Prosody: Speech Rhythms and Melodies

4. Generalising Pitch – Stylisation

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Guangzhou Prosody Lectures, November 2016
http://wwwhomes.uni-bielefeld.de/~gibbon/Guangzhoulectures2016/

Schedule

Week 1:

01 *Forms and functions of prosody: models and methods*

Nov. 2 (Wednesday) 2:30pm--4:30pm

02 *Forms and functions of prosody: prosodic semantics*

Nov. 4 (Friday) 10am--12am

Week 2:

03 *Basics of digital phonetics*

Nov. 8 (Tuesday) 10am--12am

04 ***Pitch Stylisation: tone and intonation***

Nov. 9 (Wednesday) 10am--12am

Week 3:

05 *Syllables and Prosody Modelling*

Nov.15 (Tuesday) 10am--12am

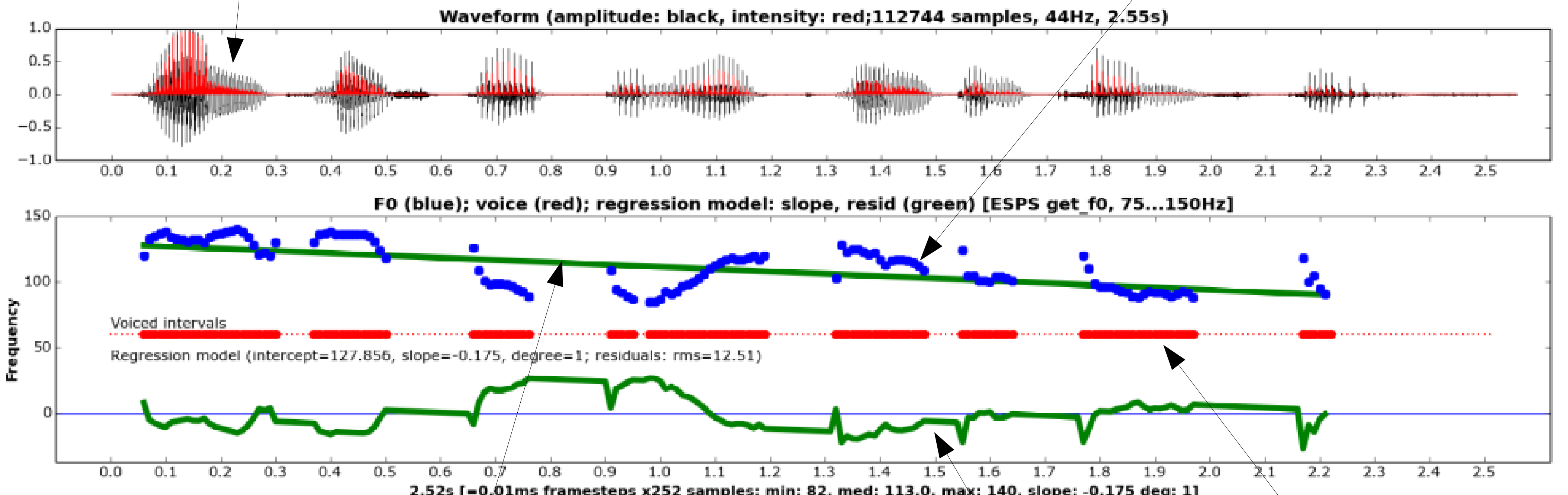
06 *SpeechTiming: durations and rhythm*

Nov.15 (Tuesday) 2:30pm--4:30pm

Global prosodic patterns

waveform (amplitude; intensity in red):
syllable patterns

F0 contour (‘pitch contour’)



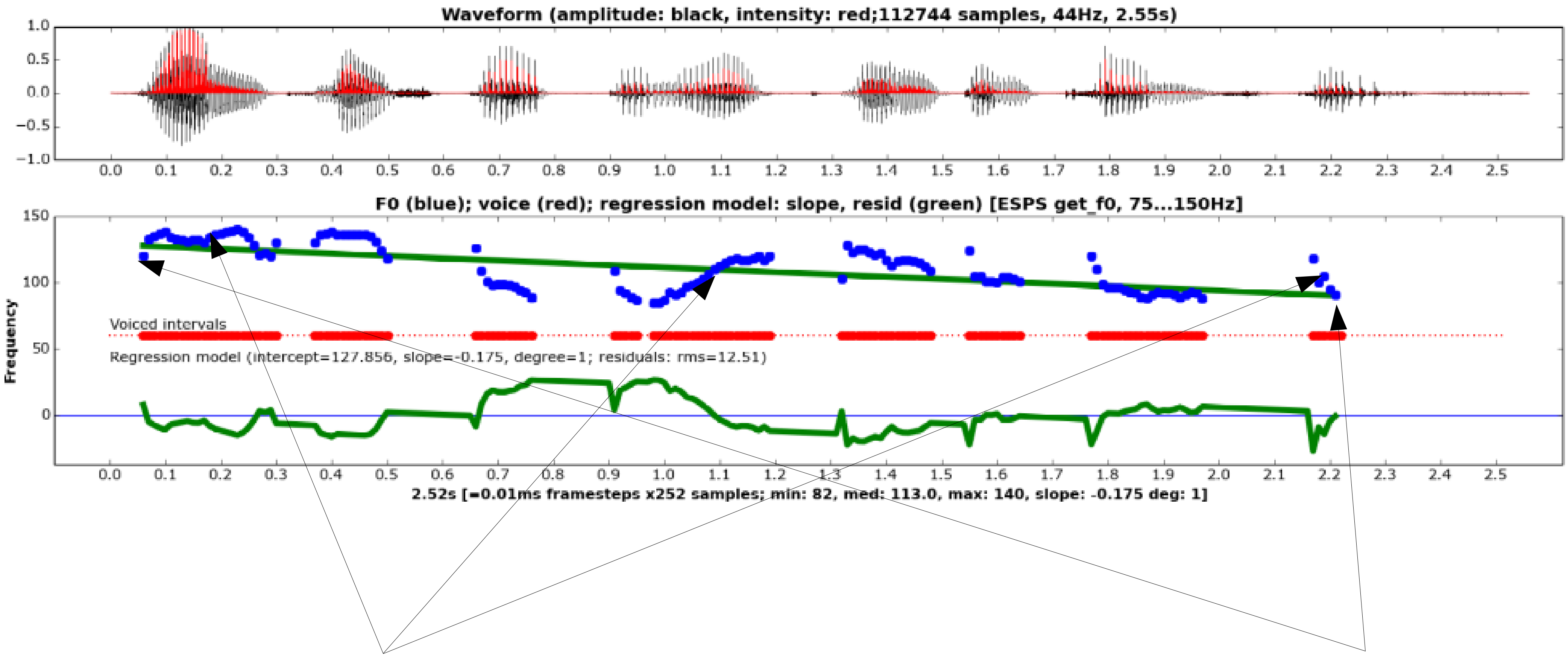
voicing

linear regression slope: model of <u>global declination</u> of F0

slope residuals: model of pitch accents/tones and consonant and vocalic perturbations of F0

Endlich gab der Nordwind den Kampf auf.

Local prosodic patterns



local pitch accents / tones

boundary tones

<u>End</u>lich gab der <u>Nord</u>wind den Kampf <u>auf</u>.

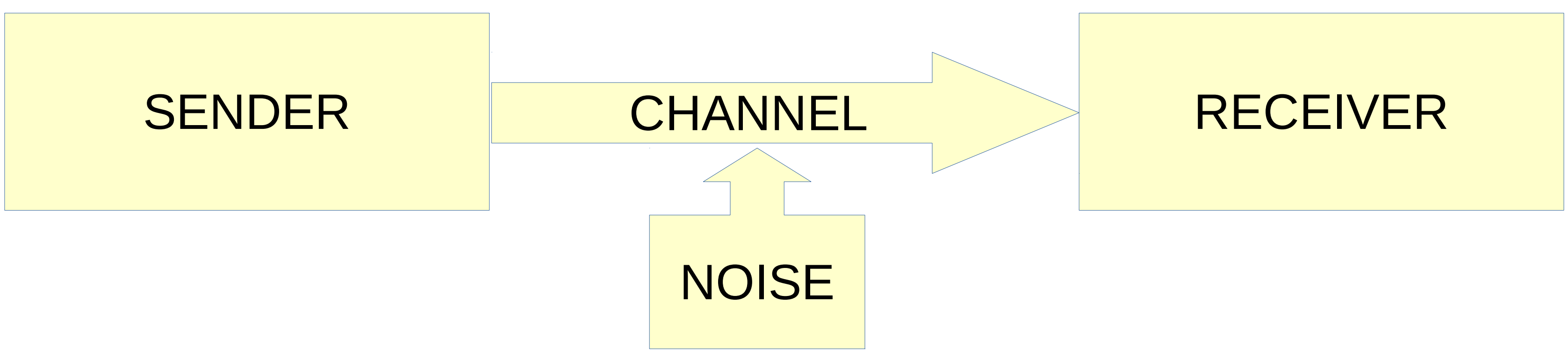
Phonetic interpretation: parameters and trajectories

- Phonetic domain parameters for prosody
  - *melody*:
    - variation of fundamental frequency properties in time
  - *volume*:
    - variation of intensity properties in time
  - *duration*:
    - variation of unit duration properties in time
      - Note that *duration* has two temporal dimensions

- Phonological domains for prosody
  - structural and functional units and patterns

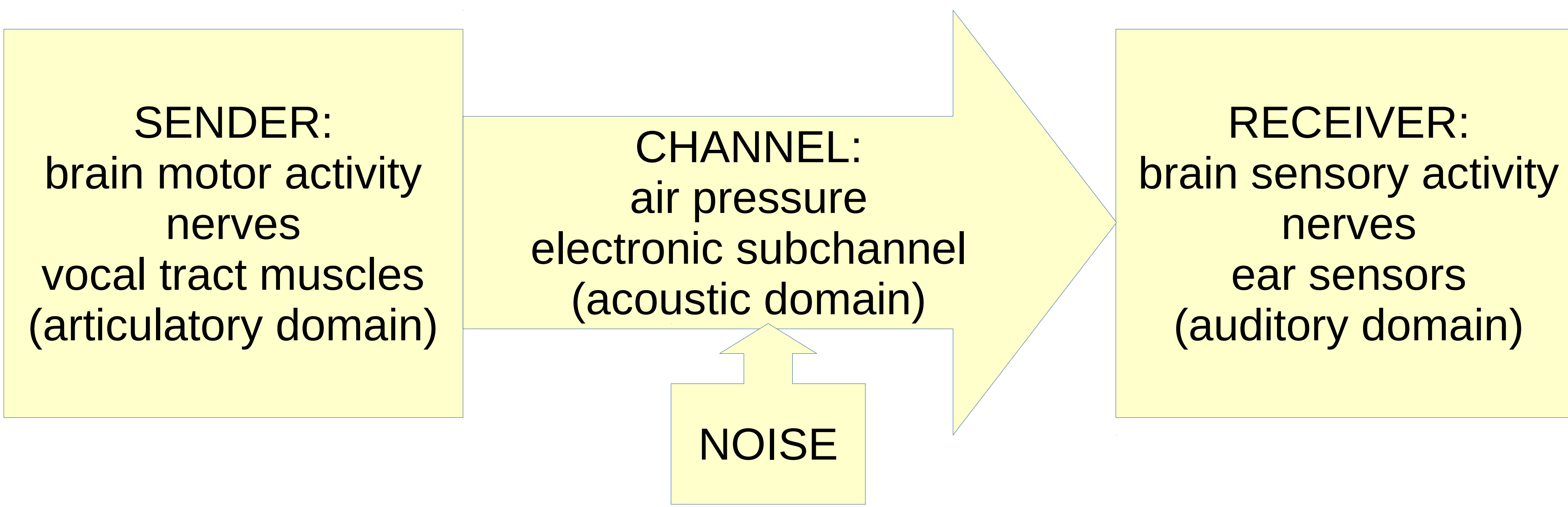
Phonetic domains as phases

- speaker, production, articulatory phonetics:
  - articulation rate - effort
- channel, acoustic phonetics:
  - fundamental frequency - intensity
- hearer, reception, auditory phonetics:
  - pitch - loudness



Forms of prosody: phases and subphases

- each of the phases has subphases:
  - → brain motor activity → nerves → vocal tract muscles
  - → air pressure → (electronic channel →) air pressure
  - → ear sensors – nerves – brain sensory activity



Phonetic methods:

observations – measurements – models

From phonetic measurements to phonetic models

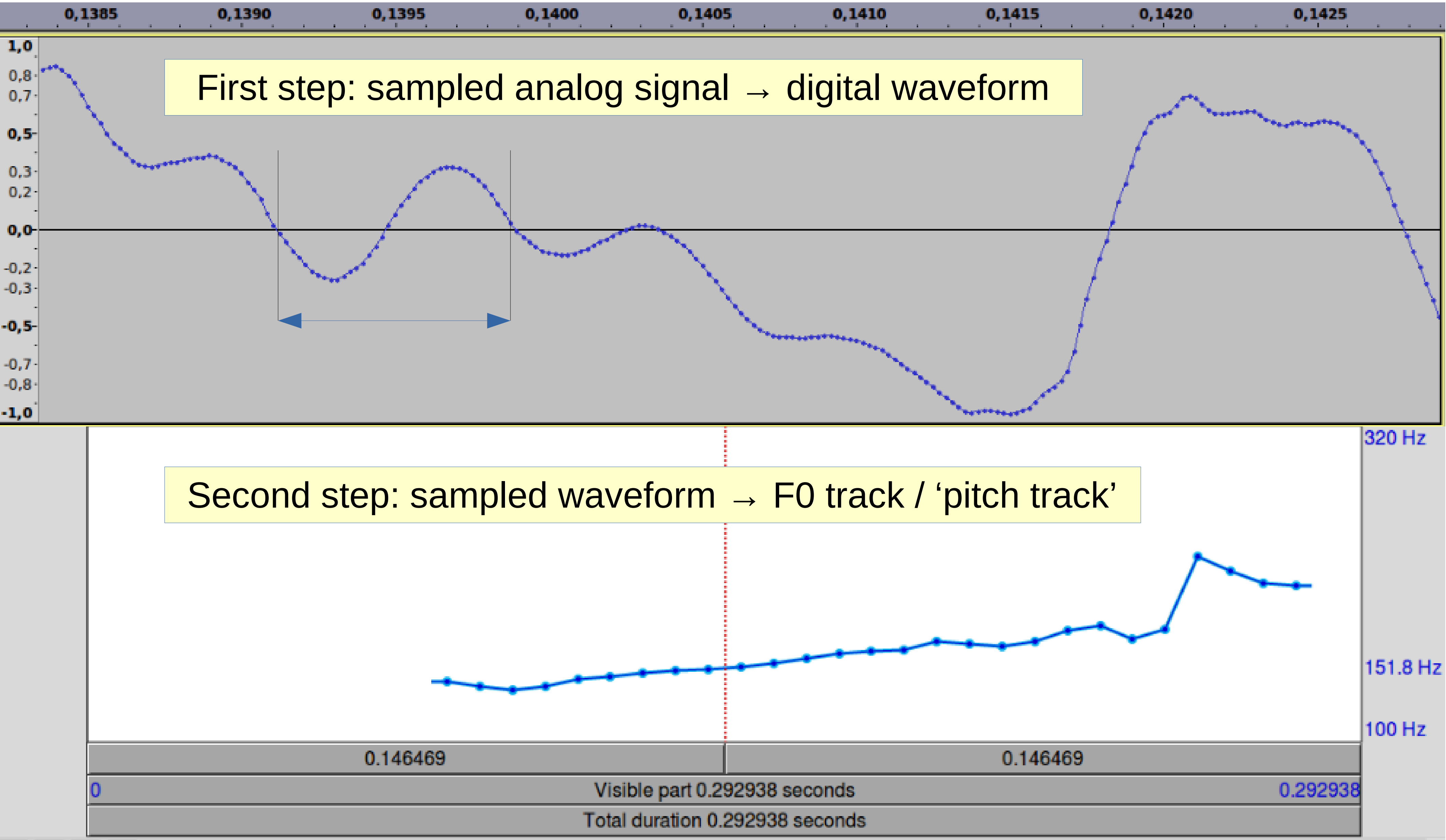
- First steps: collect data, extract F0
- Induce a prosodic model
- Evaluate prosodic model:
  - Method 1, machine learning:
    - use new data, predict goodness of fit of new data
  - Method 2, perception:
    - re-synthesise prosodic model
    - test results with perception experiments
      - same-different comparison
      - naturalness judgments
      - comprehensibility judgments

