Automatic Music Score Recognition

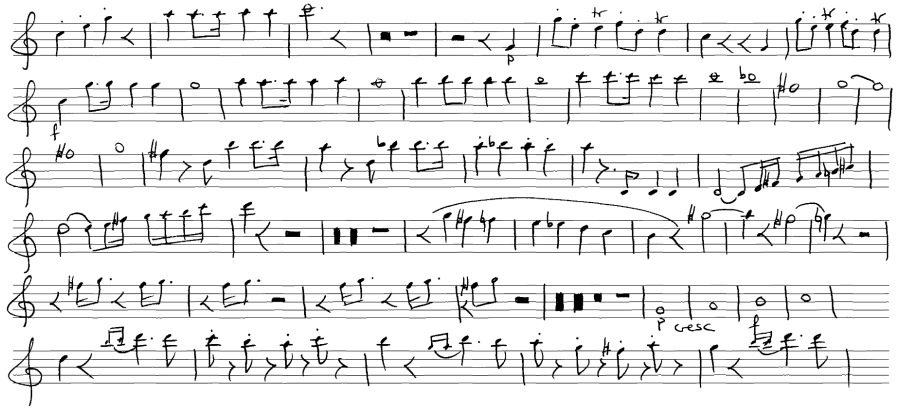
Oral Defense

HW Lee, 07.11.2016

Acoustic and **H**earing **G**roup

Optical Music Recognition

- Score in Western Music
- Image to Symbolic Representation (MusicXML)

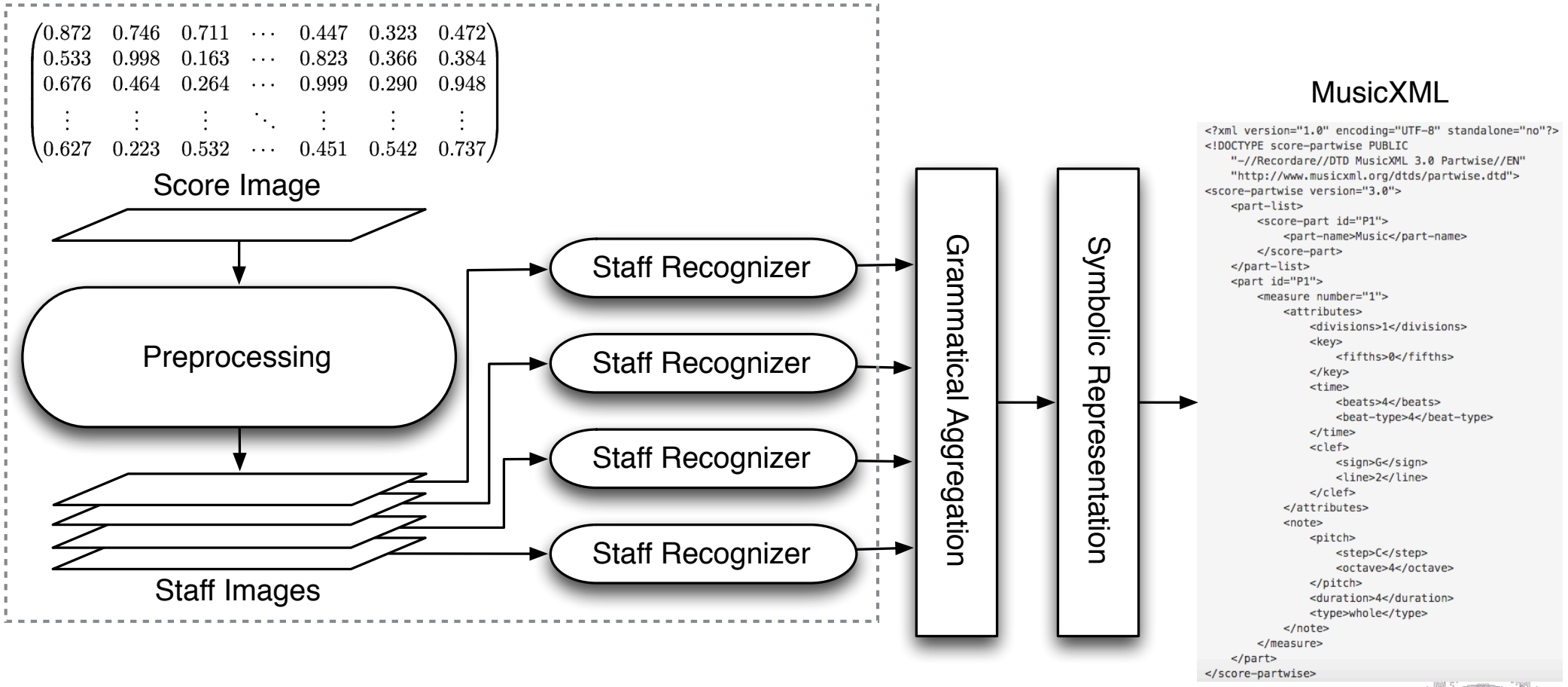


For human

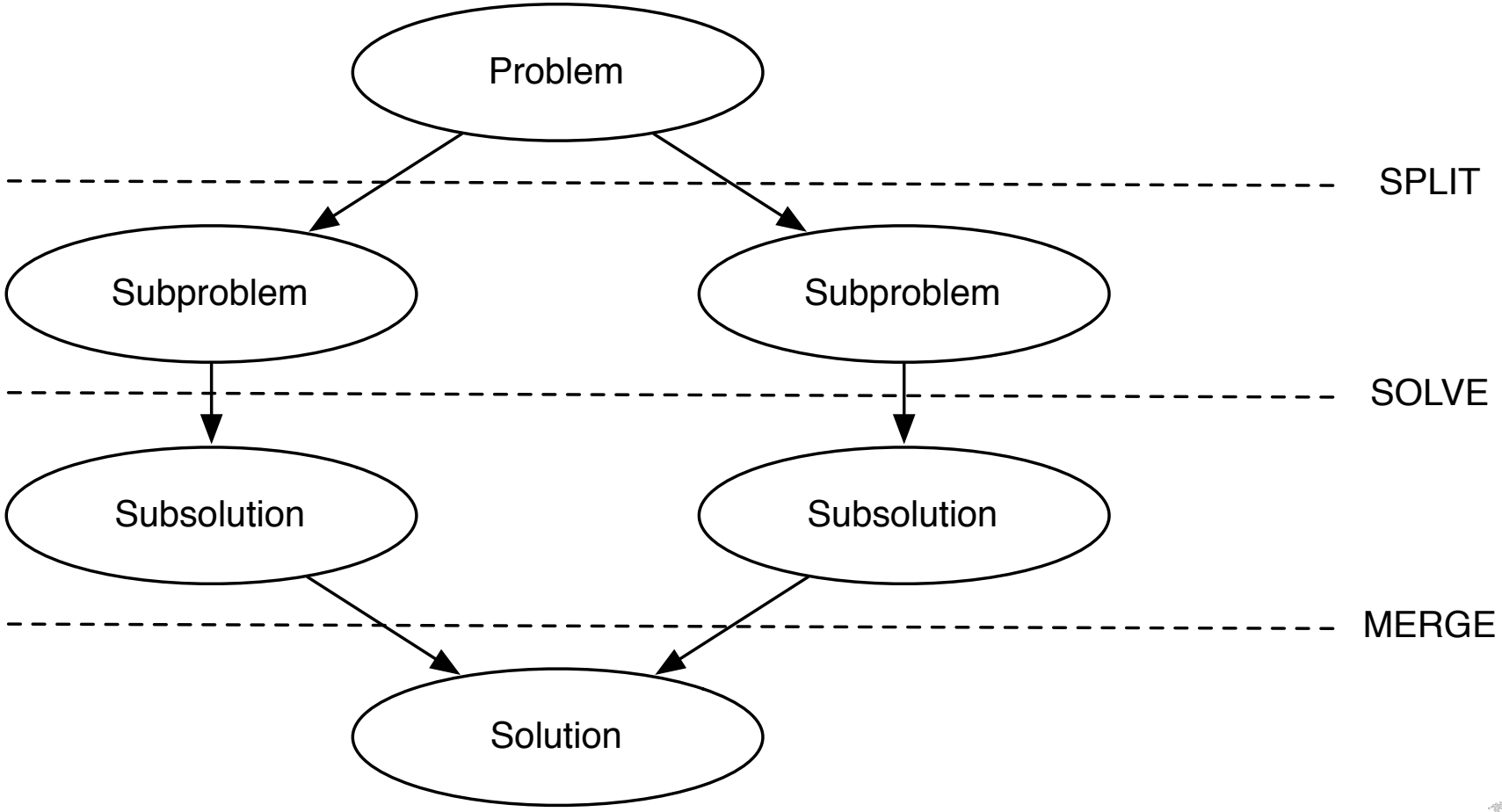
$$\begin{pmatrix} 0.872 & 0.746 & 0.711 & \cdots & 0.447 & 0.323 & 0.472 \\ 0.533 & 0.998 & 0.163 & \cdots & 0.823 & 0.366 & 0.384 \\ 0.676 & 0.464 & 0.264 & \cdots & 0.999 & 0.290 & 0.948 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0.627 & 0.223 & 0.532 & \cdots & 0.451 & 0.542 & 0.737 \end{pmatrix}$$

