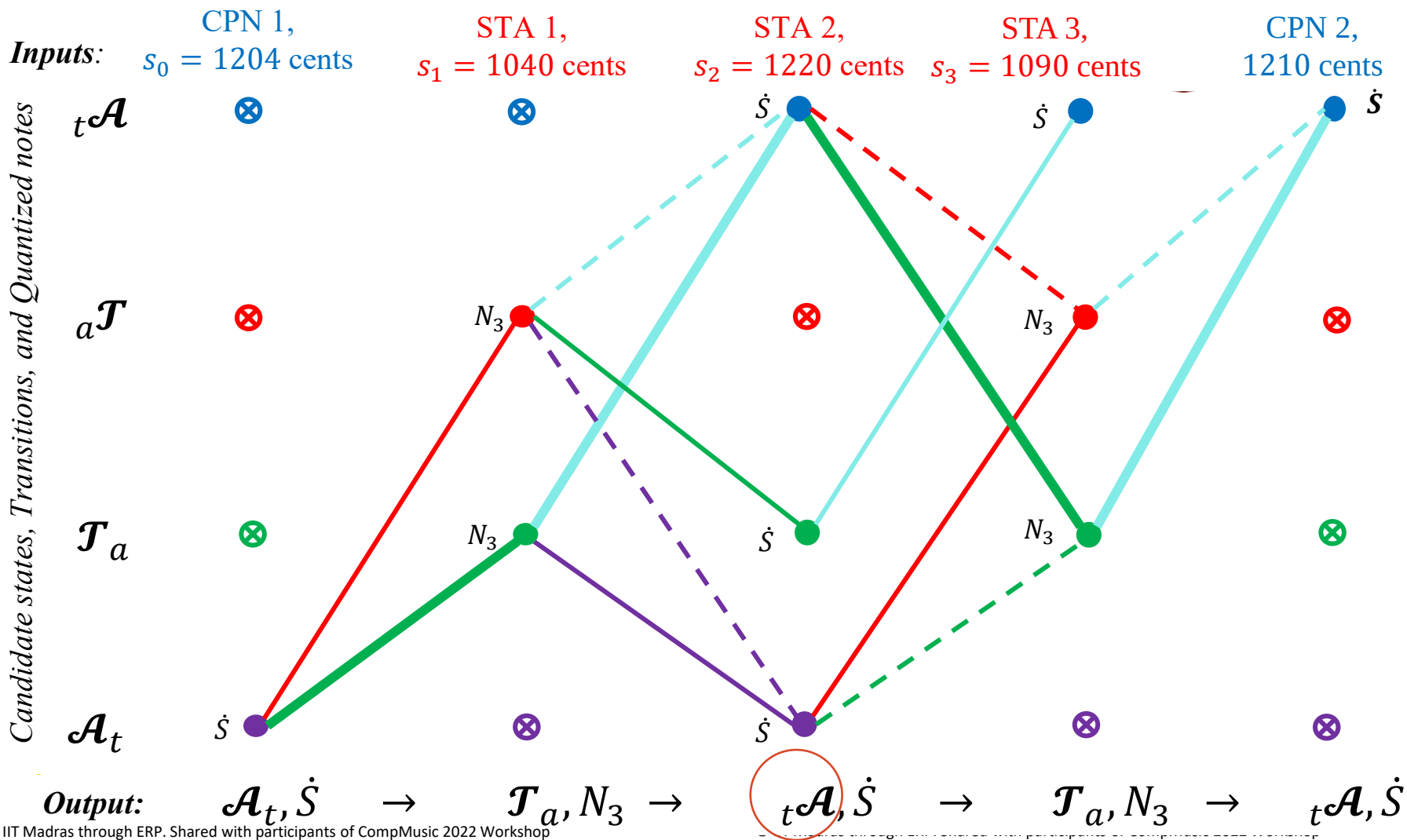


- Two basic transitions
  - Anchor $\boldsymbol{\mathcal{A}}_t$ to STA ${}_a\boldsymbol{\mathcal{T}}$: $w_{j-1} = a \in \tilde{\mathbf{A}}_u$ and $w_j \in \tilde{\mathbf{S}}_{a,\max}$
  - STA $\boldsymbol{\mathcal{T}}_a$ to anchor ${}_t\boldsymbol{\mathcal{A}}$: $w_j = a \in \tilde{\mathbf{A}}_d$ and $w_{j-1} \in \tilde{\mathbf{S}}_{a,\min}$
- Maximize probability of state transition $\mathcal{Q} \to \mathcal{R}$ given s_{j-1}, s_j

$$P\left(\mathcal{Q} \to \mathcal{R} \middle| s_{j-1}, s_j\right) = \frac{f\left(s_{j-1}, s_j \middle| \mathcal{Q} \to \mathcal{R}\right) P(\mathcal{Q} \to \mathcal{R})}{f\left(s_{j-1}, s_j\right)}$$