First: from waveform to F0

From Waveform to F0

- Time domain methods
  - frequency = 1 / period
  - peak picking: intervals between peaks
  - intervals between zero crossing measurement
  - autocorrelation
- Frequency domain methods
  - overtone differences
  - spectral comb
  - cepstrum

From Waveform to F0

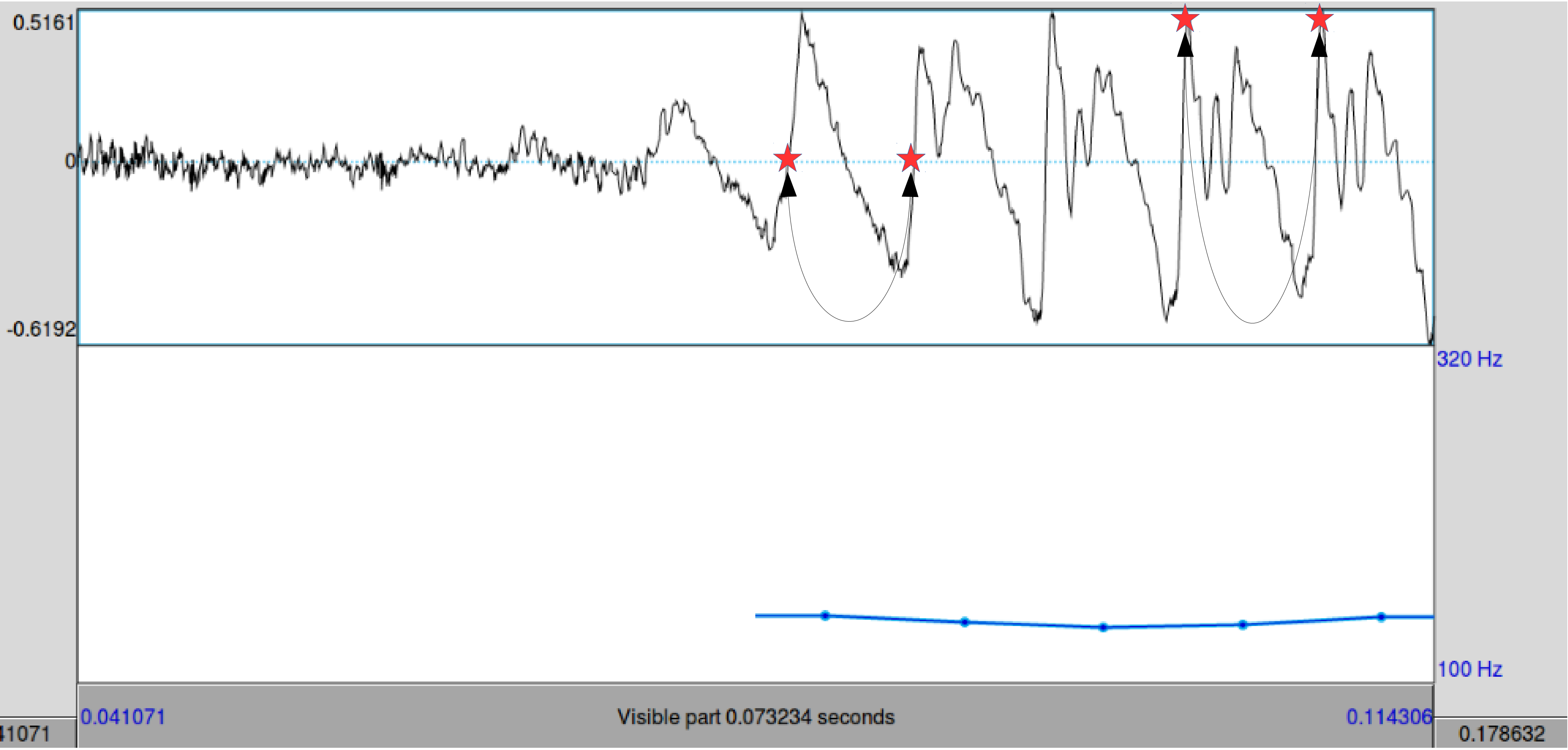


From Waveform to F0: pitch extraction

Time domain pitch extraction

Zero-crossing detection

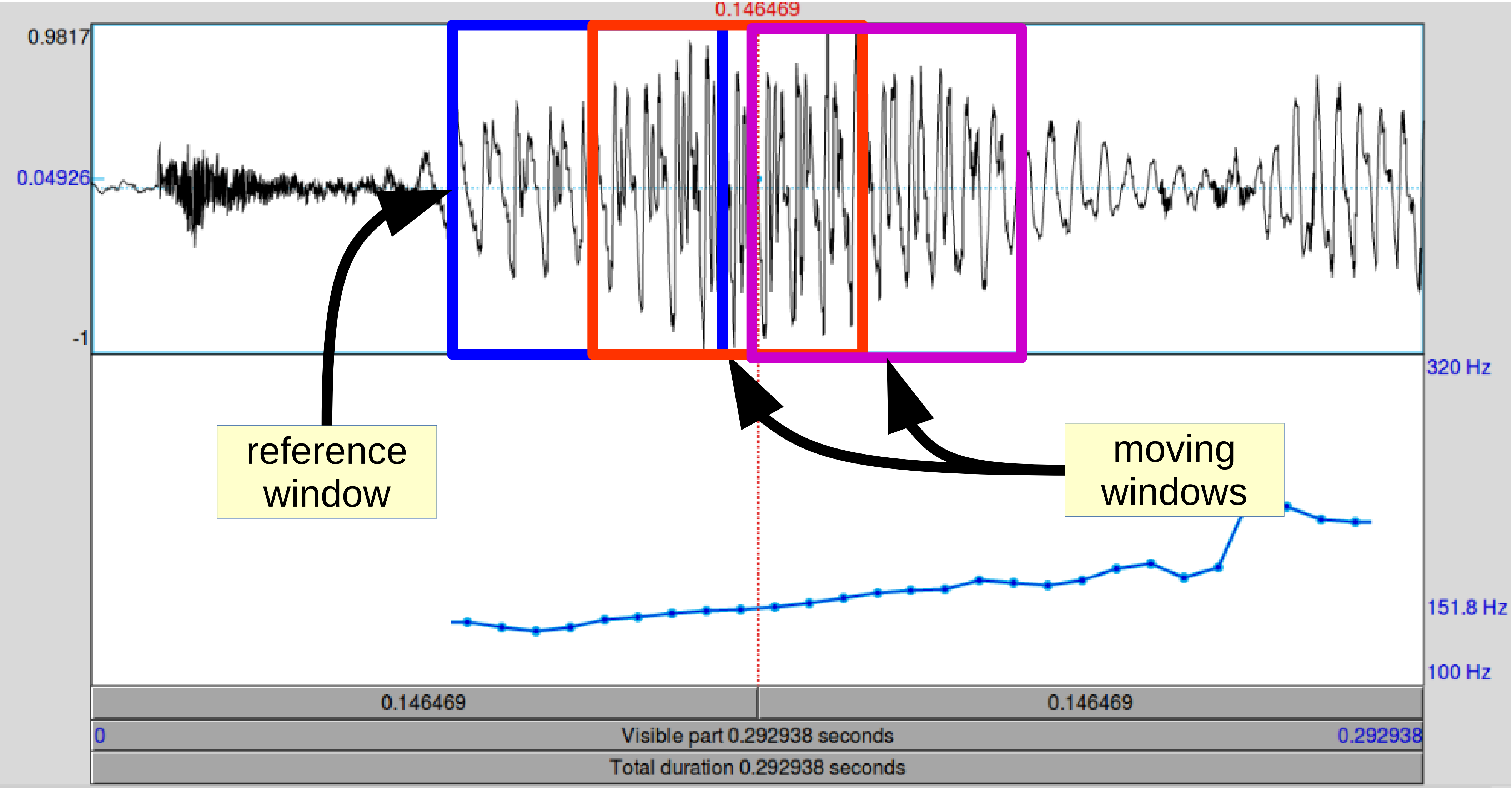
Peak Picking



From Waveform to F0

Autocorrelation

Procedure: ompare moving windows with a reference window, and find the one which is the closest fit



From phonetic measurements to phonetic models

From phonetic measurements to phonetic models

- Phonetic models:
  - smoothing models:
    - median smoothing
    - global regression
    - local regression (IPO)
  - segment models
    - voiced signal segments
    - quadratic interpolation between reference points
  - structured models
    - Fujisaki model
    - Liberman and Pierrehumbert model
    - Hirst model

From phonetic measurements to phonetic models

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    - Hirst model

From phonetic measurements to phonetic models

- Phonetic stylisation models:
  - smoothing models:
    - median; global (Huber) and local (IPO) regression
  - segment models
    - voiced segment smoothing
    - quadratic spline segment interpolation (Hirst)
- F0 stylisation is the simplification of the F0 trajectory to remove
  - irrelevant properties
  - noise

First steps to stylisation: smoothing filters

Regression smoothing

Regression smoothing examples

1. Identify voiced intervals
2. Extract F0
3. Interpolate silent intervals

   Simplified in the following examples:

      3rd quartile (75th percentile)

4. Calculate smoothing (declination / accent model)

   Linear, quadratic etc. (polynomial) regression over interpolated F0 sequence

5. Calculate residuals (microprosody model):

   Subtract regression values from F0 values

F0 smoothing: procedure

Smoothing and ‘stylisation’ modelling:

- Local smoothing:
  - linear, median; regression; quadratic spline (Hirst)
- Global models:
  - reference line plus discrete deviant values for different accents or tones
  - Fujisaki model, Liberman & Pierrehumbert’s invariance model, Taylor’s ‘Tilt’ model
  - smoothing with regression:
  - log, linear, quadratic, polynomial of degree *n*

(used for illustration in the following examples)

F0 smoothing: different approaches

- Smoothing by median filter:
  - the median of sequences of 3 measurements
- Smoothing by linear regression

$y = a_0 + a_1x + \varepsilon$

- Smoothing by polynomial regression:

$y = a_0 + a_1 \cdot t + a_2 \cdot t^2 + a_3t^3 + \ldots + a_0t^n + \varepsilon$

- Smoothing by asymptotic descent, effectively log(x):

$F0(t_{t+1}) = m \cdot F0(t_i) + \varepsilon$, for $m < 0$

$a + F0(t_{i+1}) = a + m \cdot F0(t_i) + \varepsilon$, $m < 0$ non-zero asymptote

F0 smoothing: global procedures

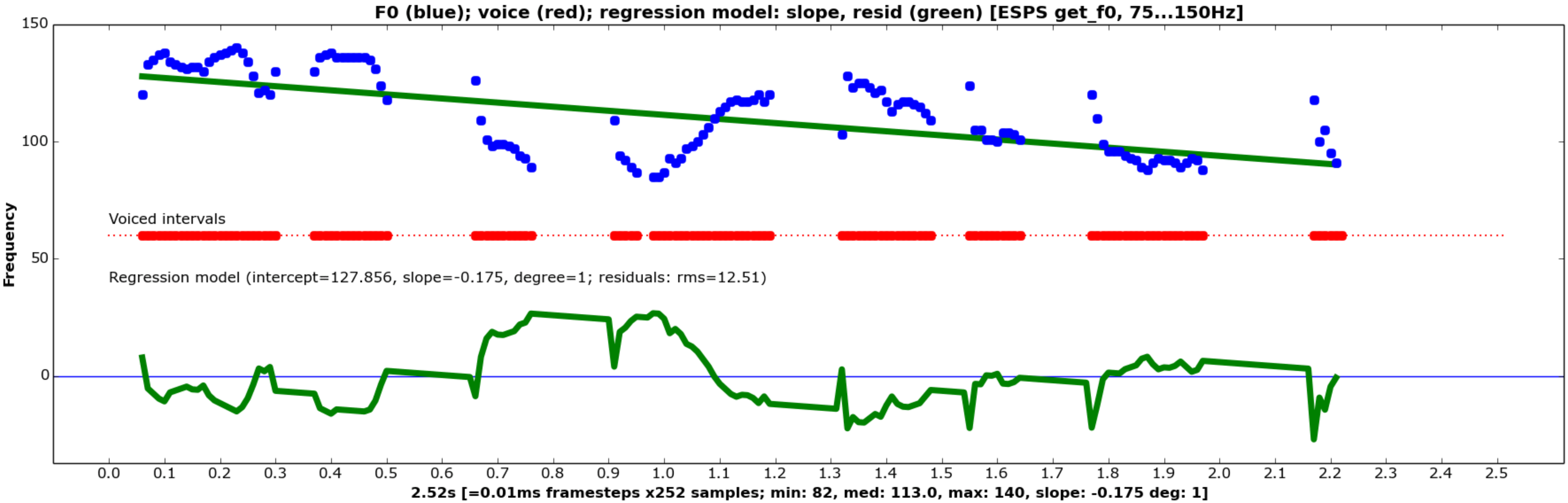
Smoothing: different approaches, different goals

- Smoothing by polynomial regression (degree *n*):

$$y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 x^3 + \ldots + a_0 x^n + \varepsilon$$

- Smoothing by linear regression (degree 1)

$$y = a_0 + a_1 x + \varepsilon$$



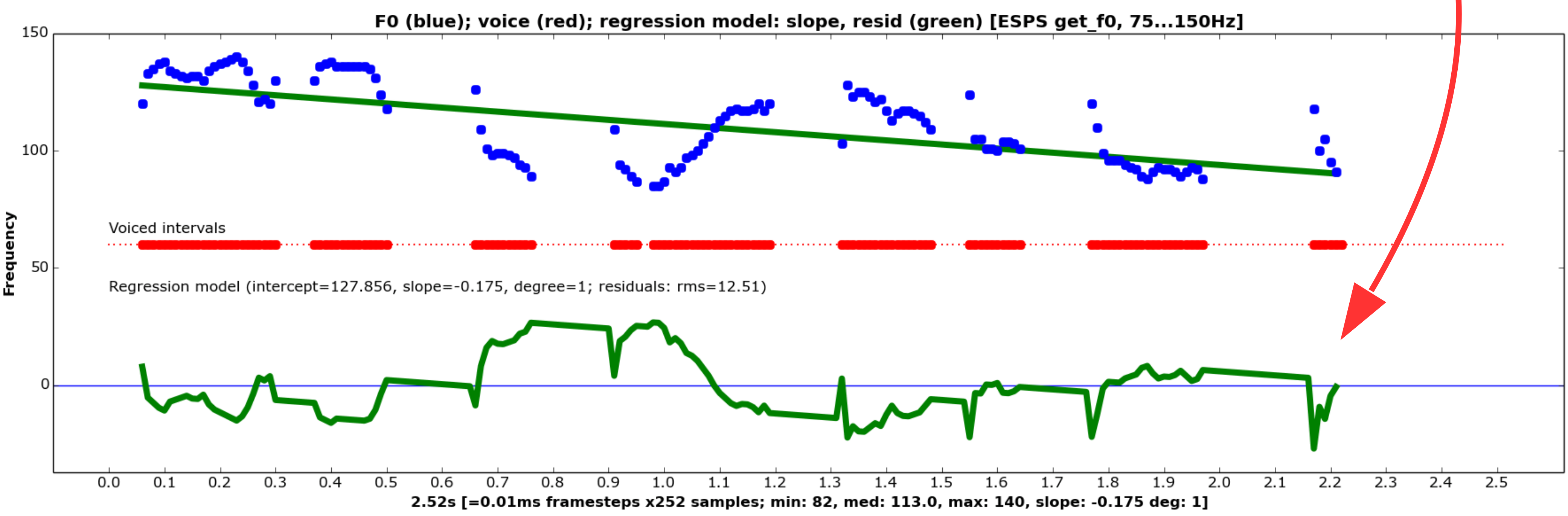
Smoothing: different approaches, different goals