For computer

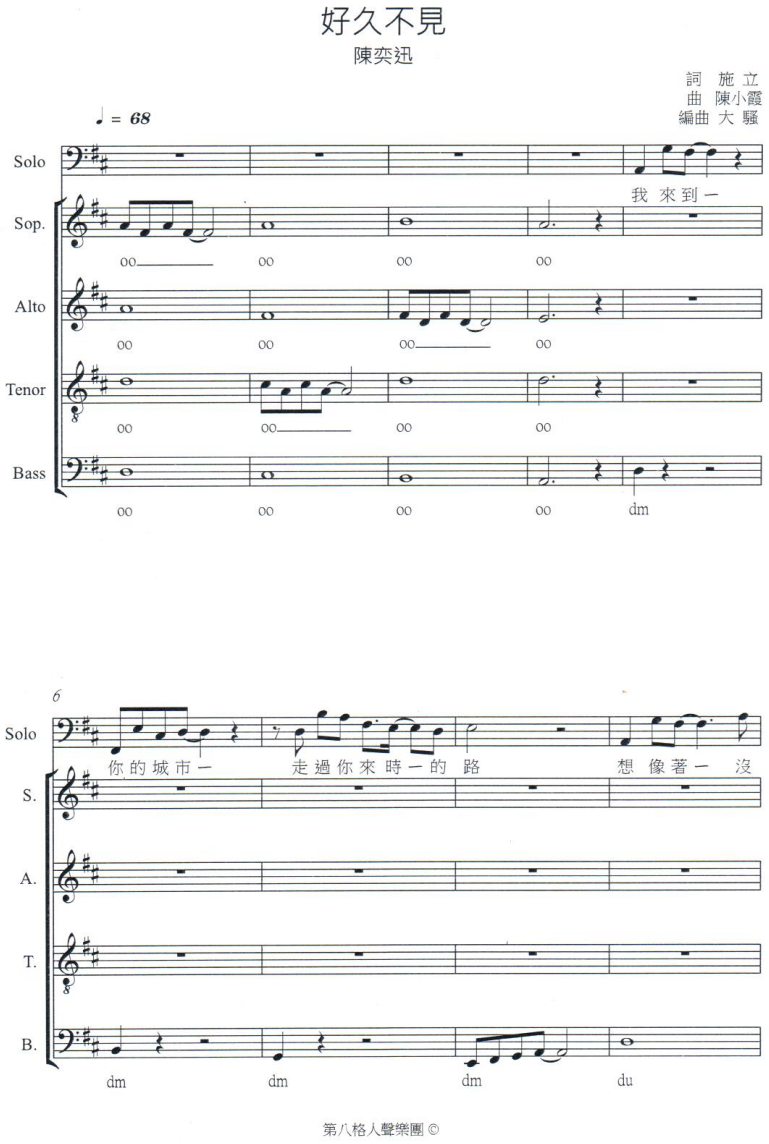
A Typical OMR System

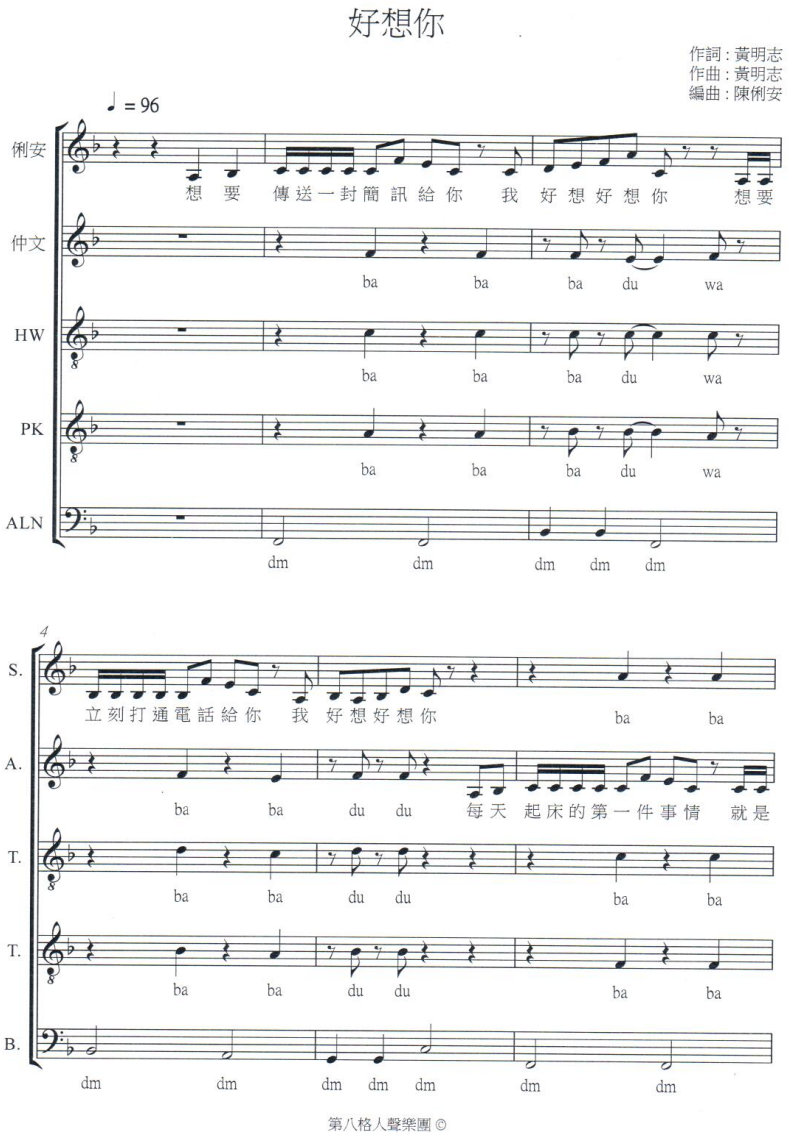


Divide & Conquer



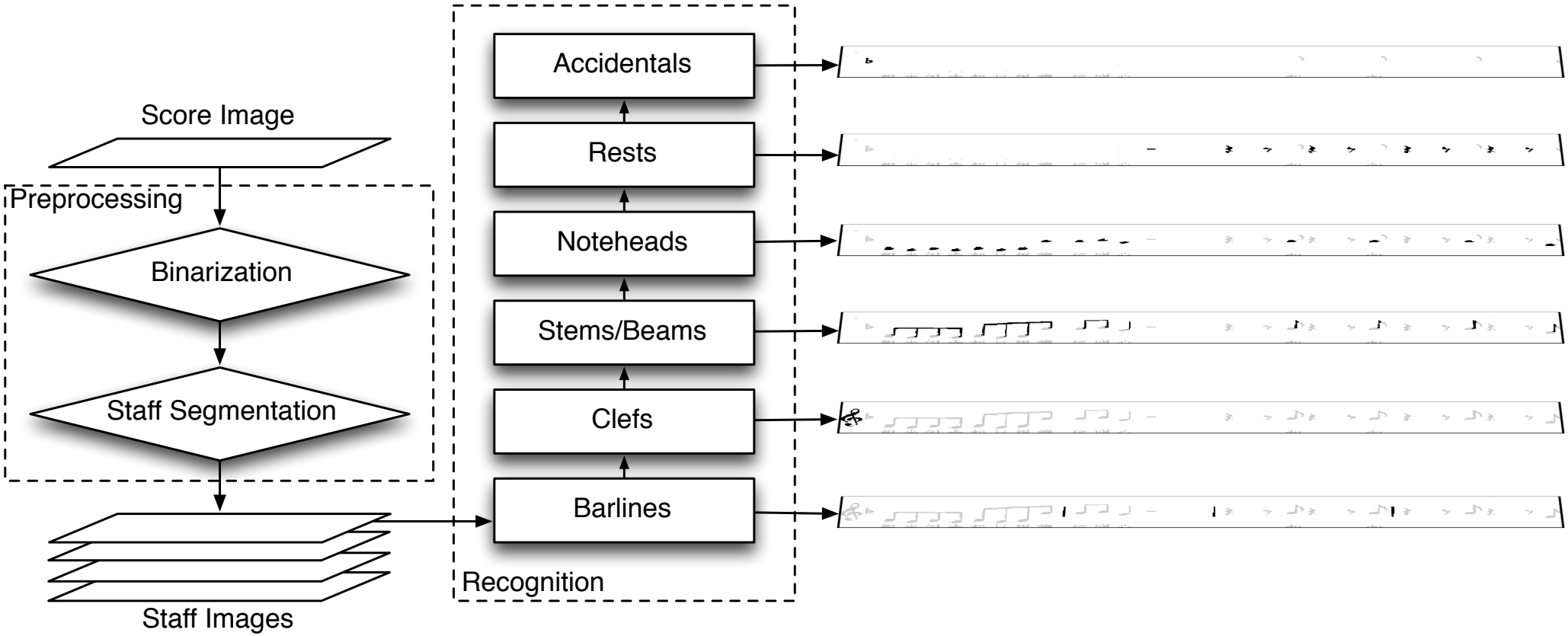
Score Sample