- Naïve Bayes formulation: Consider only the likelihood $f\left(s_{j-1}, s_j \middle| \mathcal{Q} \to \mathcal{R}\right)$
- Model s_{j-1} and s_j as independently, normally distributed around targets w_{j-1}, w_j:

$$f\left(s_{j-1}, s_j \middle| \mathcal{Q} \to \mathcal{R}\right) = \mathcal{N}\left(s_{j-1}, w_{j-1}, \sigma_{j-1}^2\right) \mathcal{N}\left(s_j, w_j, \sigma_j^2\right)$$



Example Transcription Output

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Example used in the previous slide

Element type	Start time*	Duration*	Quantized pitch	Notation	State
STA	0		7	P	${}_t\mathcal{A}$
STA	14		7	P	${}_t\mathcal{A}$
CPN	87	225	12	$\dot{S}$	$\mathcal{A}_t$
STA	327		11	N_3	$\mathcal{T}_a$
STA	347		12	$\dot{S}$	${}_t\mathcal{A}$
STA	383		11	N_3	$\mathcal{T}_a$
CPN	417	19	12	$\dot{S}$	$\mathcal{A}_t$
STA	464		9	D_2	${}_a\mathcal{T}$
STA	484		12	$\dot{S}$	$\mathcal{T}_a$
STA	529		9	D_2	${}_t\mathcal{A}$
STA	556		12	$\dot{S}$	${}_a\mathcal{T}$
STA	570		11	N_3	$\mathcal{T}_a$
CPN	585	19	12	$\dot{S}$	$\mathcal{A}_t$
STA	623		11	N_3	${}_a\mathcal{T}$
STA	640		12	$\dot{S}$	$\mathcal{T}_a$
CPN	686	70	7	P	$\mathcal{A}_t$

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*Multiples of $T_0 \approx 4.44$ ms

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Cosine Interpolation of transcription output

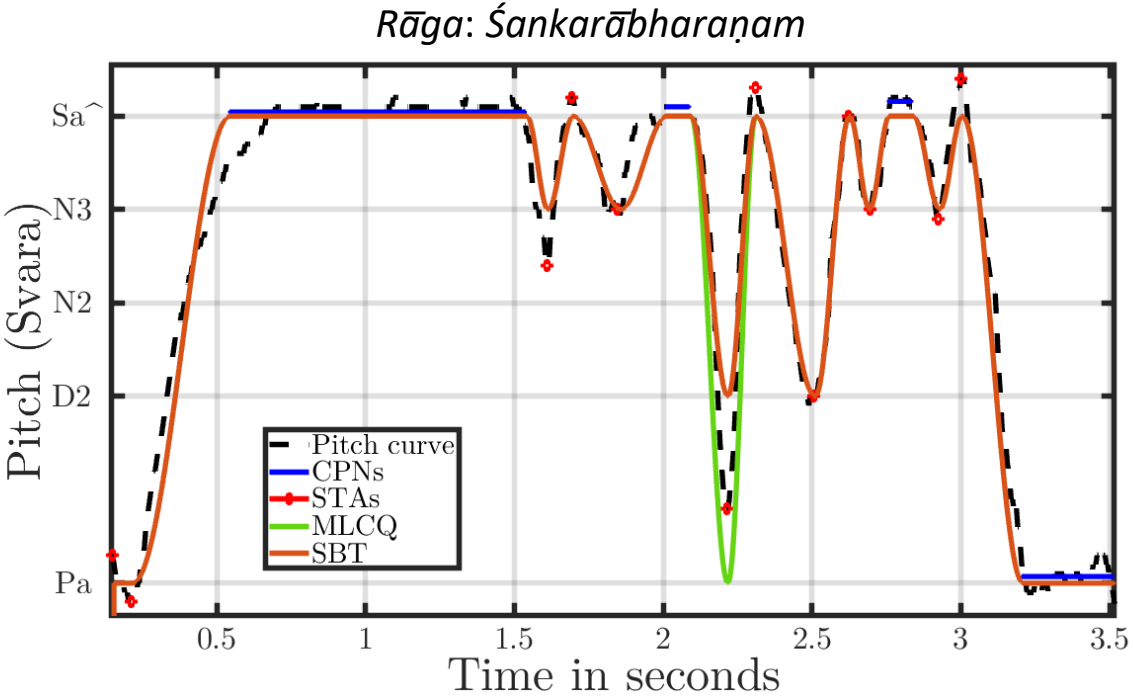
- Interpolate the transcription output to a complete pitch curve ($s[n]$ cents at nT_0)
  - Quantized CPN pitch values are used for the duration of the CPN (τ_k, d_k)
  - Quantized STA pitch values are placed at their respective locations (t_j)
- Quantized pitch-values v_1 and v_2 in semitones at time instants t_1 and t_2 are interpolated

$$\hat{s}[n] = 100v_1 + 100\frac{v_2 - v_1}{2}\left(1 - \cos\left(\pi\left(\frac{n - t_1}{t_2 - t_1}\right)\right)\right), t_1 < n < t_2$$