- Smoothing by polynomial regression (degree *n*):

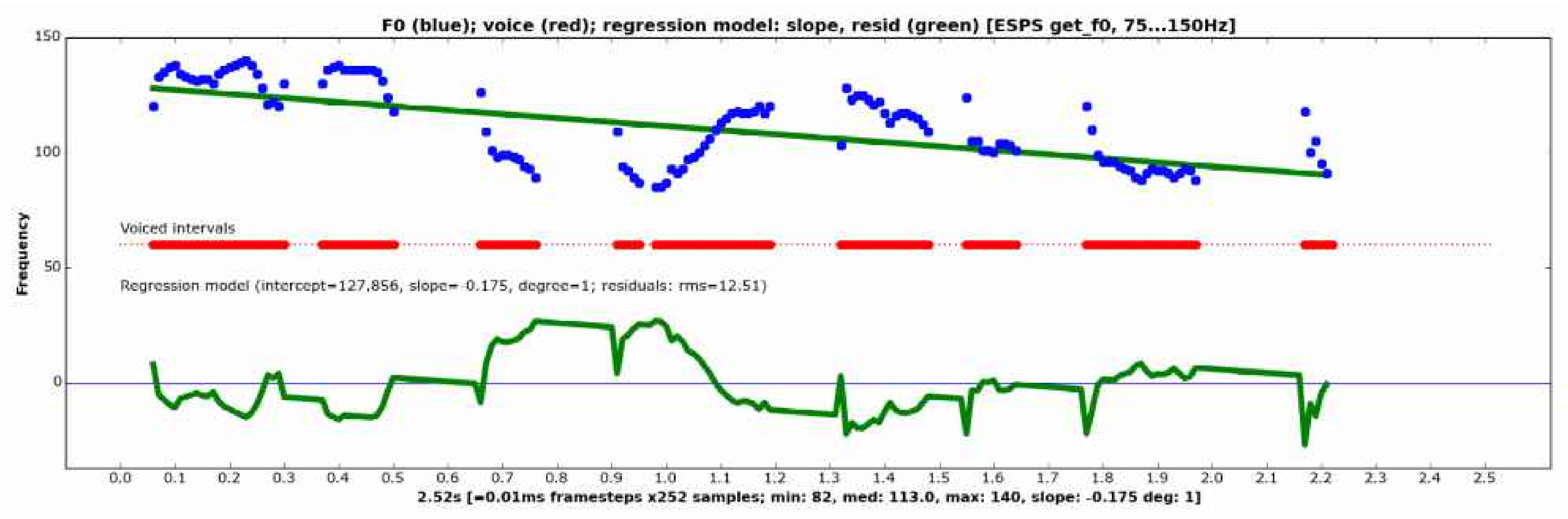
$$y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 x^3 + \ldots + a_0 x^n + \varepsilon$$

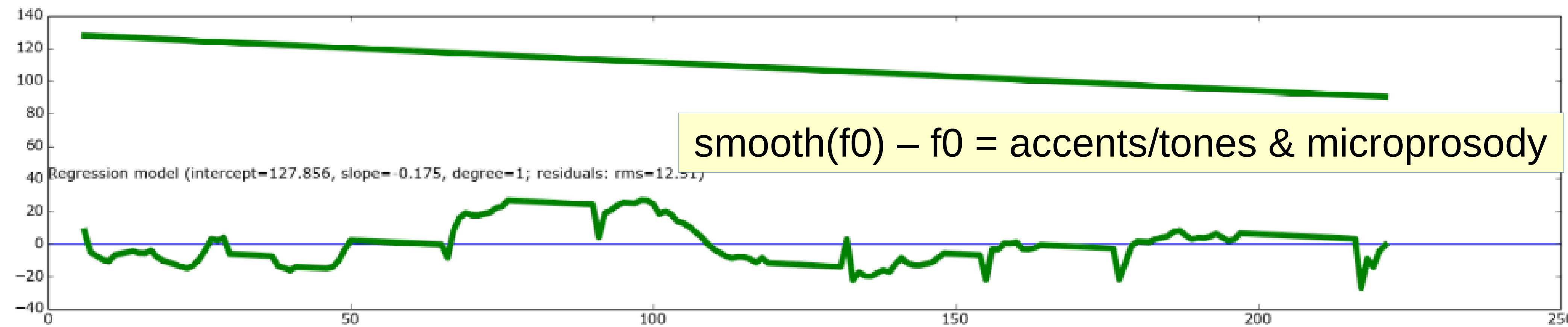
- Smoothing by linear regression (degree 1)

$$y = a_0 + a_1 x + \varepsilon$$



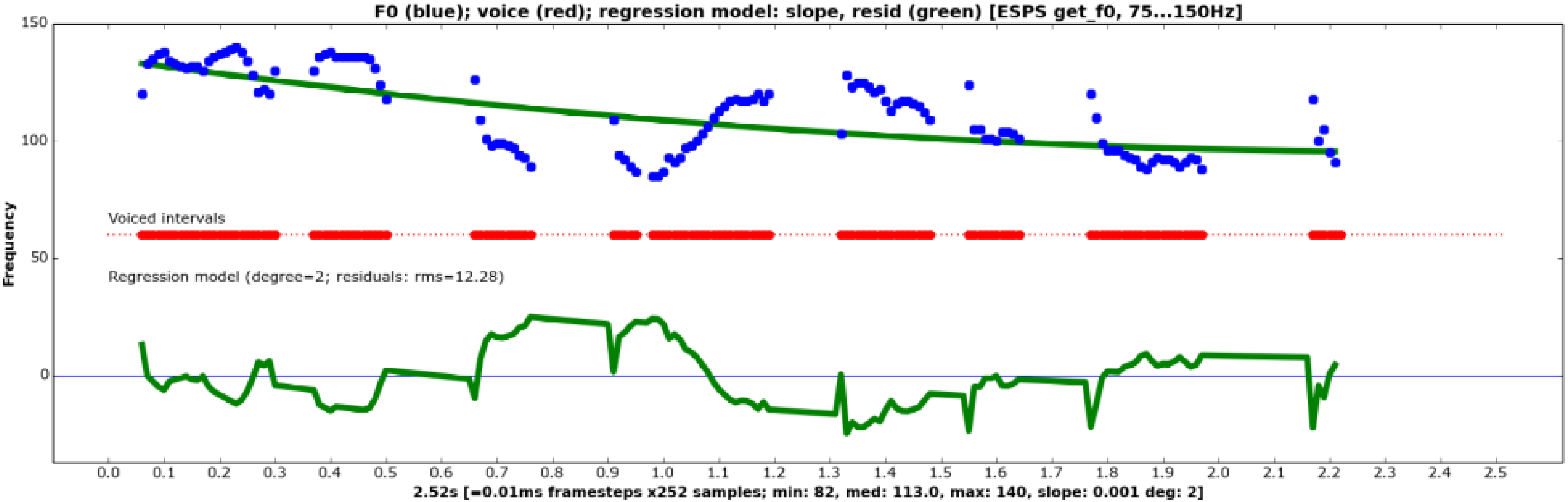
Global linear regression contour

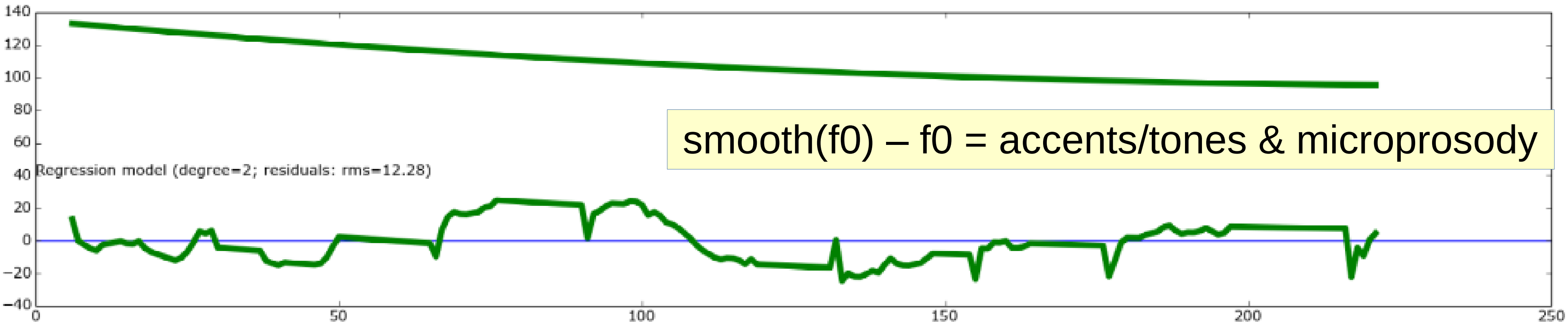




Endlich gab der Nordwind den Kampf auf.

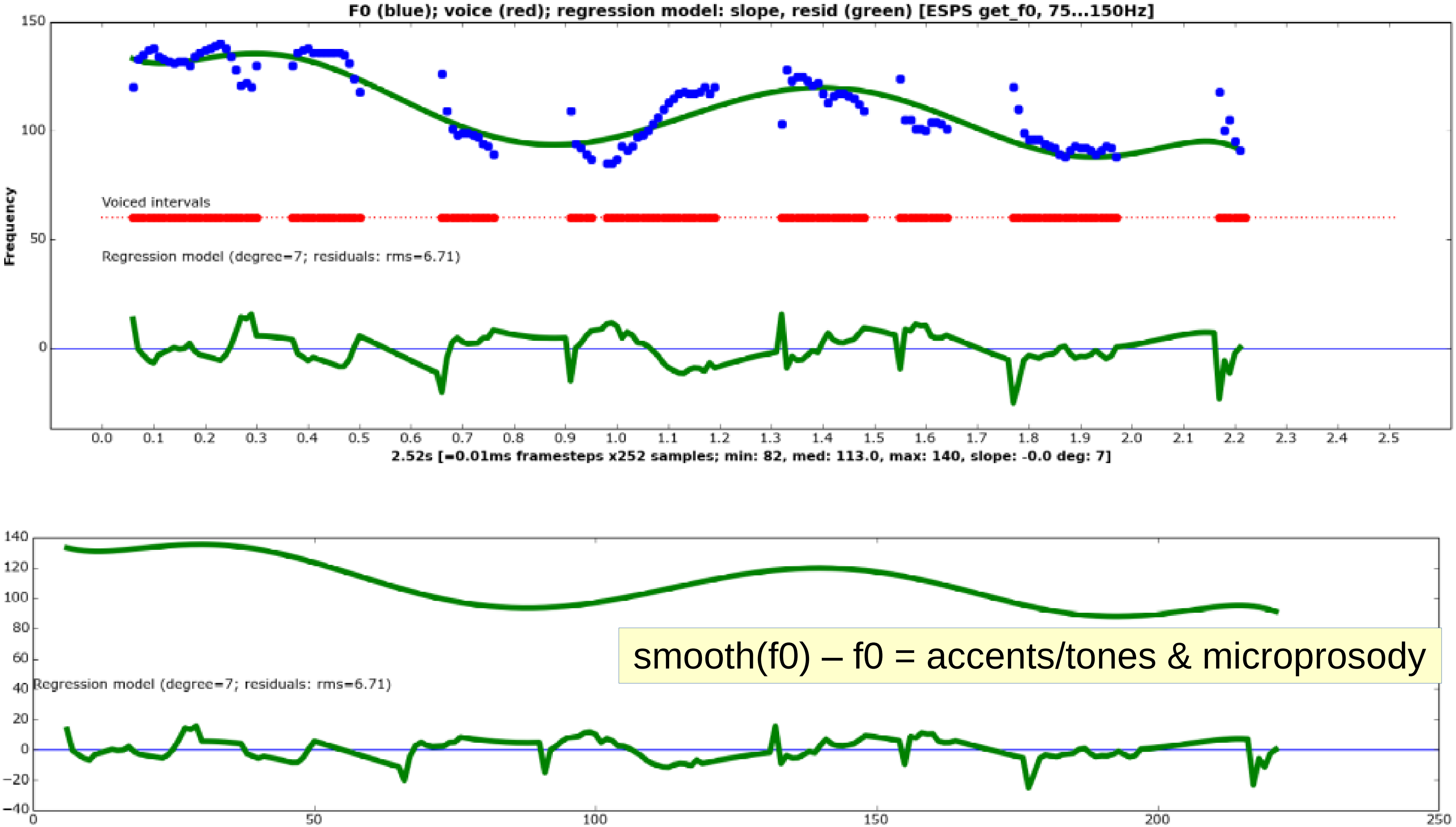
Global quadratic regression contour





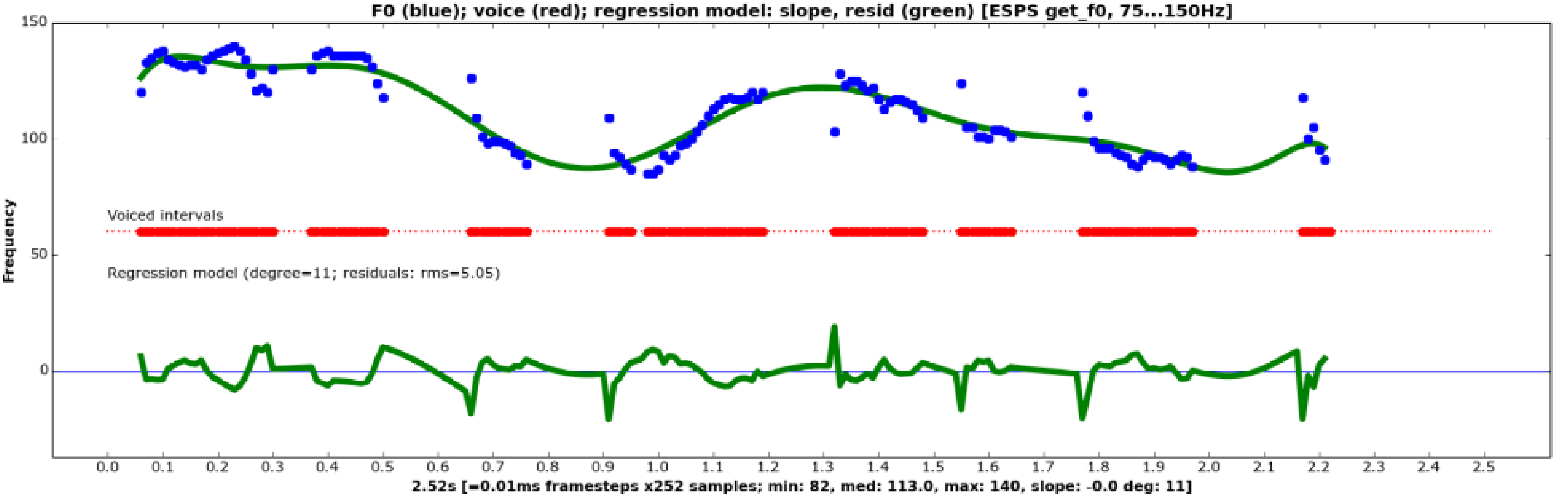
Endlich gab der Nordwind den Kampf auf.

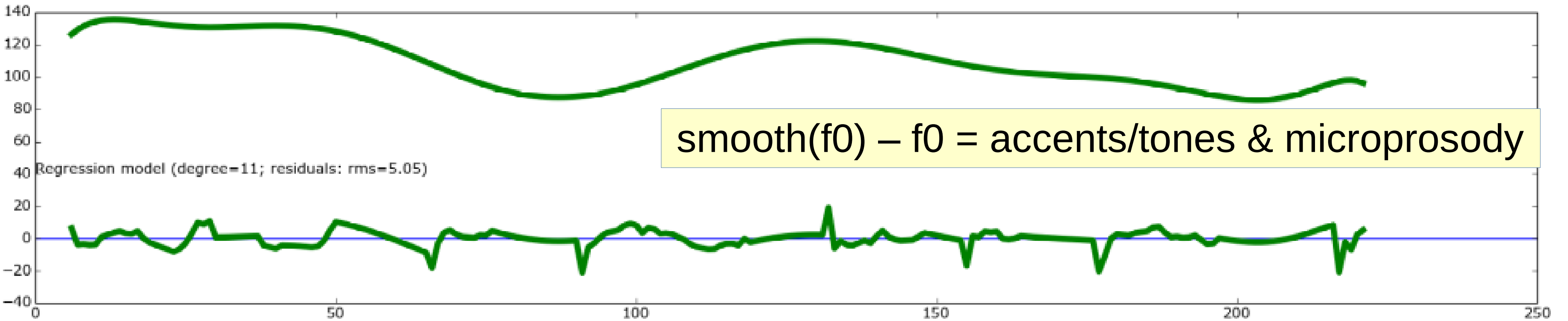
Global regression contour, degree 7



Endlich gab der Nordwind den Kampf auf.