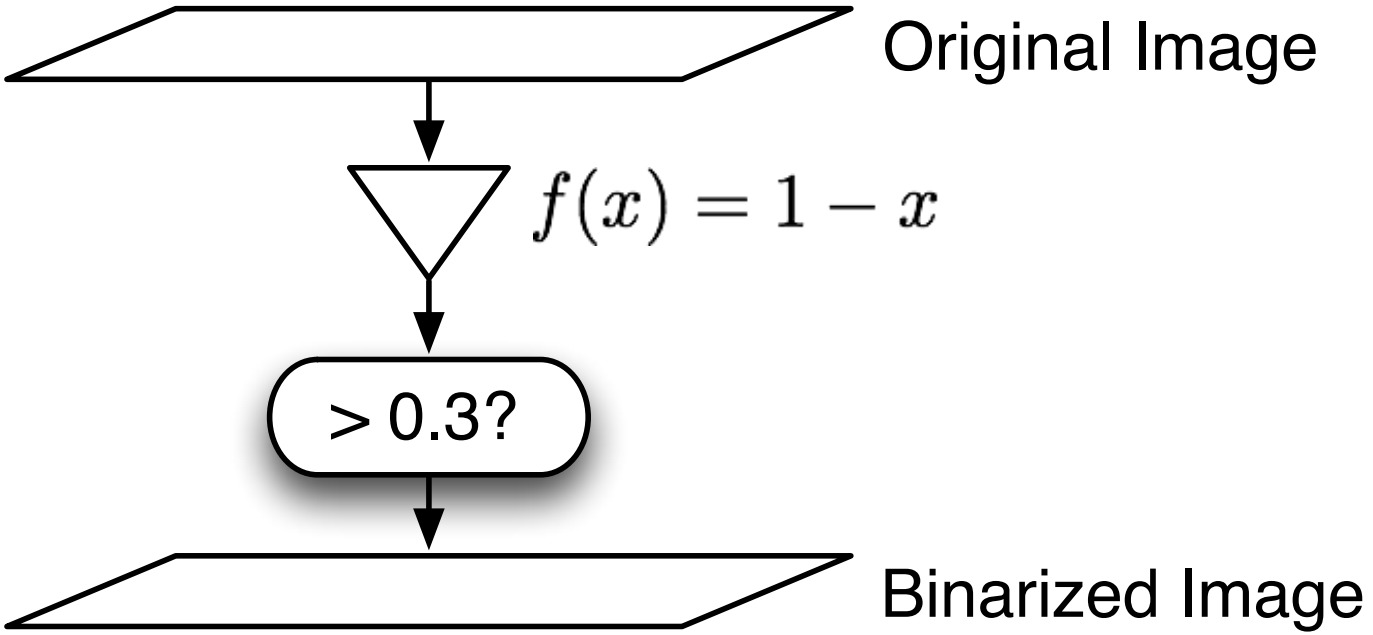
scanned scores
monophonic

System Overview



Preprocessing
Binarization

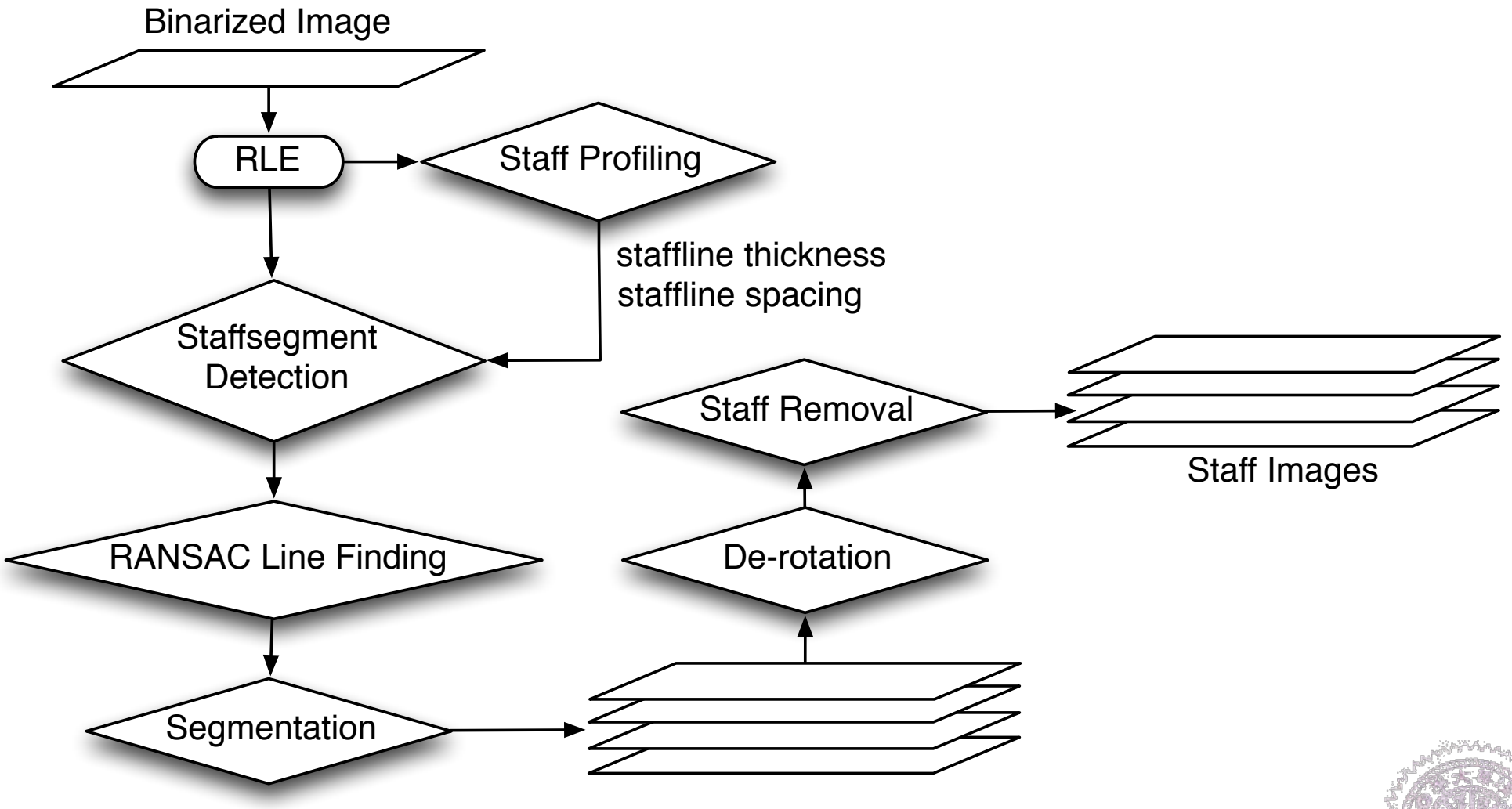
Binarization



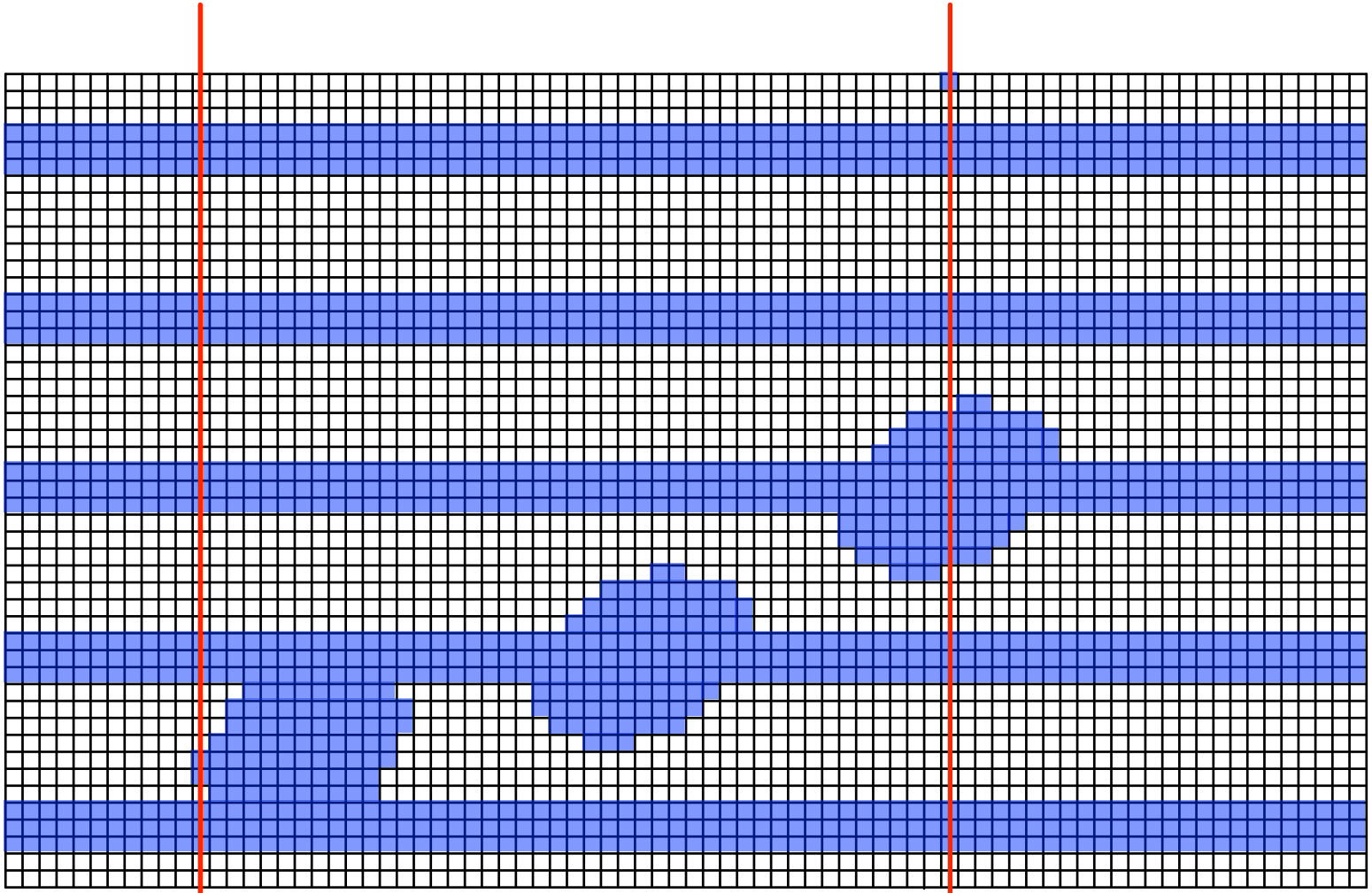
Global Thresholding