- Convert to frequency in Hz as

$$\hat{f}[n] = f_0 2^{\hat{s}[n]/1200}$$

Example of interpolated pitch curves



- Interpolated pitch curve in Hz is synthesized[1]

1. Kaustuv Kanti Ganguli and Preeti Rao, “Discrimination of melodic patterns in Indian classical music,” NCC 2015

Results: Perceptual Evaluation of Synthesis

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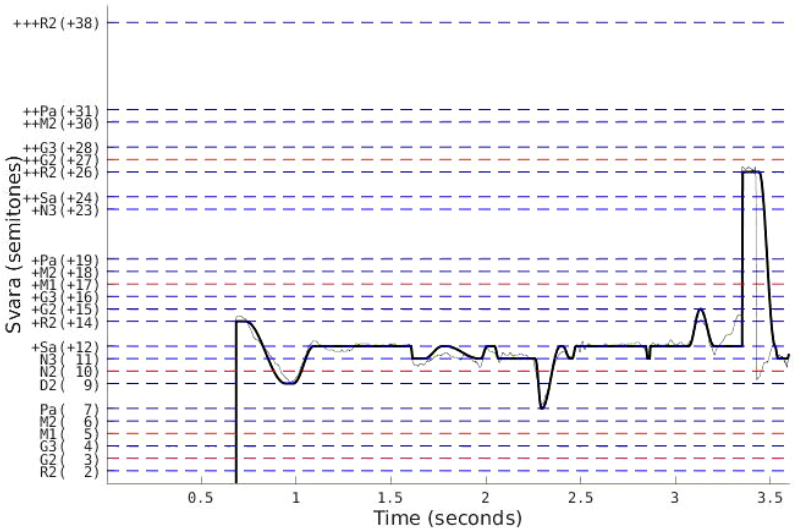
- Experiment: 27 listeners
  - Listened to original clip reference (~1 min long)
  - Rated synthesized outputs relative to the reference (0 to 100%)

Mean ratings in %		
Rāga↓ Technique→	Critical points[1] (Previous work)	SBT (Proposed)
Dhanyāsi	52	**67**
Kalyāṇī	48	**70**
Śankarābhāraṇam	47	**76**
Bhairavī	65	**74**

1. Ranjani H G et al., “A compact pitch and time representation for melodic contours in Indian art music”, JASA 2019

Transcription and synthesis of unseen renditions

- *Śankarābharaṇam*, *Tōḍī*, ***Bhairavī***, ***Rītigauḷa***
- *Yaman tān*[1] (Genre is not Carnatic)



1. Visualization was done with the assistance of Jom Kuriakose, CSE, IITM

Visualization for Correction

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- Transcription output still needs correction
- A website for correction[1]
- SBT offers granular correction

1. Front-end implemented by Jom Kuriakose, CSE, IITM

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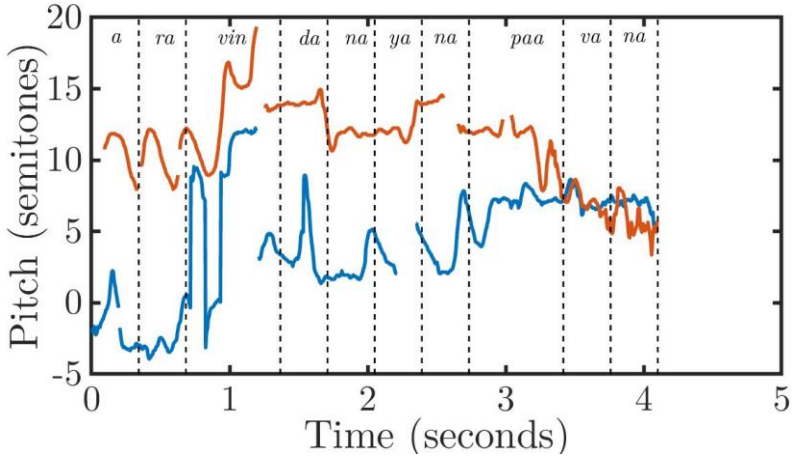
Conclusions

- CPN-STAs help understand CM pitch curves
- Detected targets
  - Explain properties of *rāga*s and *gamaka*s
  - Allow precision measurement in CM; CPNs are more precise than STAs
  - Constitute a descriptive transcription scheme
- Anchor-specific targets
  - Enable State-based Transcription
- Output needs correction by musicians to be used as ground truth
  - Granularity of anchor-specific targets helps correct systematic “errors”

Future Work



- First-level ground-truth for deep learning approaches (e.g., end to end)
- Syllables of the lyrics/*svara*s in CM must occur at specific points in the *tāḷa*.
  - Locations of syllables of lyrics/*svara*s should scale uniformly across rendition-speeds
  - The pitch curve between these points scales non-uniformly

Prescriptive transcription scales uniformly, descriptive transcription scales non-uniformly

- A joint study of syllables, rhythm, and melody is needed

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