Global regression contour, degree 11

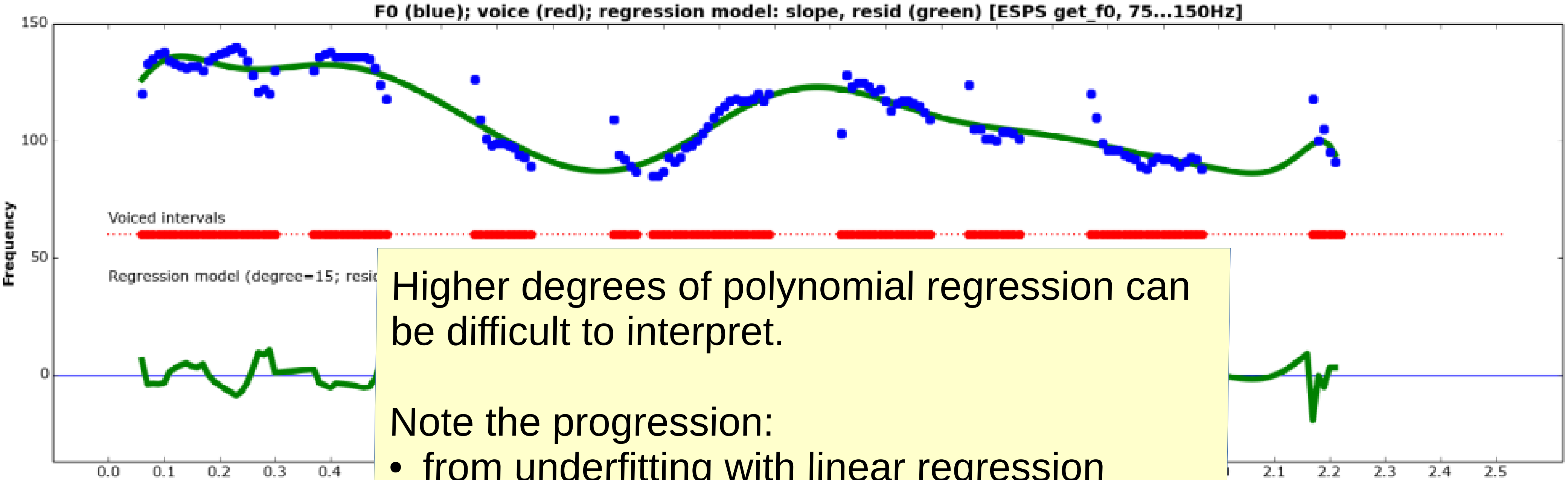




smooth(f0) – f0 = accents/tones & microprosody

Endlich gab der Nordwind den Kampf auf.

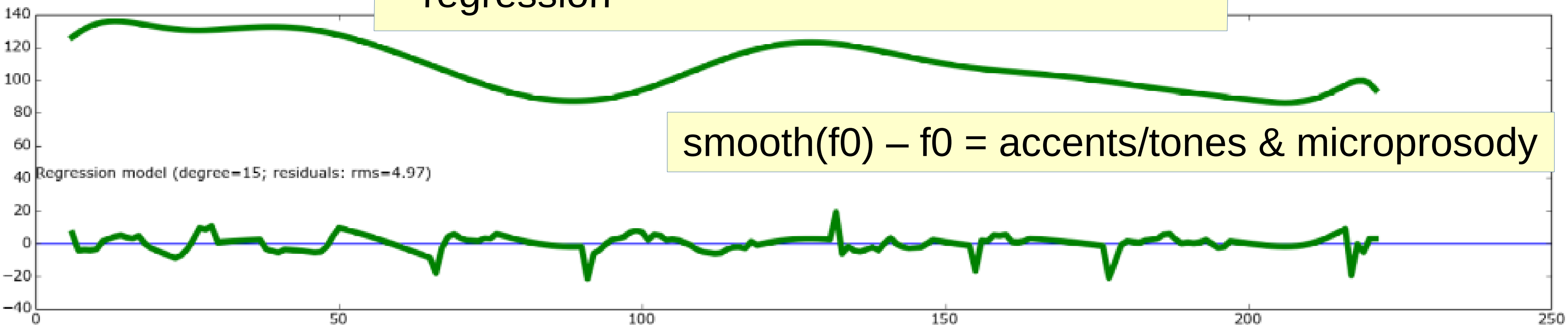
Global regression contour, degree 15



Higher degrees of polynomial regression can be difficult to interpret.

Note the progression:

- from <u>underfitting</u> with linear regression
- to <u>overfitting</u> with higher degrees polynomial regression



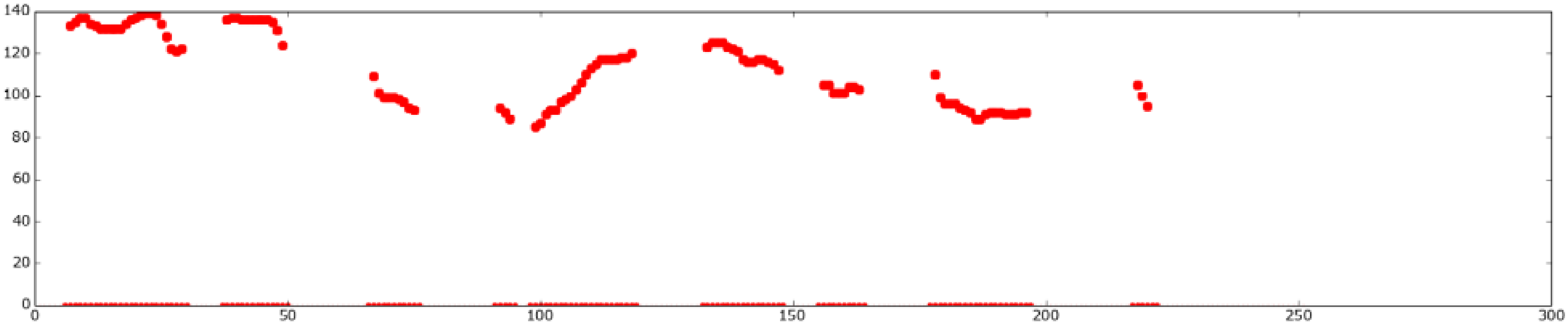
smooth(f0) – f0 = accents/tones & microprosody

Endlich gab der Nordwind den Kampf auf.

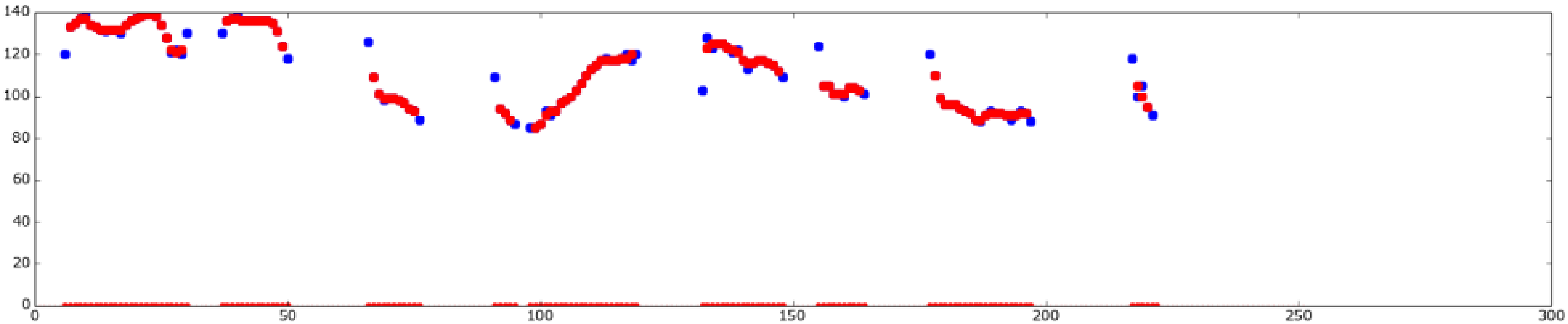
F0 smoothing: local procedures

(relevant for pitch accent and tone modelling)

Simple median filter, popular (here window: 3 F0 samples)

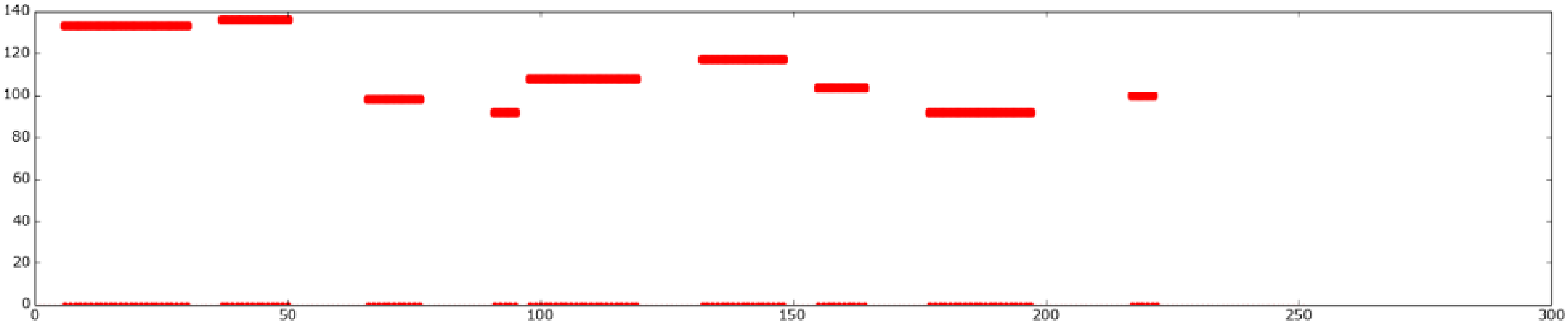


Endlich gab der Nordwind den Kampf auf.

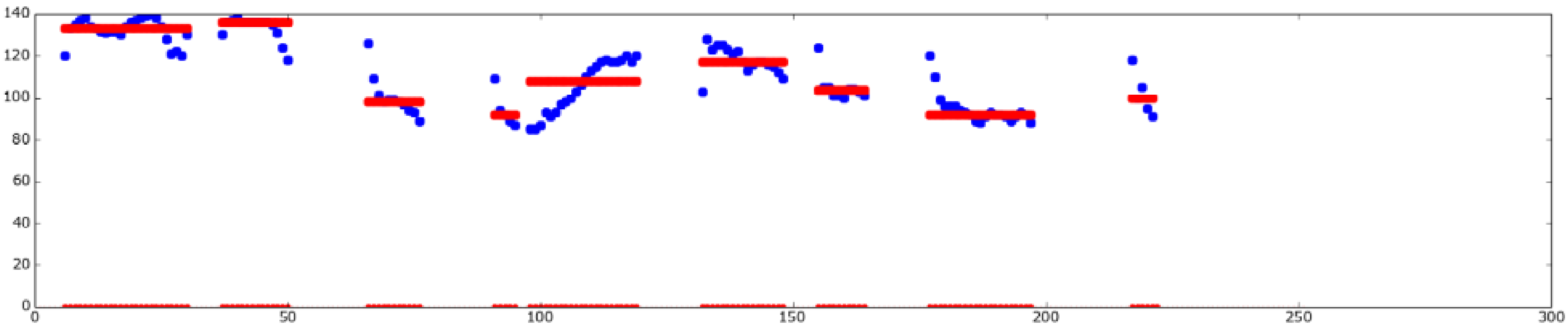


Each F0 value is normalised to the median F0 value of its immediate neighbours

Simple local median levelling filter – robotic!

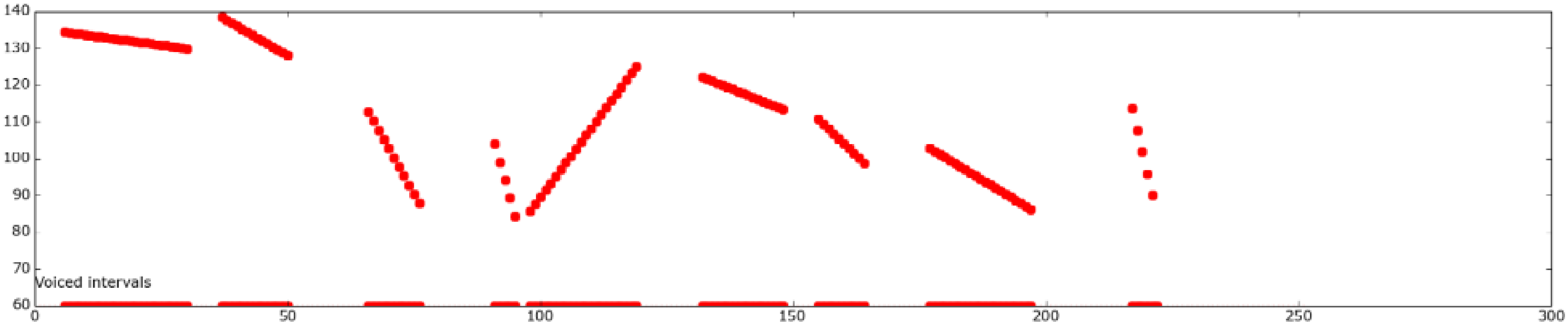


Endlich gab der Nordwind den Kampf auf.