Preprocessing
Staff Segmentation

Staff Segmentation



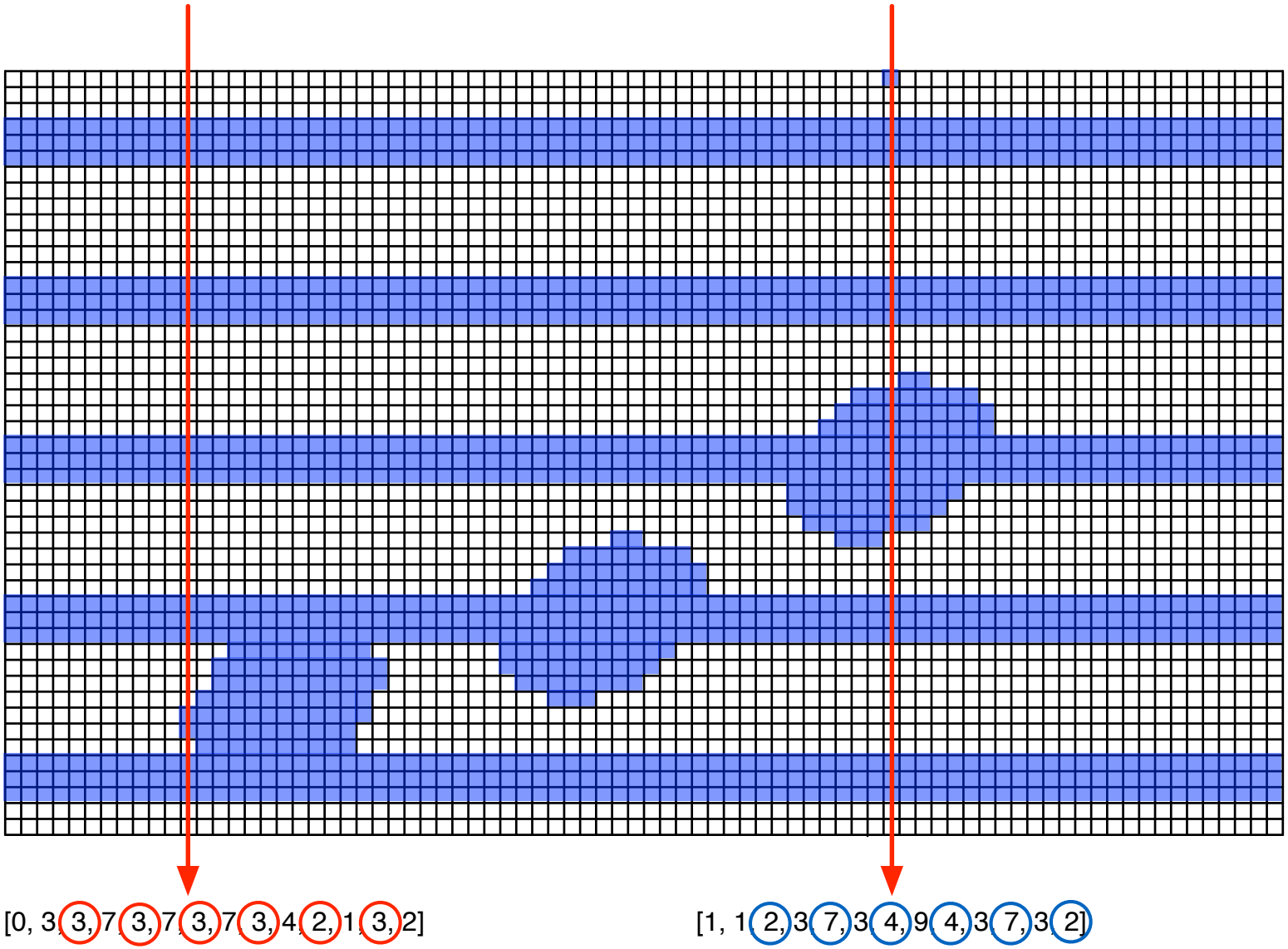
RLE (Run-length Encoding)



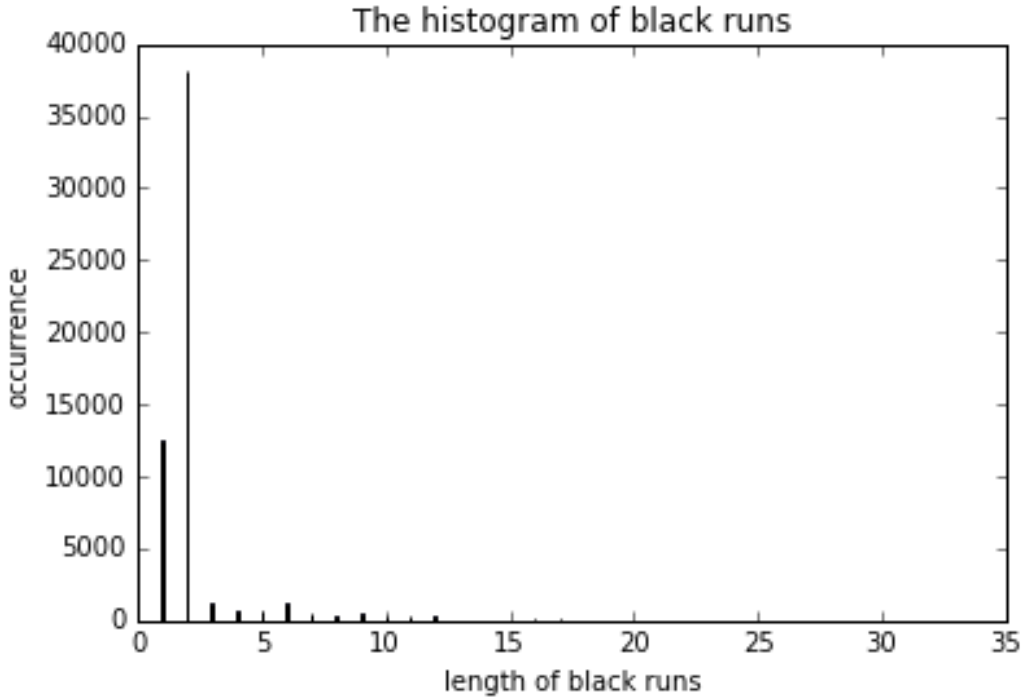
[0, 3, 3, 7, 3, 7, 3, 7, 3, 4, 2, 1, 3, 2]

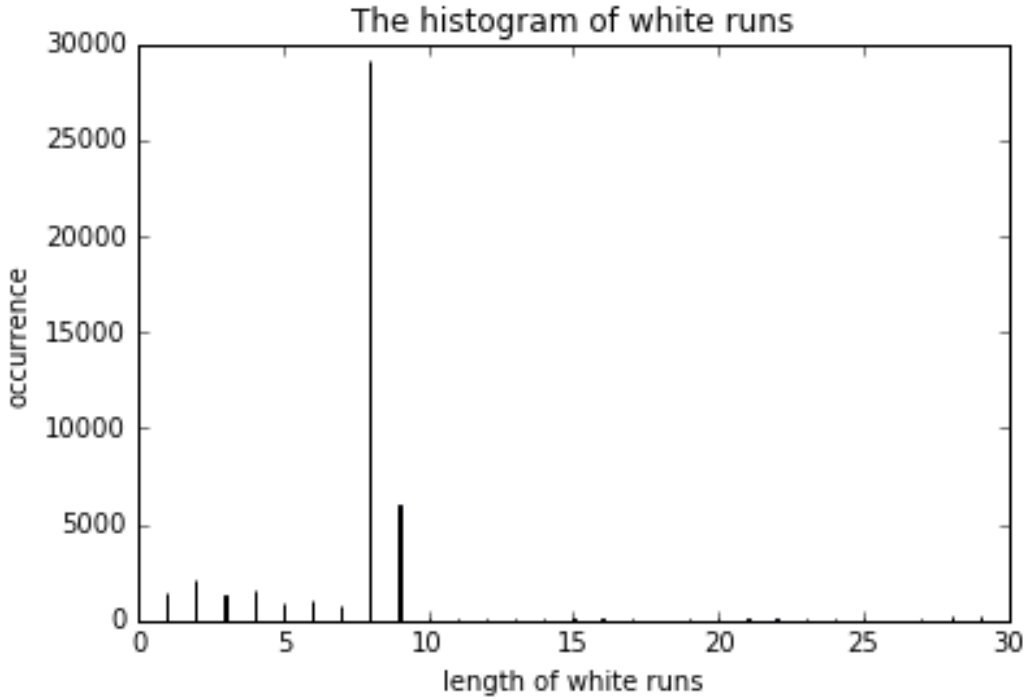
[1, 1, 2, 3, 7, 3, 4, 9, 4, 3, 7, 3, 2]