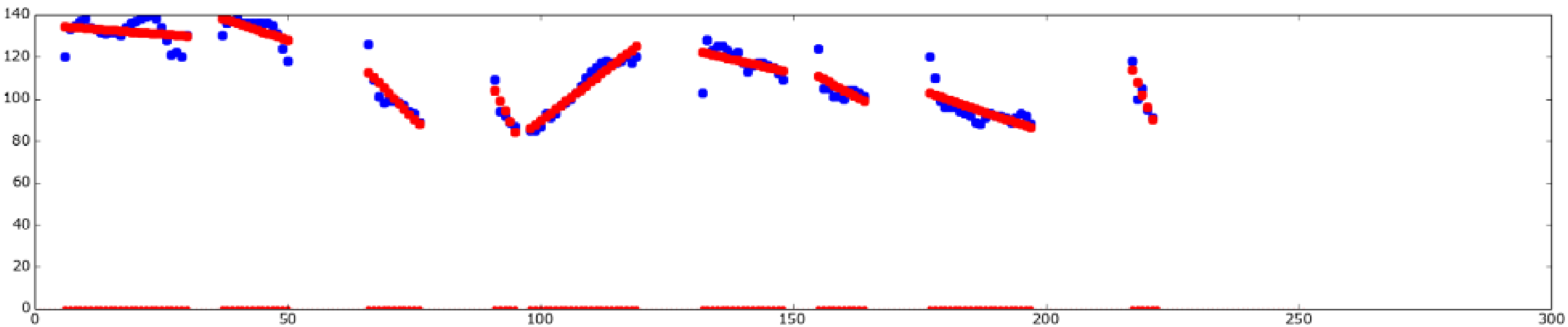


Each F0 value in a sequence is normalised to the median F0 value for the sequence

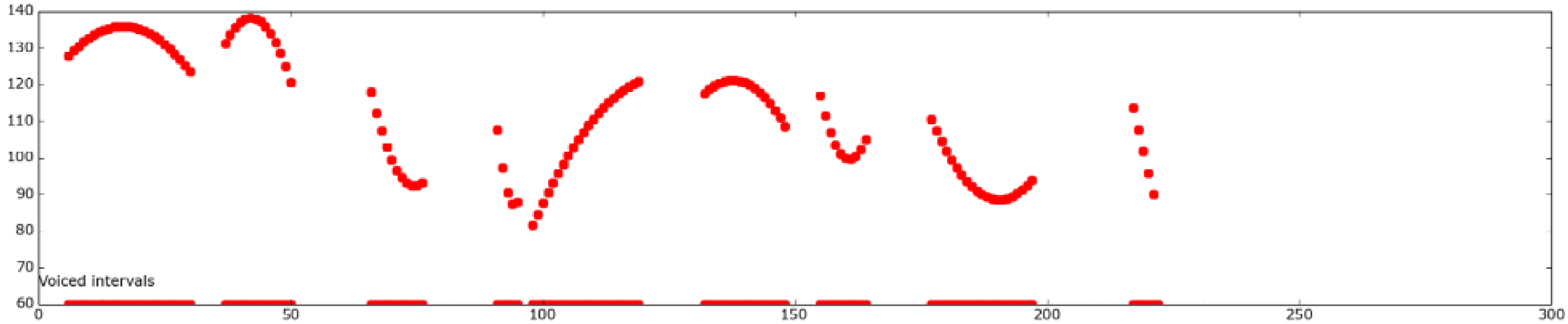
Local voicing regression contours, degree 1



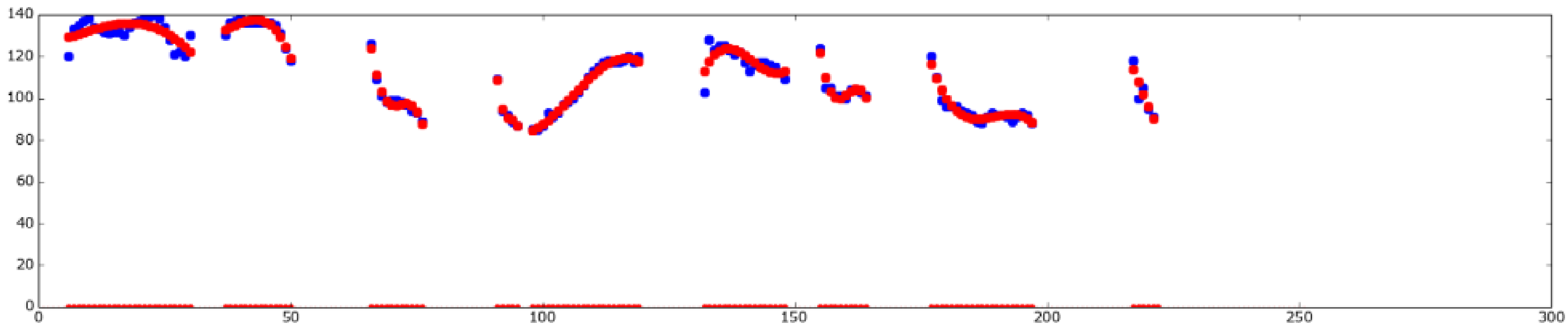
Endlich gab der Nordwind den Kampf auf.



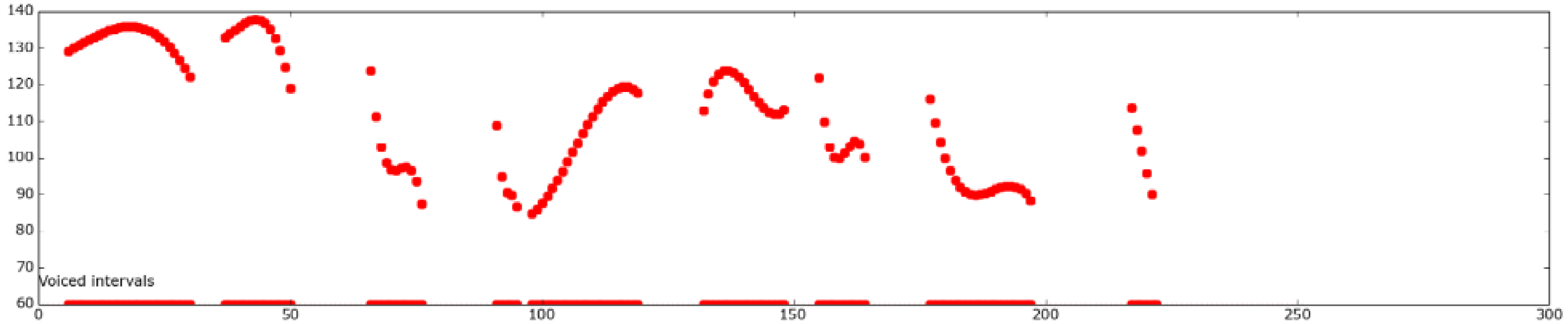
Local voicing regression contours, degree 2



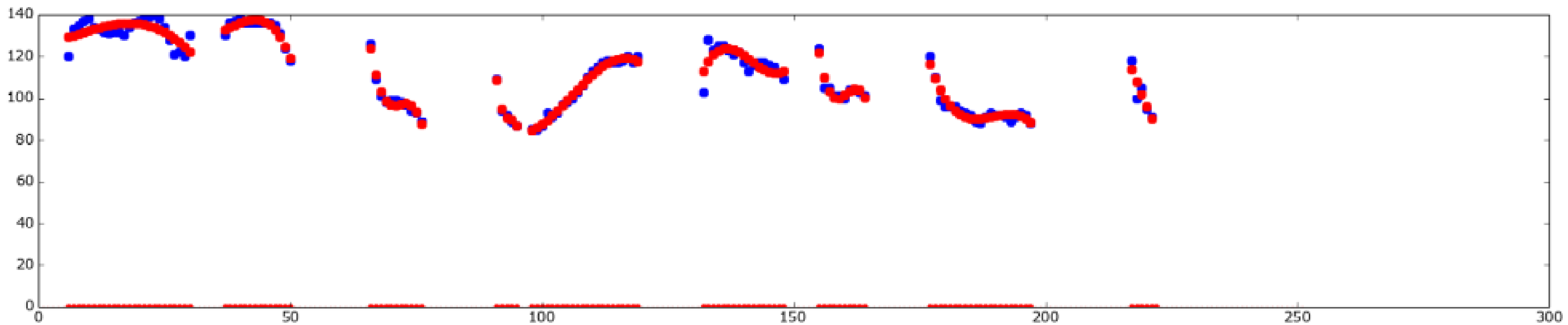
Endlich gab der Nordwind den Kampf auf.



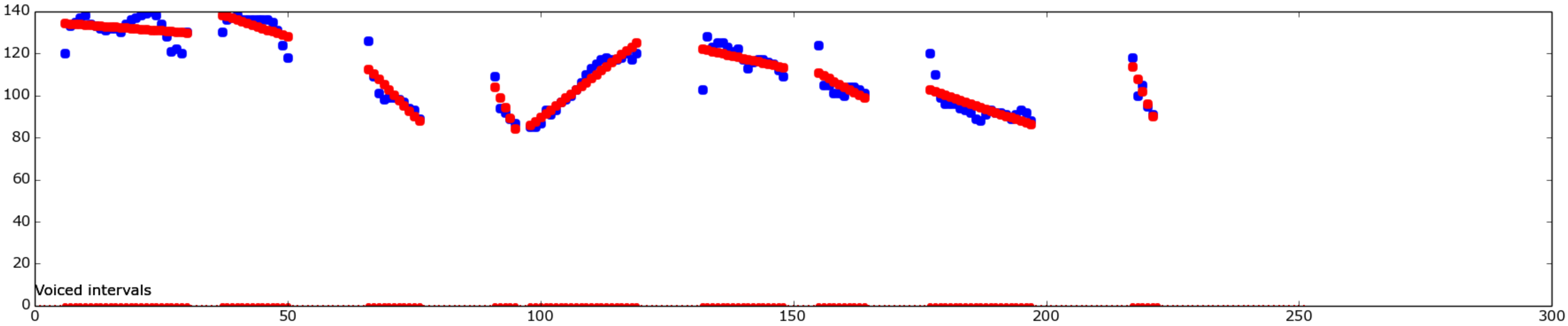
Local voicing regression contours, degree 3



Endlich gab der Nordwind den Kampf auf.



Local voicing regression contours (1...5)



Endlich gab der Nordwind den Kampf auf.

Higher degrees of polynomial regression can be difficult to interpret.

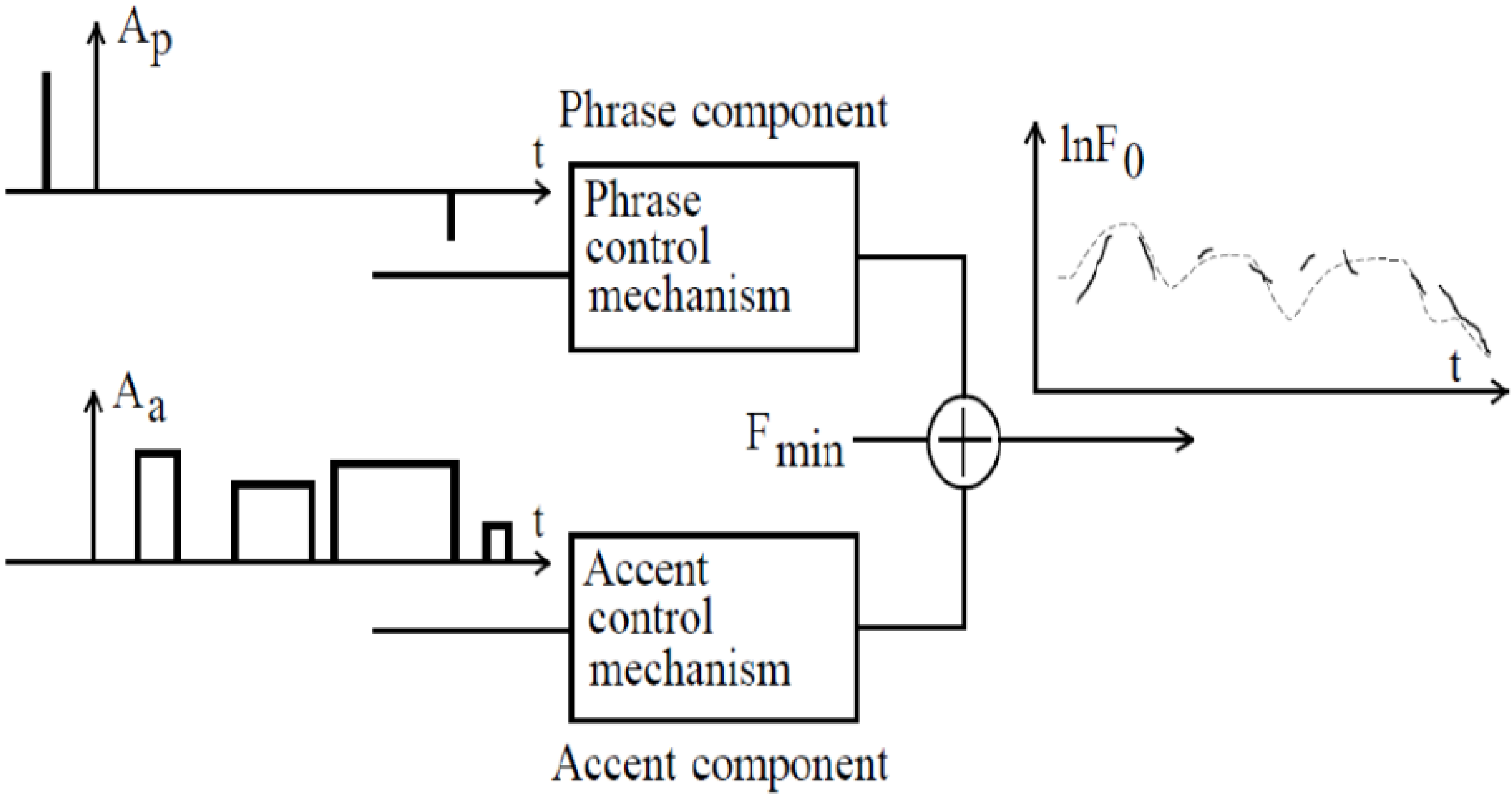
Note the progression:

- from underfitting with linear regression
- to overfitting with higher degrees polynomial regression

Many pitch stylisation / modelling methods ...

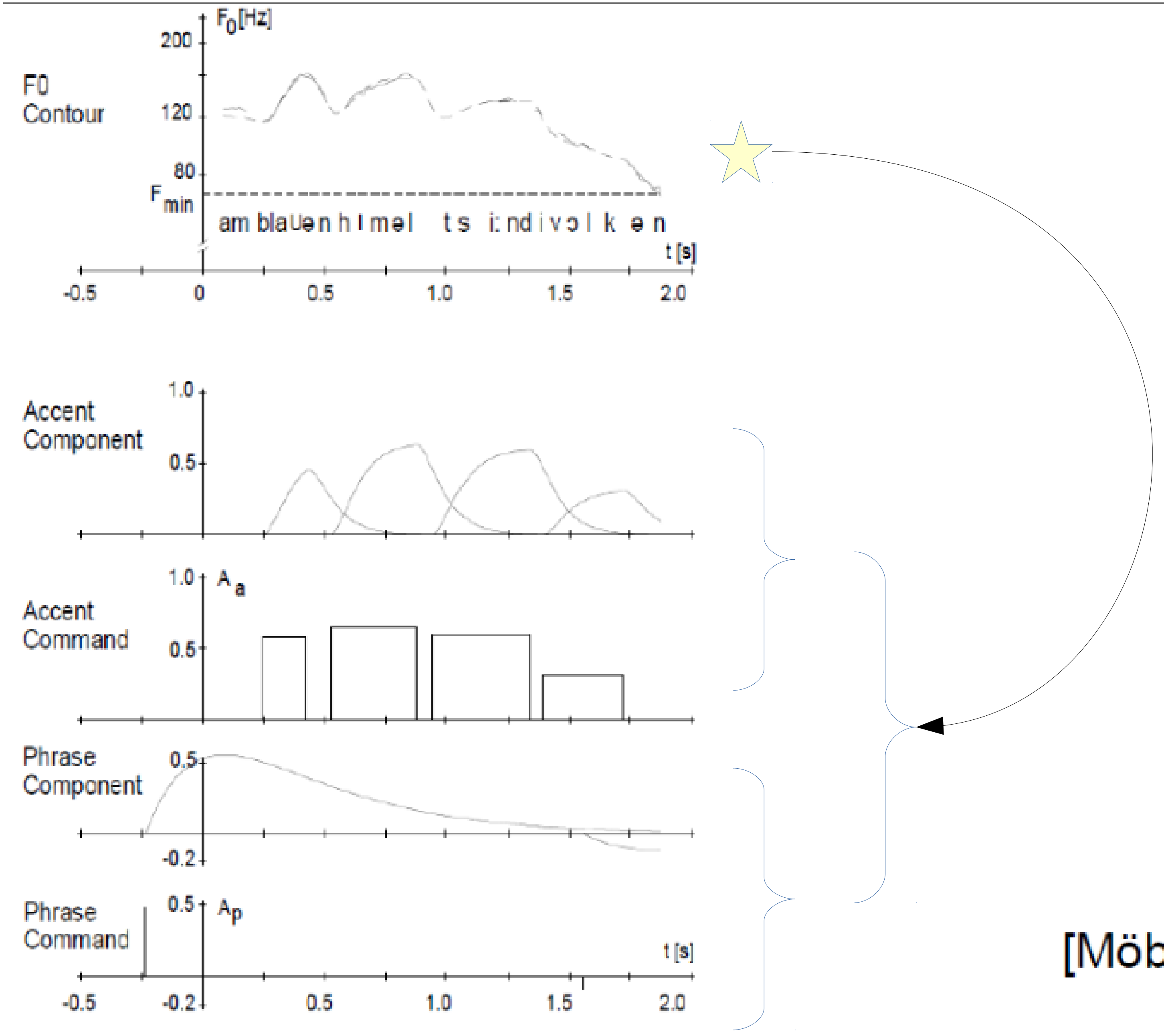
- Straight lines (IPO)
- Baseline + pulse modulation
- Gårding
- Grønnum (Thorsen)
- Asymptotic descent (Liberman & Pierrehumbert)
  - Tilt
- Spline sequence interpolation (Hirst)