Staff Profile

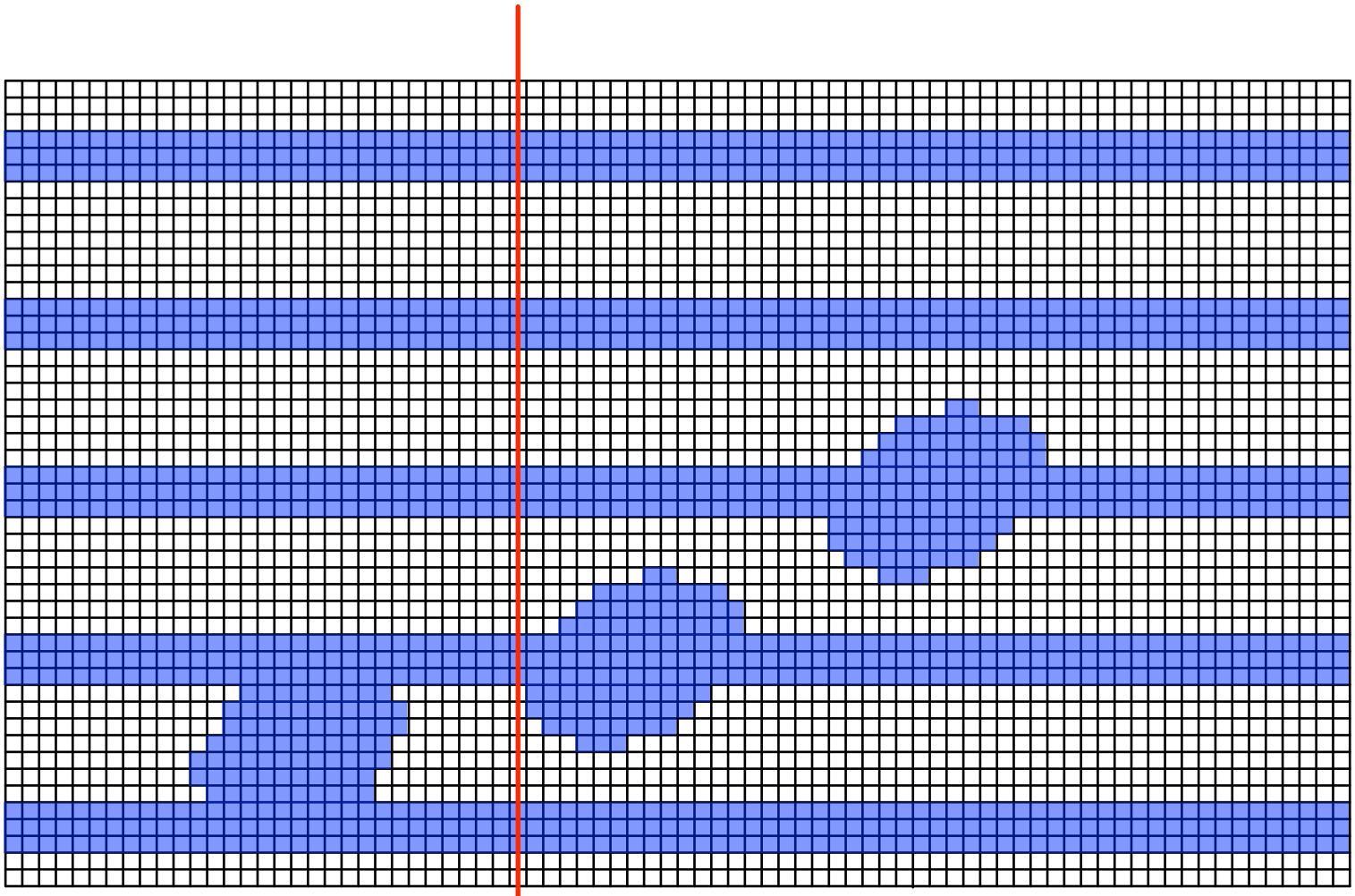


Staff Profile





Staffsegment Detection



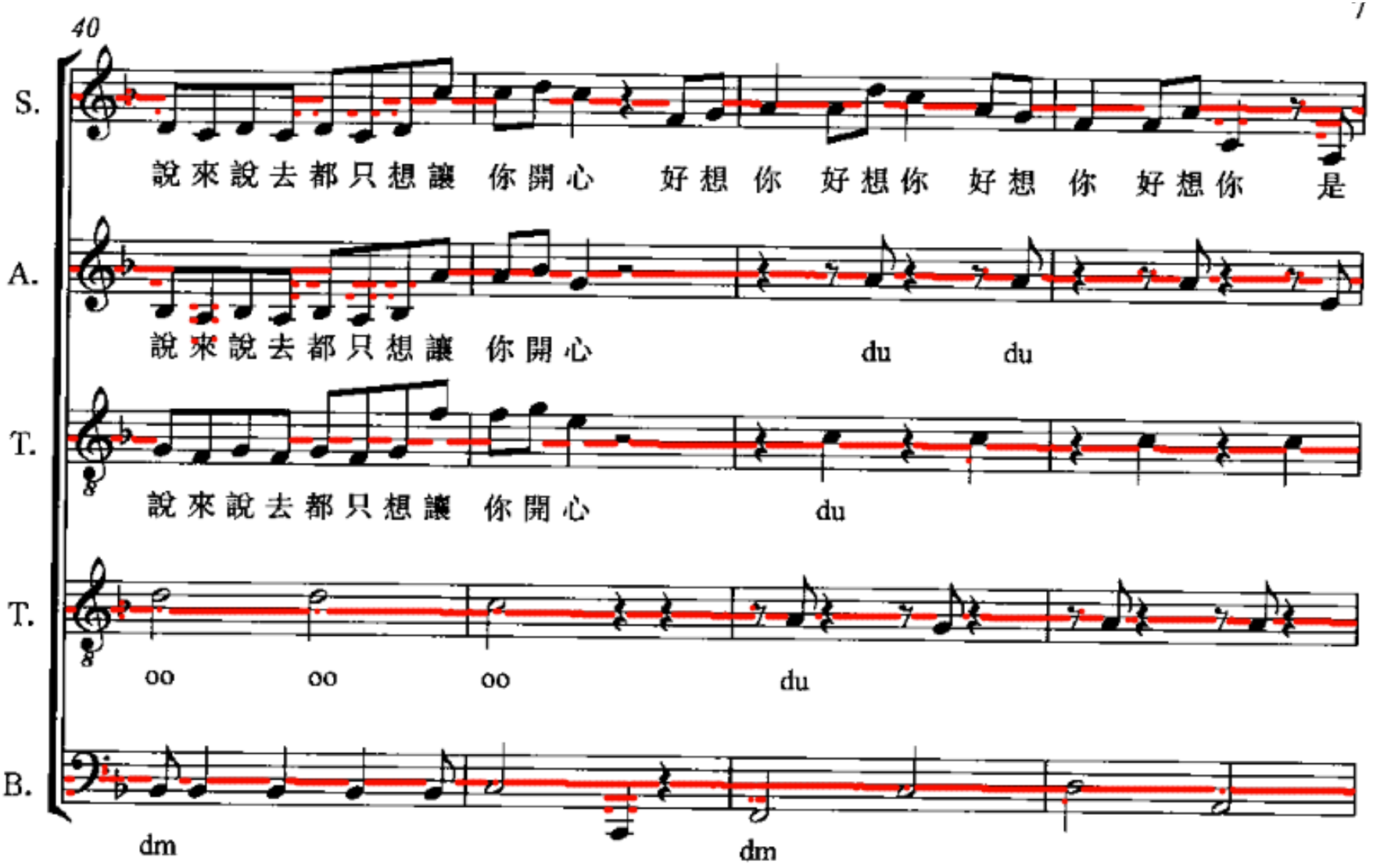
3, 3, 7, 3, 7, 3, 7, 3, 7, 3, 2

3, 3, 7, 3, 7, 3, 7, 3, 7	NO
3, 7, 3, 7, 3, 7, 3, 7, 3	YES
7, 3, 7, 3, 7, 3, 7, 3, 2	NO

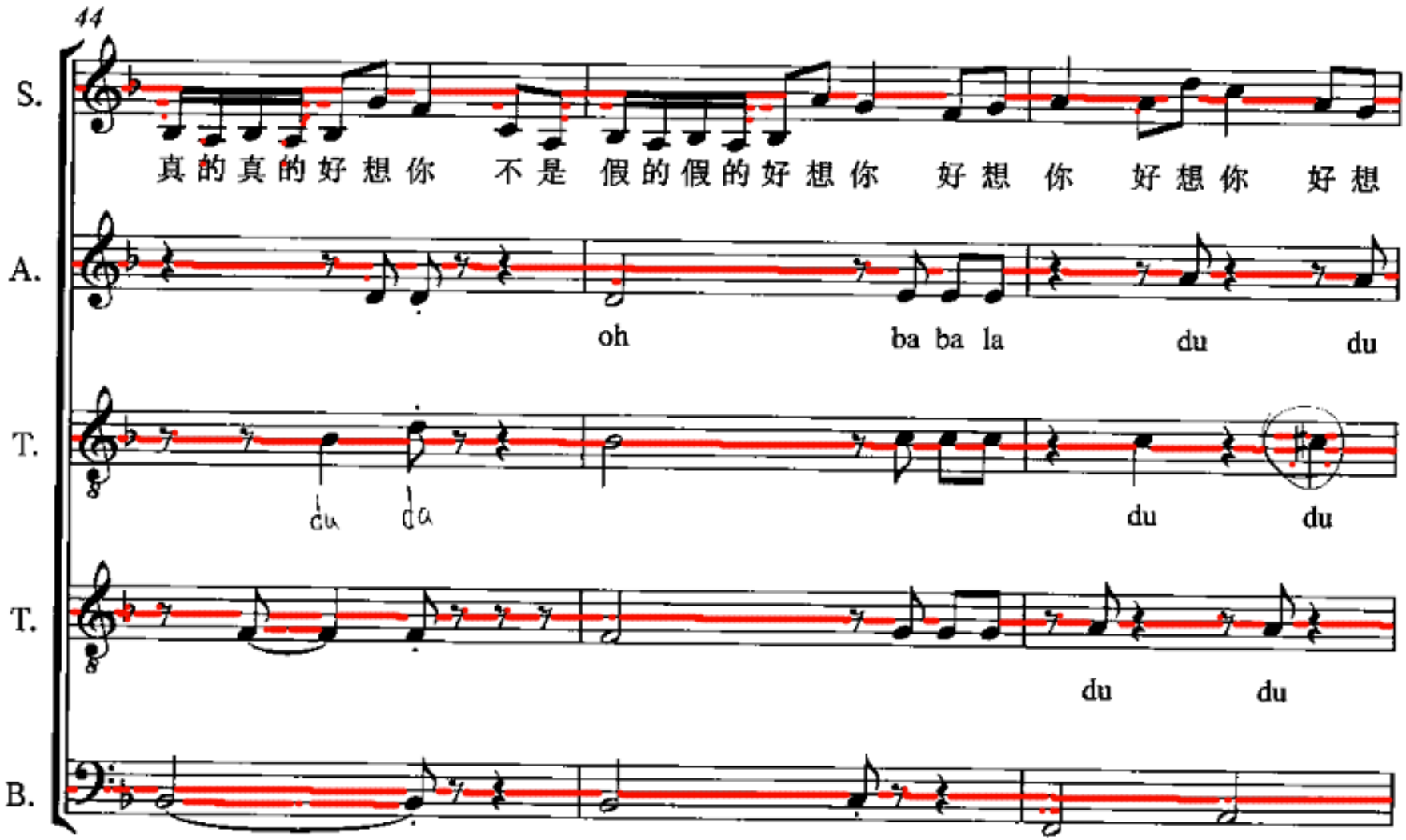
$$e(v') = \frac{\|v' - S\|_1}{\|S\|_1},$$