Models of f0 patterning: Fujisaki Model



[Fujisaki 1983, 1988; Möbius 1993]

Models of f0 patterning: Fujisaki Model



[Möbius 1993]

Models of f0 patterning: Hirst

- Intsint
  - A transcription system for representing pitch patterns:
    - Height and range
    - Direction
- Momel
  - A method and software (Praat script) for separating local pitch perturbations (e.g. by consonants) from the intonationally and tonally relevant patterns
- ProZed
  - Powerful pitch visualiser and editor software

Hirst: quadratic spline - 'piecewise quadratic function'

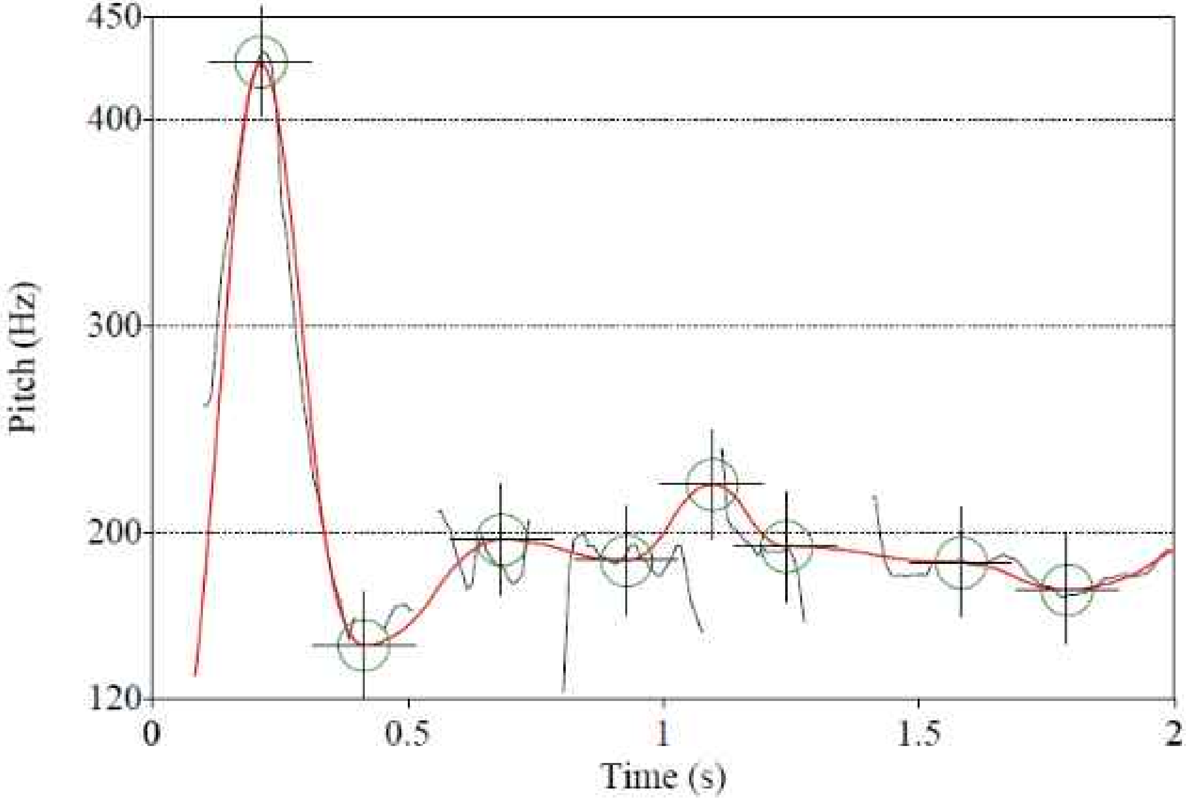


Fig. 6.7 Macromelodic profile (red) for a two-second extract from recording A01, defined as quadratic transitions between anchor points (green).

Hirst: quadratic spline - ‘piecewise quadratic function’

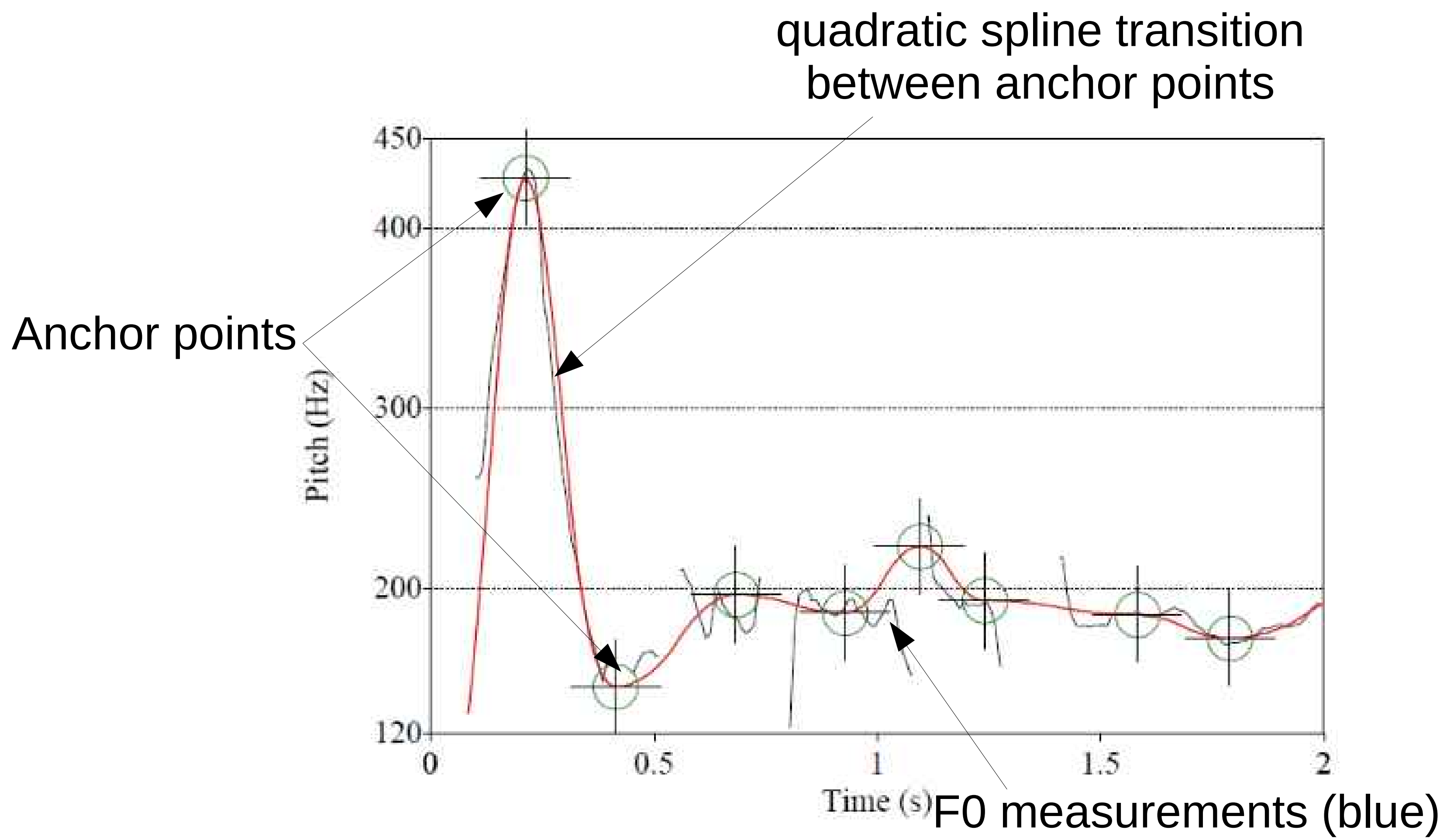
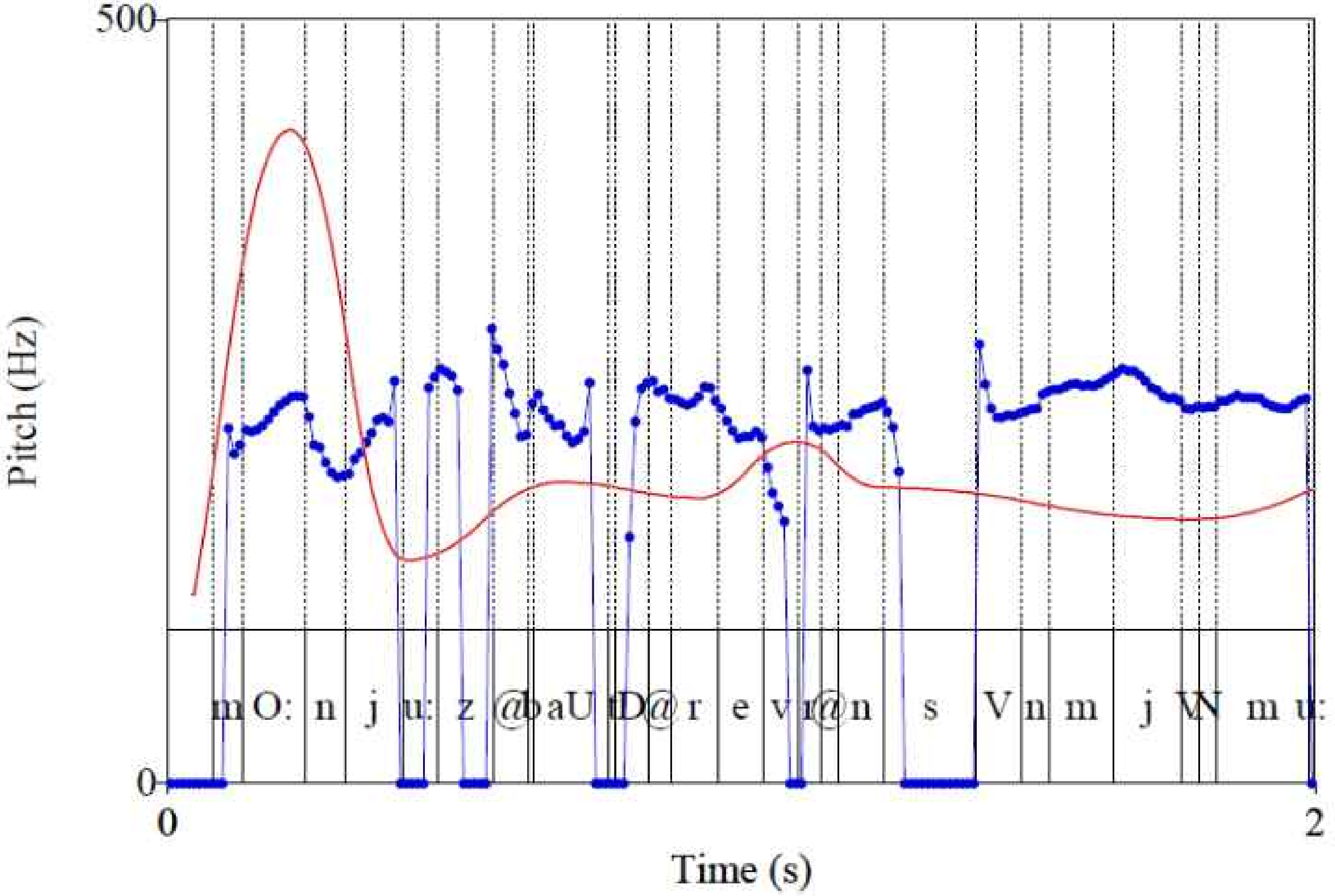


Fig. 6.7 Macromelodic profile (red) for a two-second extract from recording A01, defined as quadratic transitions between anchor points (green).

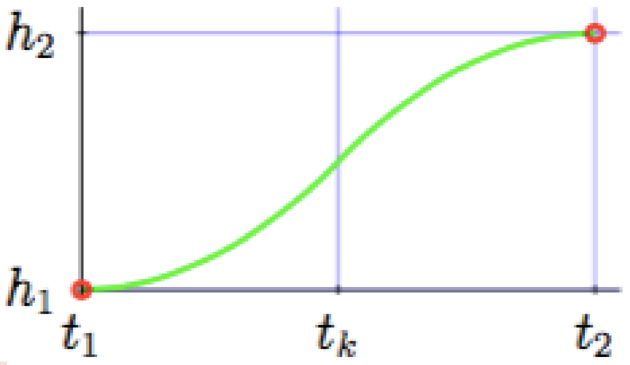
Hirst: micromelody = F0 / quadratic spline function



Macromelody (red), micromelody (blue): micromelody = F0 / spline model

Smoothing by local spline interpolation (Hirst)

Momel:
Quadratic splines:
- changing an anchor point only affects neighbouring transitions
- anchor points correspond to zeros on the first derivative of the spline
- the transition between two anchor points:
  - symmetrical
  - maximum slope at the spline "knot" - half way between two anchor points.



Hirst's f0 formulas:

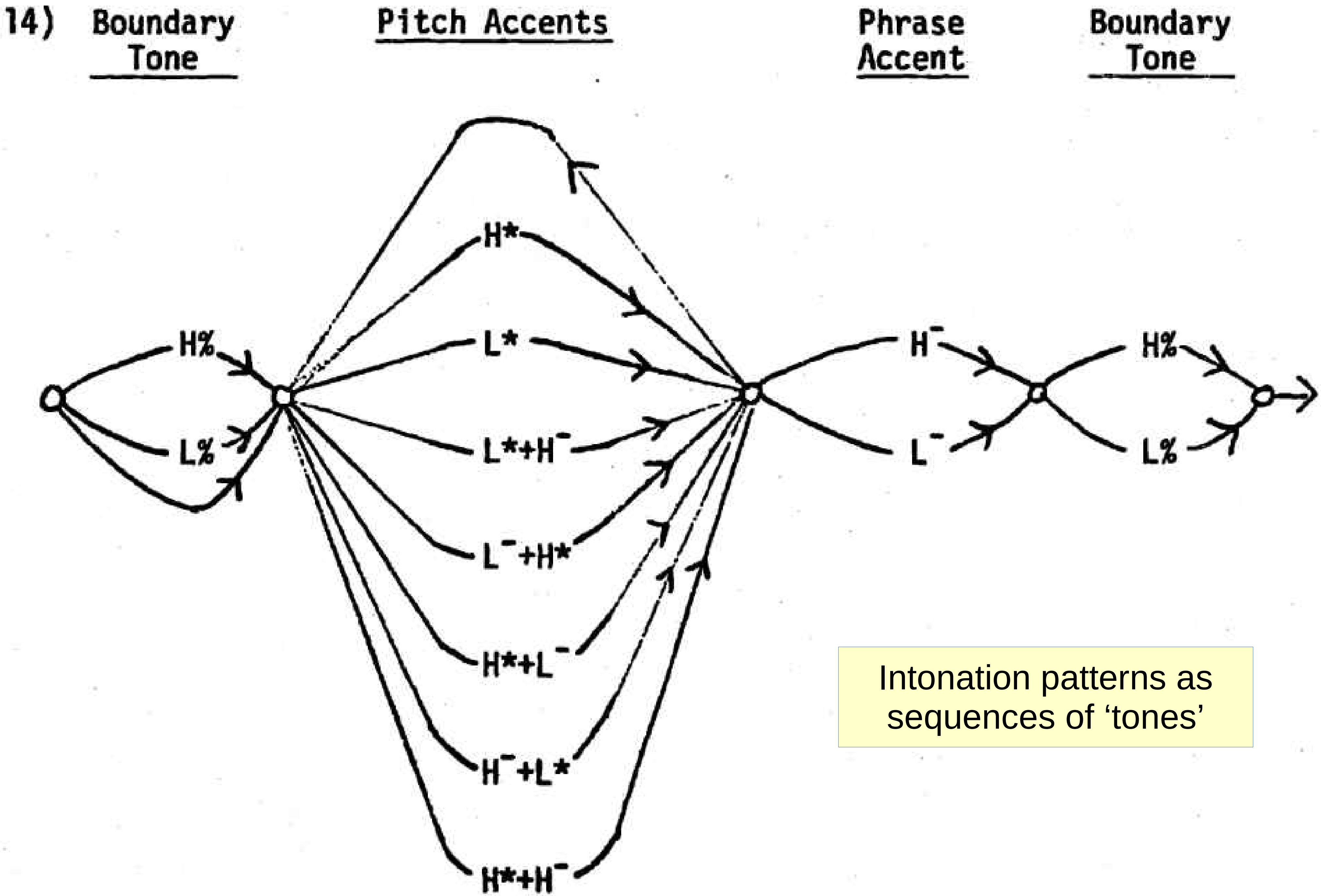
$$t_i \in [t_1 \ldots t_k] : h_i = h_1 + \frac{(h_2 - h_1) \cdot (t_i - t_1)^2}{(t_k - t_1)(t_2 - t_1)}$$

$$t_i \in [t_k \ldots t_2] : h_i = h_2 + \frac{(h_1 - h_2) \cdot (t_i - t_2)^2}{(t_k - t_2)(t_1 - t_2)}$$

Cubic spline problem, so not used in Momel:

Changing one anchor point can affect the whole curve.

An intonation grammar: Pierrehumbert (1980)



Intonation patterns as sequences of ‘tones’

Detailed models: Pierrehumbert & Liberman (1983)

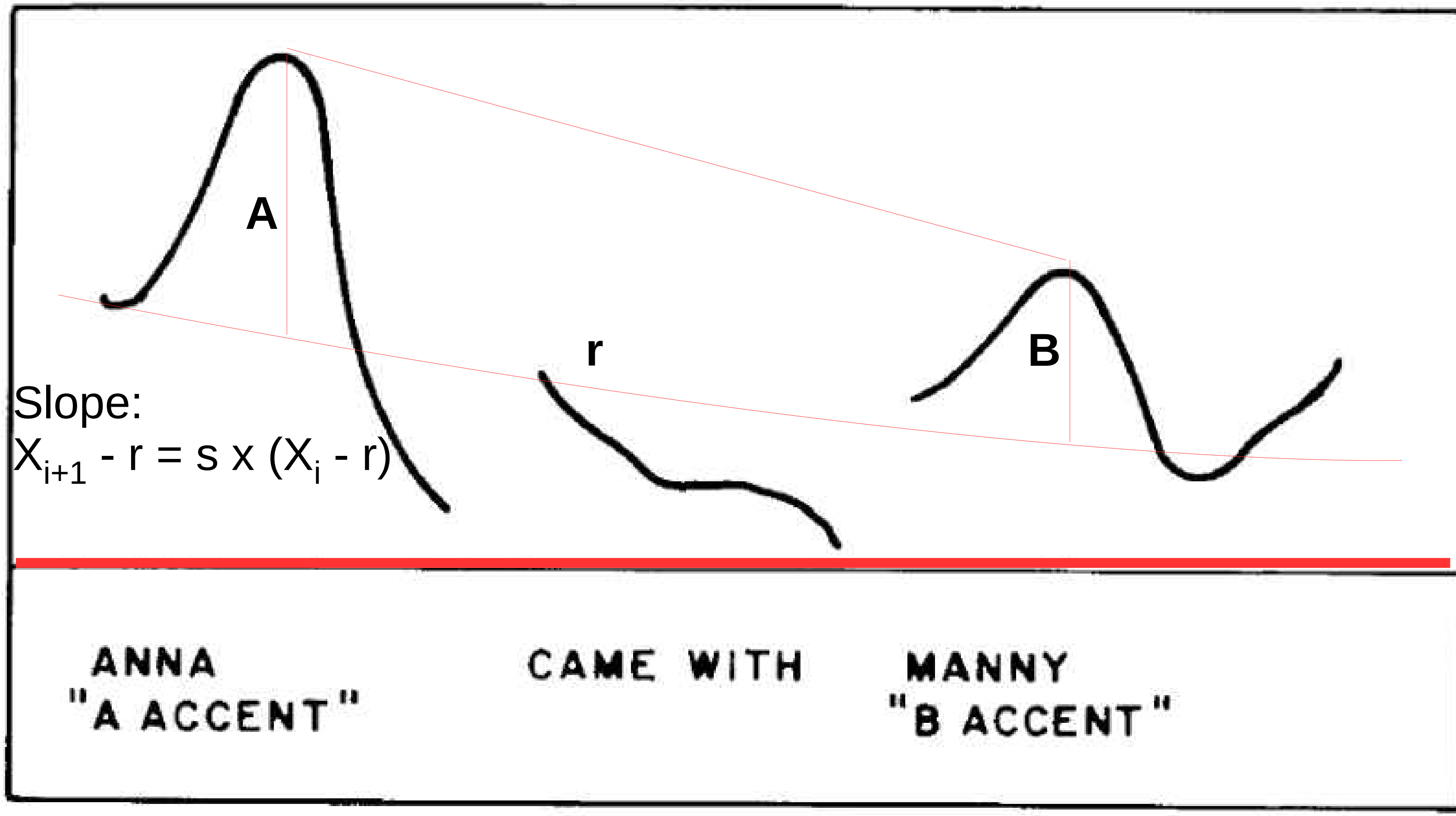


Figure 9
An F0 contour for *Anna came with Manny*, produced as a response to *What about Manny? Who came with him?*

Detailed models: Pierrehumbert & Liberman (1983)

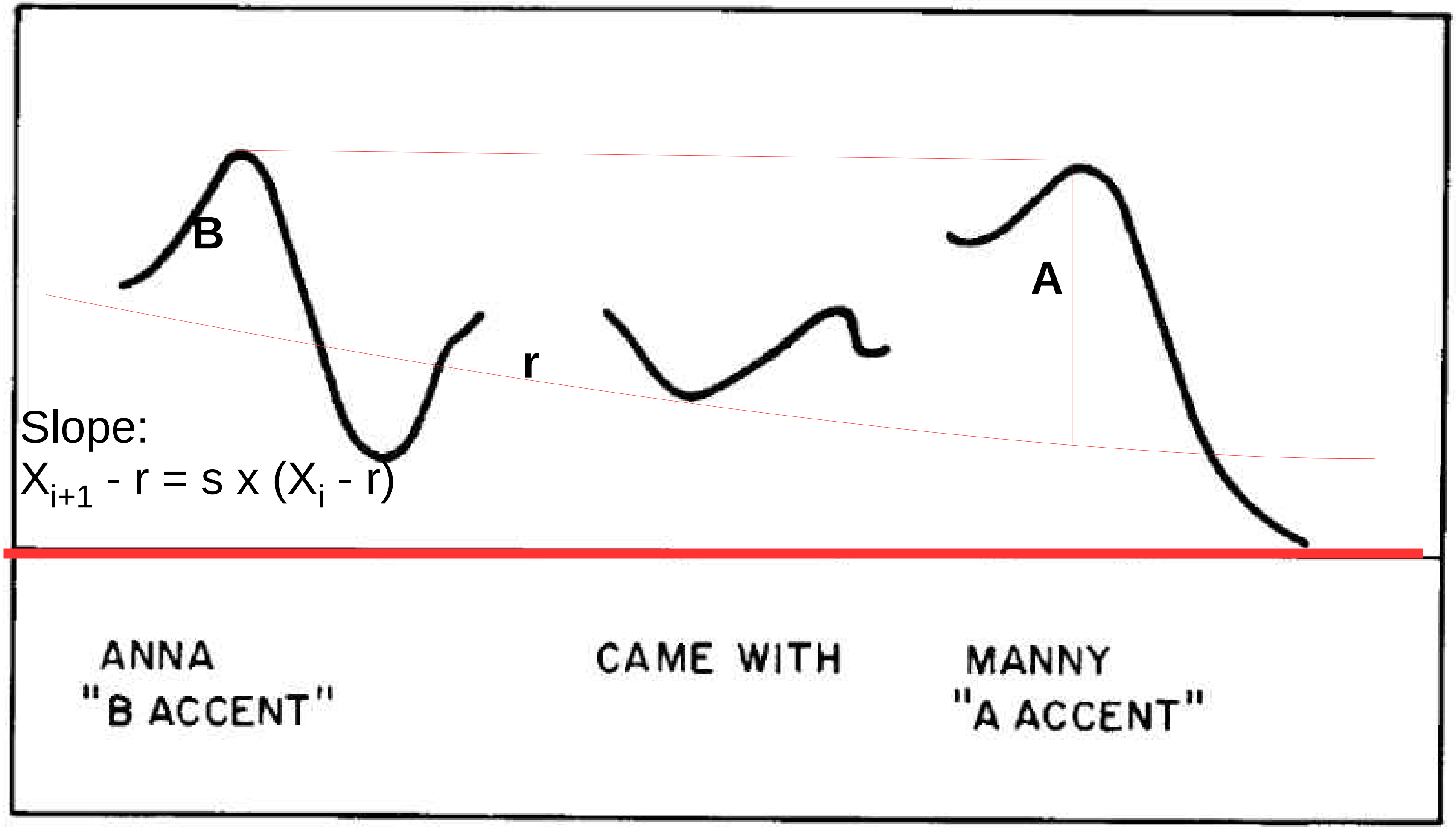
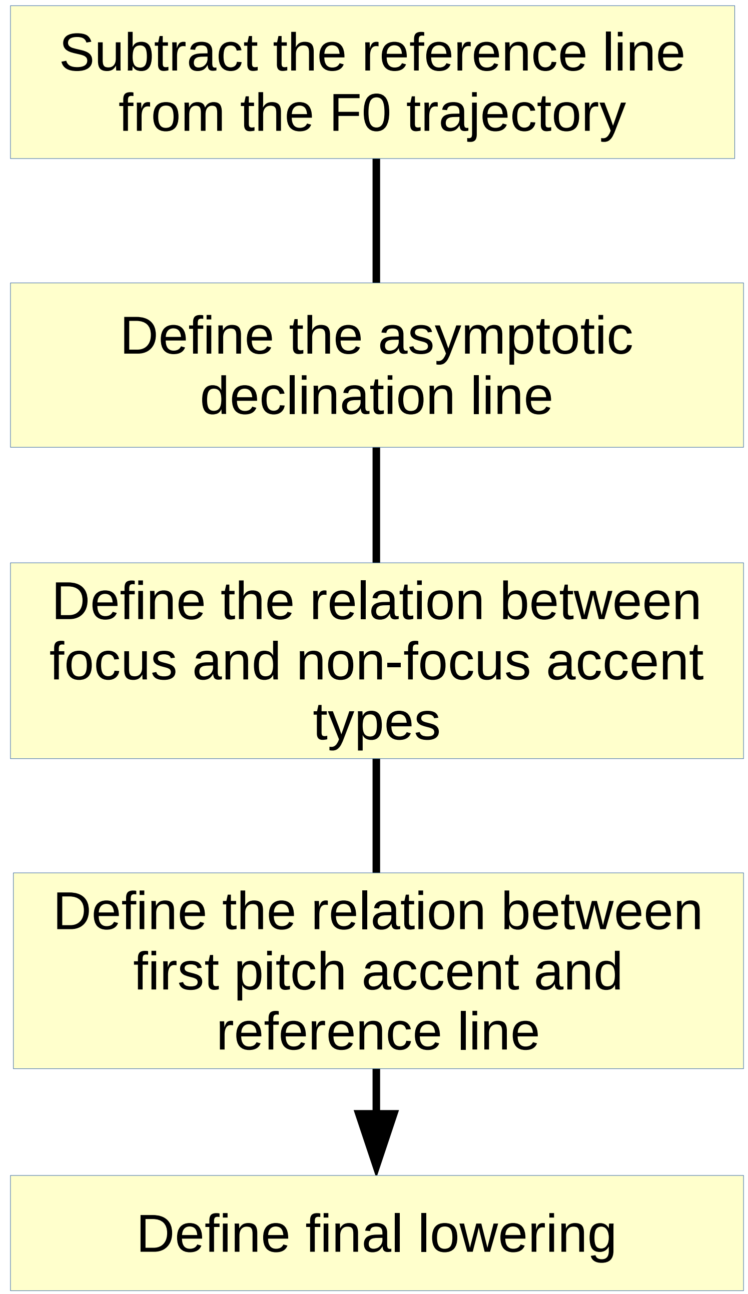


Figure 10
An F0 contour for *Anna came with Manny*, produced as a response to *What about Anna? Who did she come with?*

Models of f0 patterning: Liberman & Pierrehumbert



Detailed models: Liberman & Pierrehumbert

Model 1

a. General F0 transform

$$T(P) = P - r$$

P and r in Hz

b. Downstep

$$T(P_i) = s \cdot T(P_{i+1})$$

where P_i is the F0 target in Hz of a step accent in position i, downstepped with respect to the previous accent target P_{i-1}

c. Answer-background relation

$$T(P_A) = k \cdot T(P_B)$$

where P_A is the F0 target in Hz of the A accent, and P_B the B accent

d. Relation of r to initial accent target

$$r = f \cdot (P_0 - b)^e + d + b$$

where P_0 is the target in Hz of the first pitch accent, and d. e. f. and b are constants

e. Final Lowering

$$P \rightarrow r + l \cdot (P - r) / \_\_\_\_ \$$$

where $l < 1$

Modified transform for model 1

$$T(P) = (1/l) \cdot (P - r)$$

where $l < 1$ in final position, $l = 1$ otherwise

Model 1A

Substitute

$$r = f \cdot (P_0)^e + d$$

for equation (5d) in model 1.

Model 1B

Substitute

$$r = f \cdot P_0 + d$$

for equation (5d) in model 1.

Model 1C

Substitute

$$P \rightarrow l \cdot P / \_\_\_\_ \$$$

for rule (5e) in model 1.

Detailed models: Liberman & Pierrehumbert

Model 1

a. General F0 transform

$T(P) = P - r$

P and r in Hz

Subtract the reference line from the F0 trajectory

Modified transform for model 1

)

where $l < 1$ in final position, $l = 1$ otherwise

b. Downstep

$T(P_i) = s \cdot T(P_{i+1})$

where P_i is the F0 targ… …tion i, down-stepped with respect to the previous accent target P_{i-1}

Define the asymptotic declination line

c. Answer-background relation

$T(P_A) = k \cdot T(P_B)$

where P_A is the F0 targ…

the B accent

Define the relation between focus and non-focus accent types

Model 1A

Substitute

$r = f \cdot (P_0)^e + d$

for equation (5d) in model 1.

d, e, f, and b

d. Relation of r to initial accent target

$r = f \cdot (P_0 - b)^e + d + b$

where P_0 is the target i…

are constants

Define the relation between first pitch accent and reference line

Model 1B

Model 1C

Substitute

$r = f \cdot P_0 + d$

for equation (5d) in model 1.

e. Final Lowering

$P \rightarrow r + l \cdot (P - r) / \_\_\_\_$ S…

where $l < 1$

Define final lowering

for rule (5e) in model 1.

Detailed models: Liberman & Pierrehumbert

Model 1

a. General F0 transform

$T(P) = P - r$

P and r in Hz

Subtract the reference line

...dified transform for model 1

...P) = $(1/l) \cdot (P - r)$

where $l < 1$ in final position, $l = 1$ otherwise

b. Downstep

$T(P_i) = s \cdot T(P_{i+1})$

Define the asymptotic declination line

where P_i is the F0 target in Hz of a step accent in position i, down-stepped with respect to the previous accent target P_{i-1}

c. Answer-background relation

$T(P_A) = k \cdot T(P_B)$

where P_A is the F0 target in ... the B accent

Define the relation between focus and non-focus accent types

...odel 1A

Substitute

... $= f \cdot (P_0)^e + d$

...r equation (5d) in model 1.

d. Relation of r to initial accent ...

$r = f \cdot (P_0 - b)^e + d + b$

where P_0 is the target in Hz ... are constants

Define the relation between first pitch accent and reference line

... l. e. f. and b

Model 1B

...ıbstitute

... $= f \cdot P_0 + d$

for equation (5d) in model 1.

Model 1C

Su...

P ...

for rule (5e) in model 1.

e. Final Lowering

$P \rightarrow r + l \cdot (P - r) / \_\_\_\_ \$$

where $l < 1$

Define final lowering

Detailed models: Liberman & Pierrehumbert

Model 1A

Substitute

$r = f \cdot (P_0)^e + d$

for equation (5d) in model 1.