$$S = [w, s, w, s, w, s, w, s, w]$$

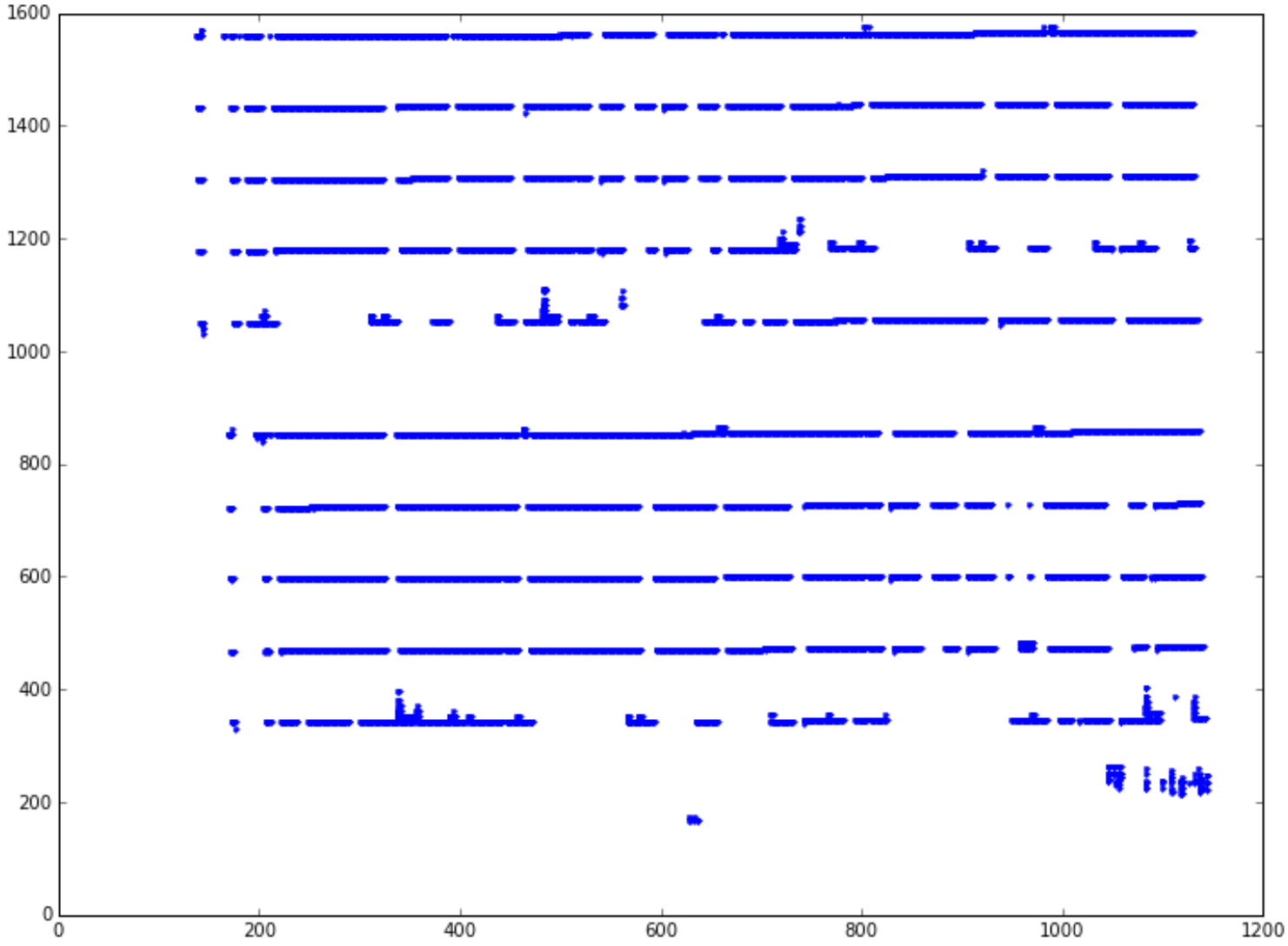
Staffsegment



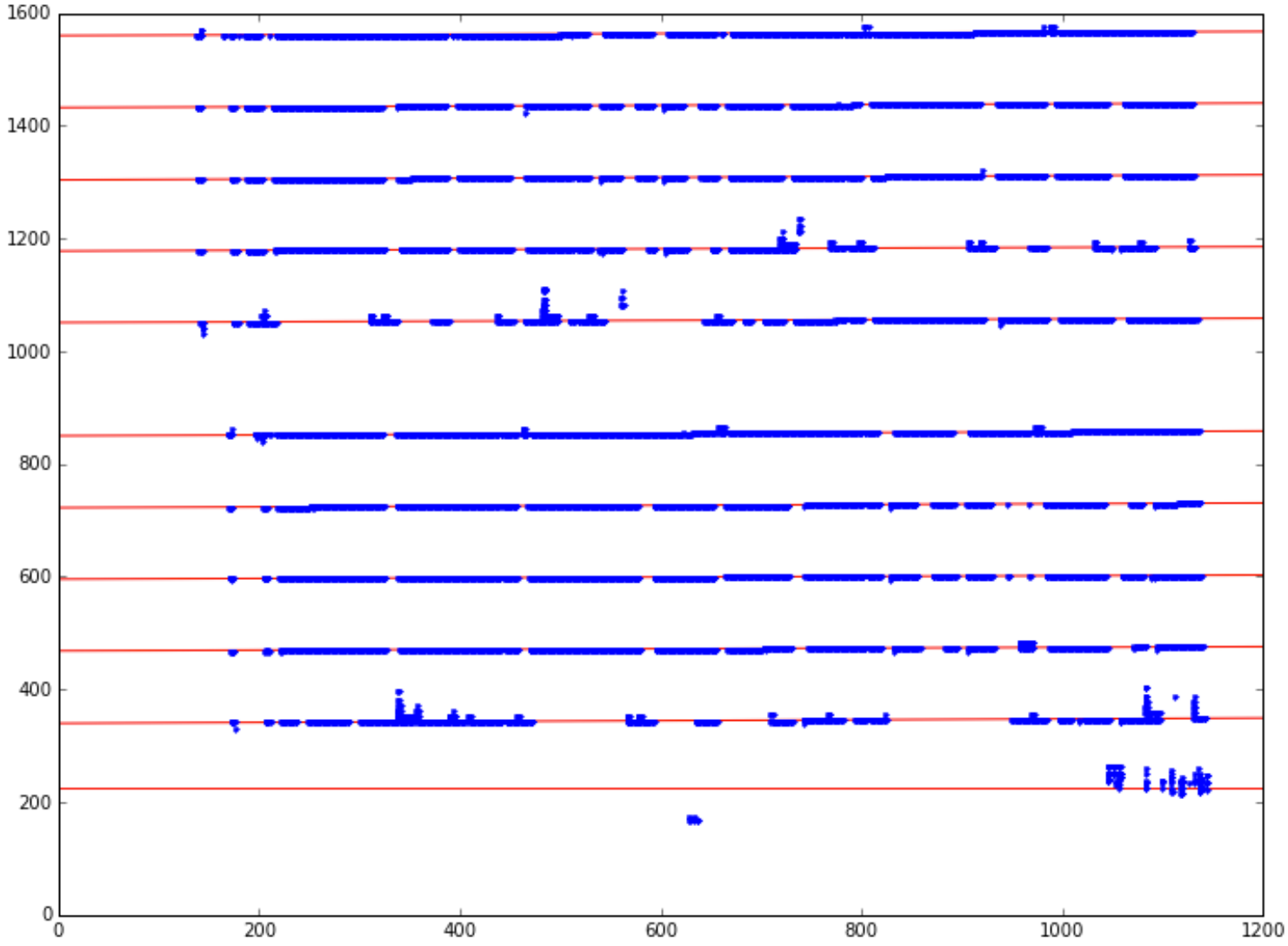
Staffsegment



Multiple Lines Fitting



Multiple Lines Fitting



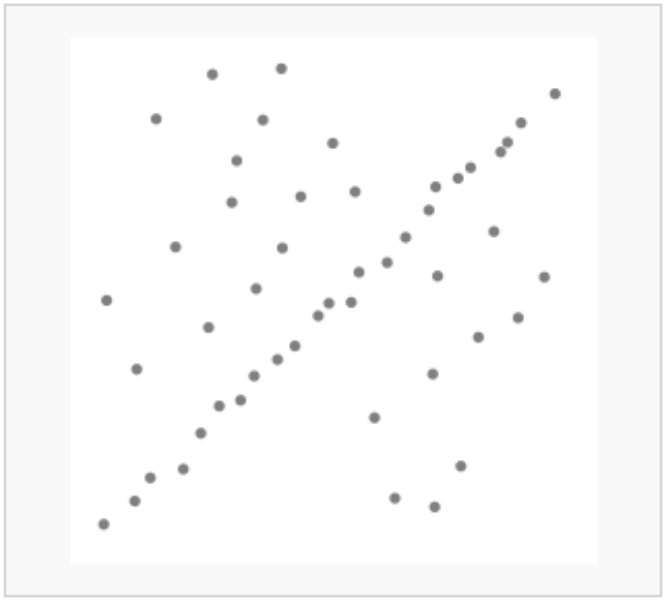
Multiple Lines Fitting

- Dynamic Programming: $O((\frac{N}{W})^2 \times W)$
- Hough Transform: $O(L \times N)$
- **RANSAC**: $O(N_{\text{iter}} \times N)$

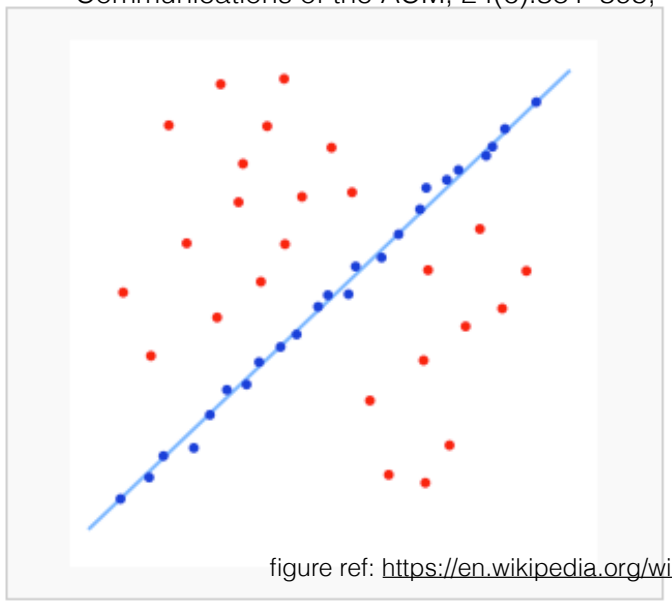
Multiple Lines Fitting

- RANSAC (RANdom SAmple Consensus)
  - single model fitting method
  - robust to outliers

M.A. Fischler and R.C. Bolles. **Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography**. Communications of the ACM, 24(6):381–395, 1981.