Model 1B

Substitute

$r = f \cdot P_0 + d$

for equation (5d) in model 1.

Model 1C

Substitute

$P \rightarrow l \cdot P / \_\_\_\_ \$$

for rule (5e) in model 1.

Modified transform for model 1

$T(P) = (1/l) \cdot (P - r)$

where $l < 1$ in final position, $l = 1$ otherwise

Model 2

Substitute

$T(P) = \log((P - b) / (r - b))$

for equation (5a) in model 1.

Detailed models: Liberman & Pierrehumbert

Zero asymptote:

X_i+1 = s x X_i

X_i+1 - r = s x (X_i -r)

F0 transform: converts measured F0 values into a new set of values that are assumed to behave in a simpler way - coser to underlying phonetic control parameters for intonation.

Answer-background relation: taken to be constant ratio in transformed F0 values: k

Downstep relation: taken to be constant ratio in transformed F0 values: s

Lowering of F0 targets in utterance-final position; final lowering constant: l, utterance-final is bottom of entire system: b

Transformed value of F0 target P depends on pitch range; reference level for each phrase: r

Transformed value of P is its distance above r

r constrained to remain is above final F0 value: b + d

Evaluation of stylised contours – 2 methods:

Difference between F0 and stylised contour

Difference between contours in perception test

From:
Demenko Grażyna, Wagner Agnieszka (2006). The Stylization of Intonation Contours. *Proceedings of Speech Prosody 3,* May 2-5, 2006, Dresden, Germany.

Evaluation of stylised contours: Demenko & Wagner

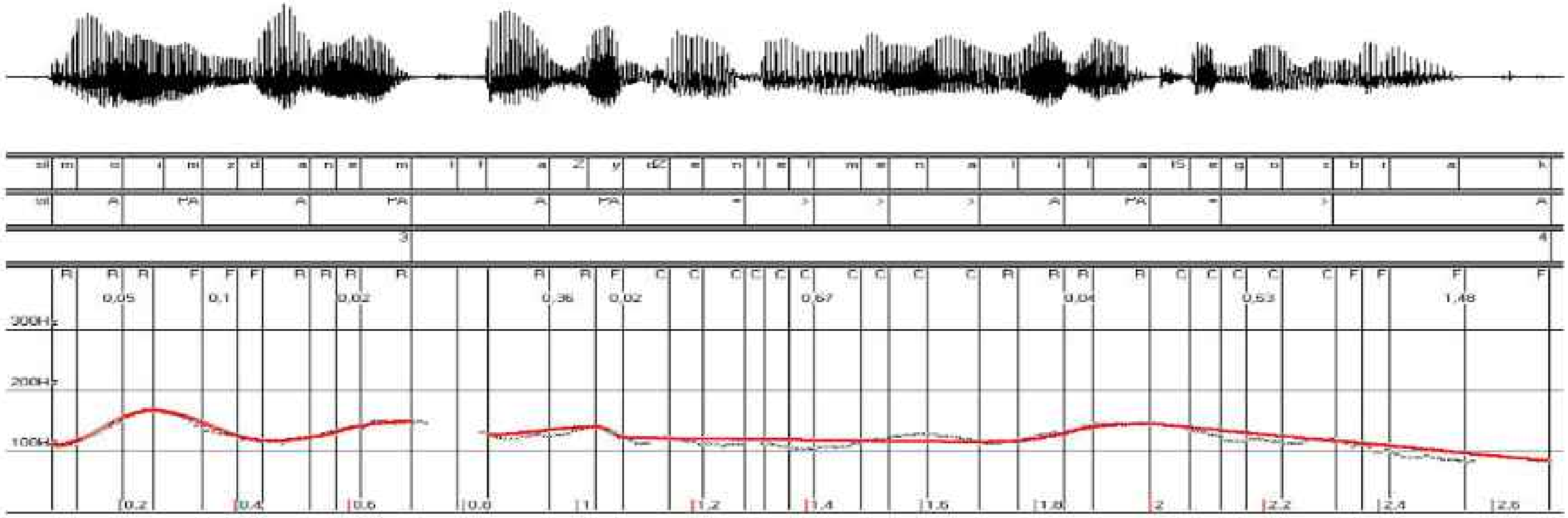


Figure 1: *Sentence:* In my opinion, the face of the lilac gentleman lacks something. *From top to bottom of the picture: waveform, .lab, .syl and .break tiers, and the stylization window. The original F0 contour is marked by dotted black line and the stylized F0 contour in red line.*

D&W 2006 stylisation model (SP3):

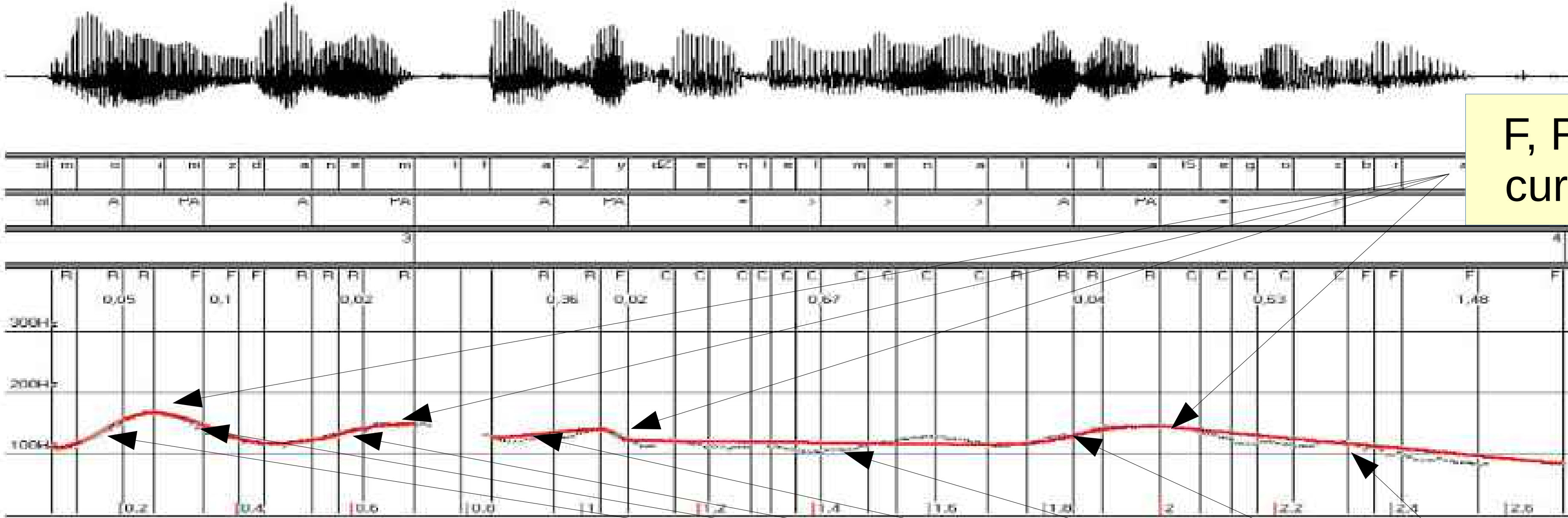
$IP \rightarrow IE^{+}$

$IE_i + SL_{i+1} + IE_{i+1}$

IP: Intonation Phrase
IE: Intonation Event
SL: Straight Line

$IE \in \{R, F, C\}$
IE parameters:
- slope
- Fp (F0 at start of event)
- range of F0 change
- shape coefficient of curve:
  - $y = y^{\gamma}$ for $0<x<1$
  - $y = 2-(2-x)y^{\gamma}$ for $1<x<2$

Evaluation of stylised contours: Demenko & Wagner



F, R, C curves

Figure 1: *Sentence:* In my opinion, the face of the lilac gentleman lacks something. *From top to bottom of the picture: waveform, .lab, .syl and .break tiers, and the stylization window. The original F0 contour is marked by dotted black line and the stylized F0 contour in red line.*

straight lines

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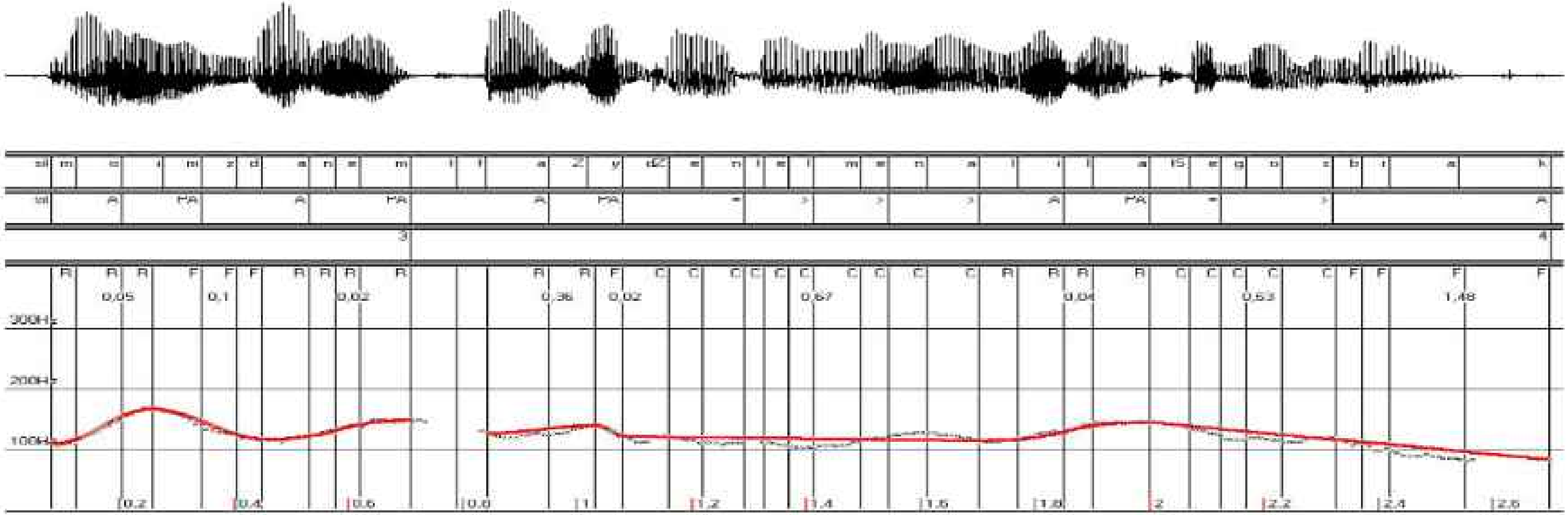


Evaluation 1: goodness of fit

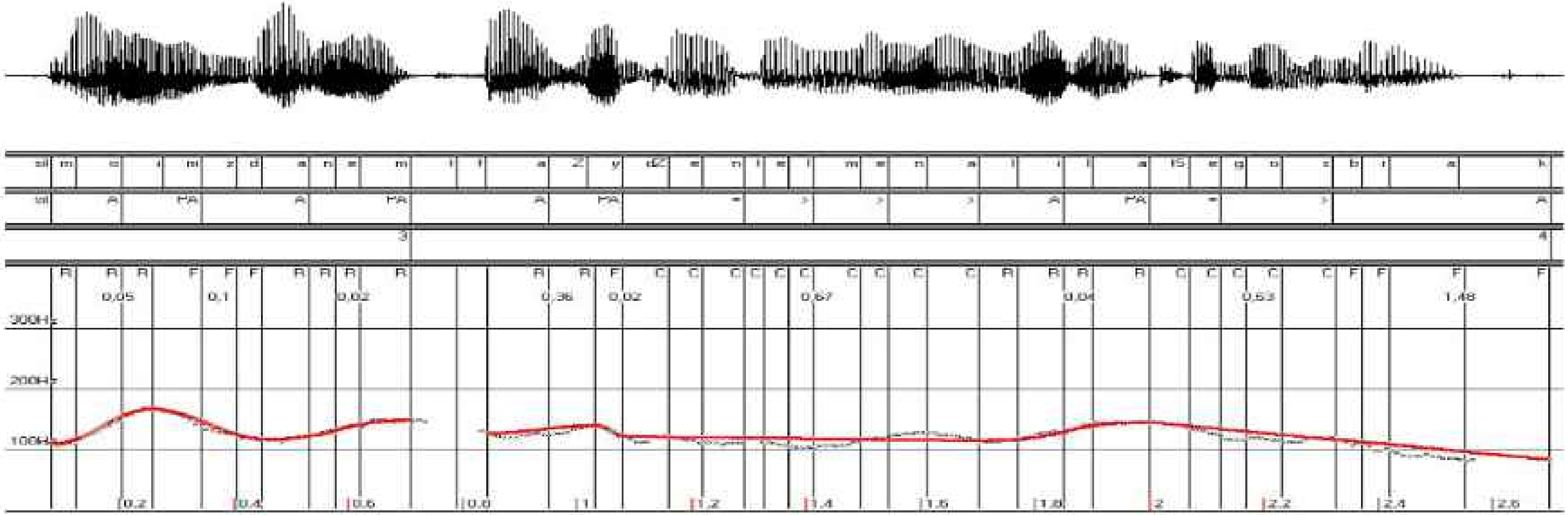
Compare F0 with stylised function with Normalised Mean Square Error:

$$NMSE(t) = \frac{\overline{\left(F_0(t_i) - Sty(t_i)\right)^2}}{\overline{F_0(t)} \cdot \overline{Sty(t)}}$$

	Accented syllable				
	Slope (Hz/s)	Fp (Hz)	Range (Hz)	bend	error
median	*58,51*	*112*	*14,2*	*1,51*	*0,01*
min	*-357,5*	*70,1*	*-96,8*	*1*	*0*
max	*401,7*	*176,7*	*93,7*	*9,549*	*0,64*
	Post-accented syllable				
	Slope (Hz/s)	Fp (Hz)	Range (Hz)	bend	error
median	*-64,5*	*129*	*-13,1*	*1,05*	*0,001*
min	*-529,4*	*65*	*-135,6*	*1*	*0*
max	*364,7*	*208,5*	*86,6*	*9,549*	*0,25*

Table1. *The range of variability of parameters describing accented and post-accented syllables.*

Evaluation of stylised contours: Demenko & Wagner



Evaluation 2: perception test

1 (identical: F0 & Sty perceived as same)
2 (a bit different: small differences in pitch height (<10Hz) perceived between F0 & Sty (e.g. pitch too high at stylized phrase end), from microprosody, errors in F0 extraction or phone or syllable segmentation.
3 (very different: F0 & Sty differ significantly – different melody, from unrecognized accents (i.e. syllable accented but not labelled “A”; cf. also #2).
Subjects could listen as often as necessary.

Result:

n=400	**Test**
Score 1:	256
Score 2:	68
Score 3:	76

After revision of stylisation criteria, items with score 3 re-tested:
30% still with score 3.

From phonetic models to phonological models

Phonology: representation systems

- Reminder:
  - Tonetic
  - Conversation analysis
  - Levels
    - 4 levels + junctures: Pike
    - 2 levels + break indices: ToBI (Pierrehumbert)
  - Relations
    - linear, hierarchical
    - multilinear, autosegmental

http://mi.eng.cam.ac.uk/~pat40/examples.html

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But I will leave the details of moving from phonetics to phonology to your own research!

☺

http://mi.eng.cam.ac.uk/~pat40/examples.html

Rank-Interpretation Architecture of Language

Paradigmatic structures as classificatory relations: choices between lexical lemmata, incl. idioms and partially regular choices from compositional rules

Syntagmatic structures	*Conceptual-intentional interpretation*	*Multimodal interpretation* *Auditory*	*Multimodal interpretation* *Visual*
DIALOGUE	dialogue act turns	dialogue and text prosody	greeting and turn gestures
TEXT	narrative, inference	intonation: phrasing, continuation, focus marking	structure indicating beat, iconic and deictic gestures
SENTENCE CLAUSE PHRASE	modality, predication, quantification, description iteration, nesting		
INFLECTED WORD	linear morphosyntax	phrase tone and accent	deictic gestures
COMPOUND WORD DERIVED WORD	iterative word-formation	word formation tone and accent	lexical iconic, metaphoric, nonce gestures
MORPHEME PHONEME	form-meaning atoms coding atoms	tone and accent distinctive features	