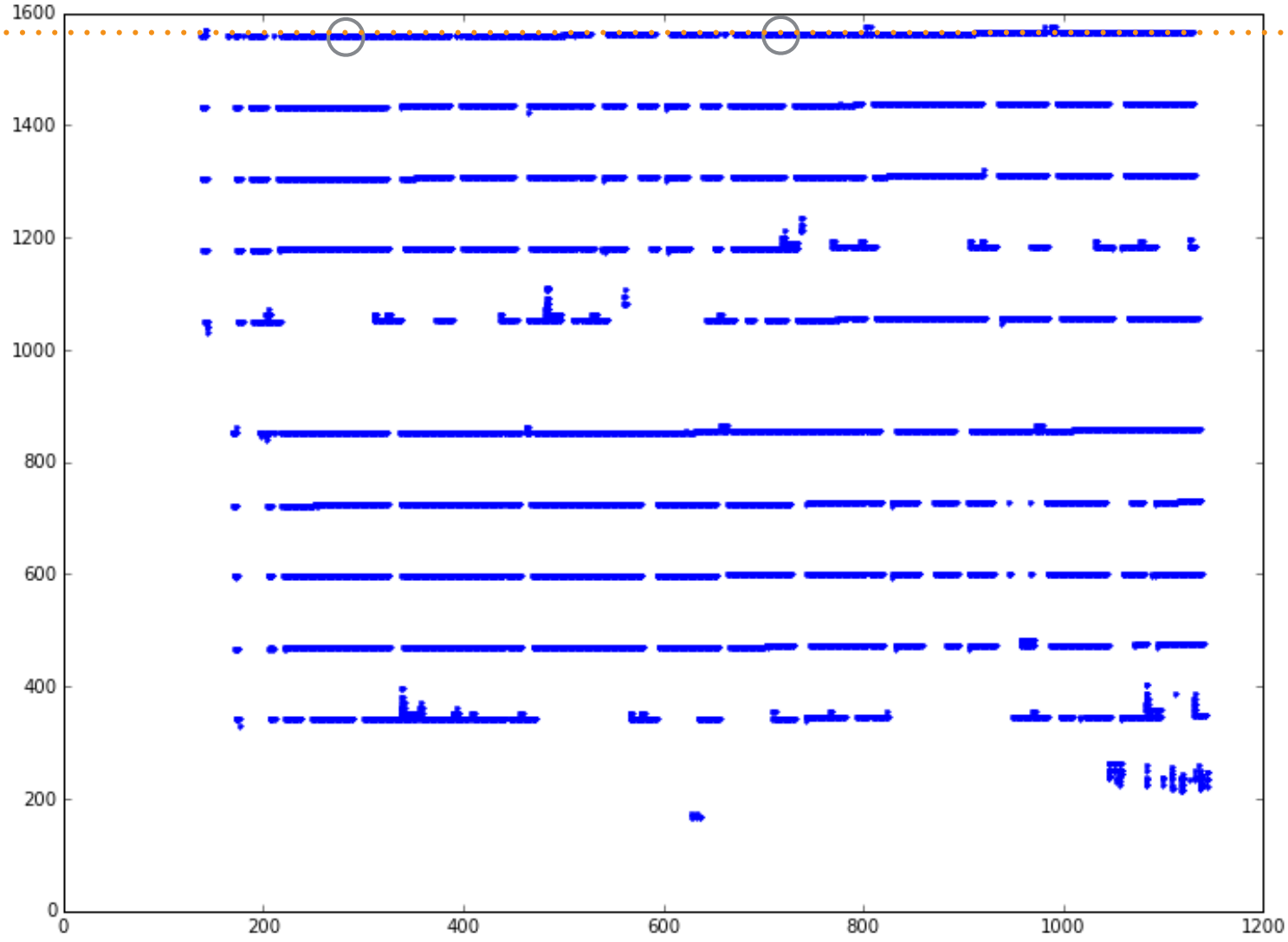
A data set with many outliers for which a line has to be fitted.



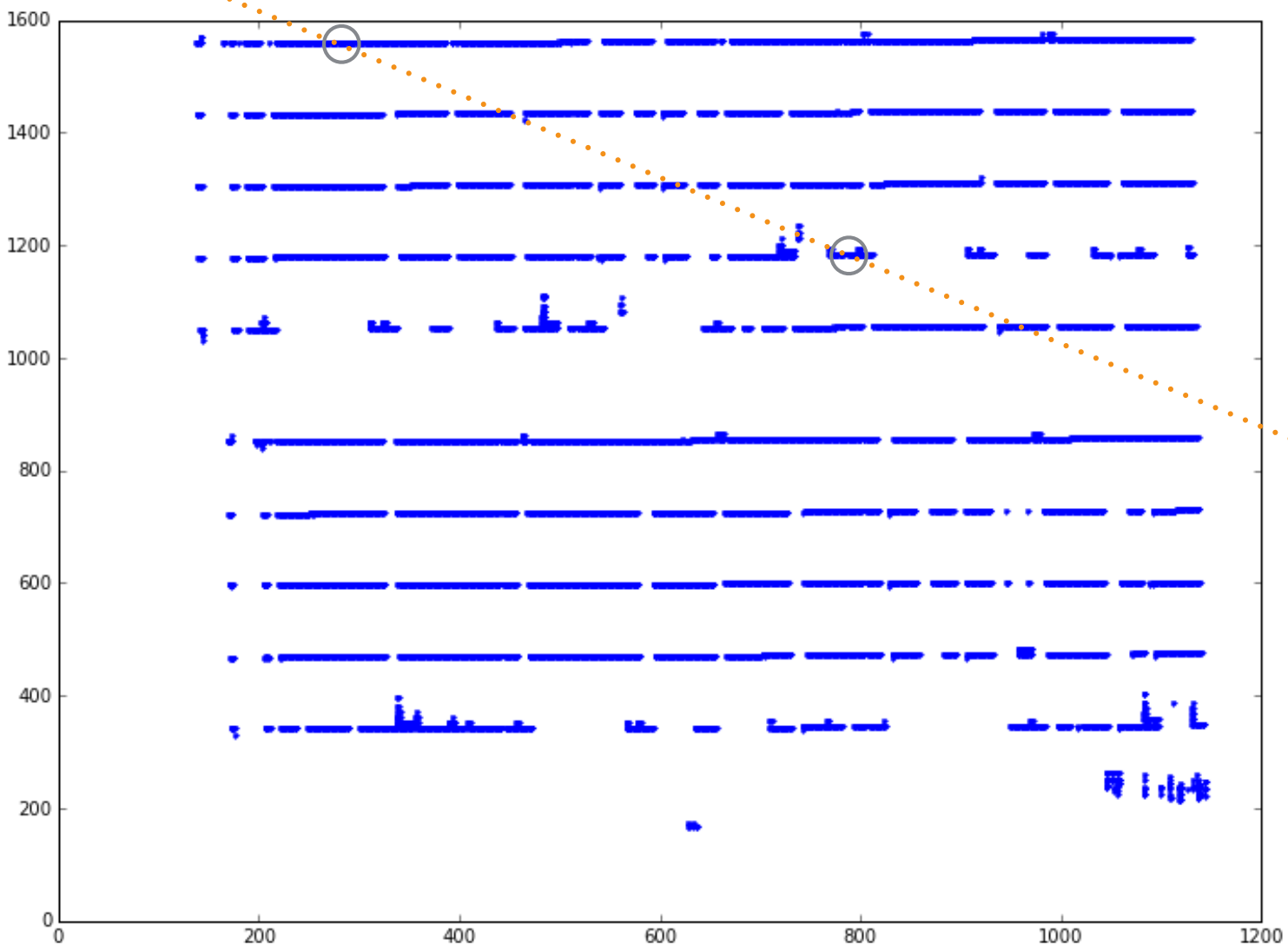
Fitted line with RANSAC; outliers have no influence on the result.

figure ref: https://en.wikipedia.org/wiki/RANSAC

RANSAC: Example

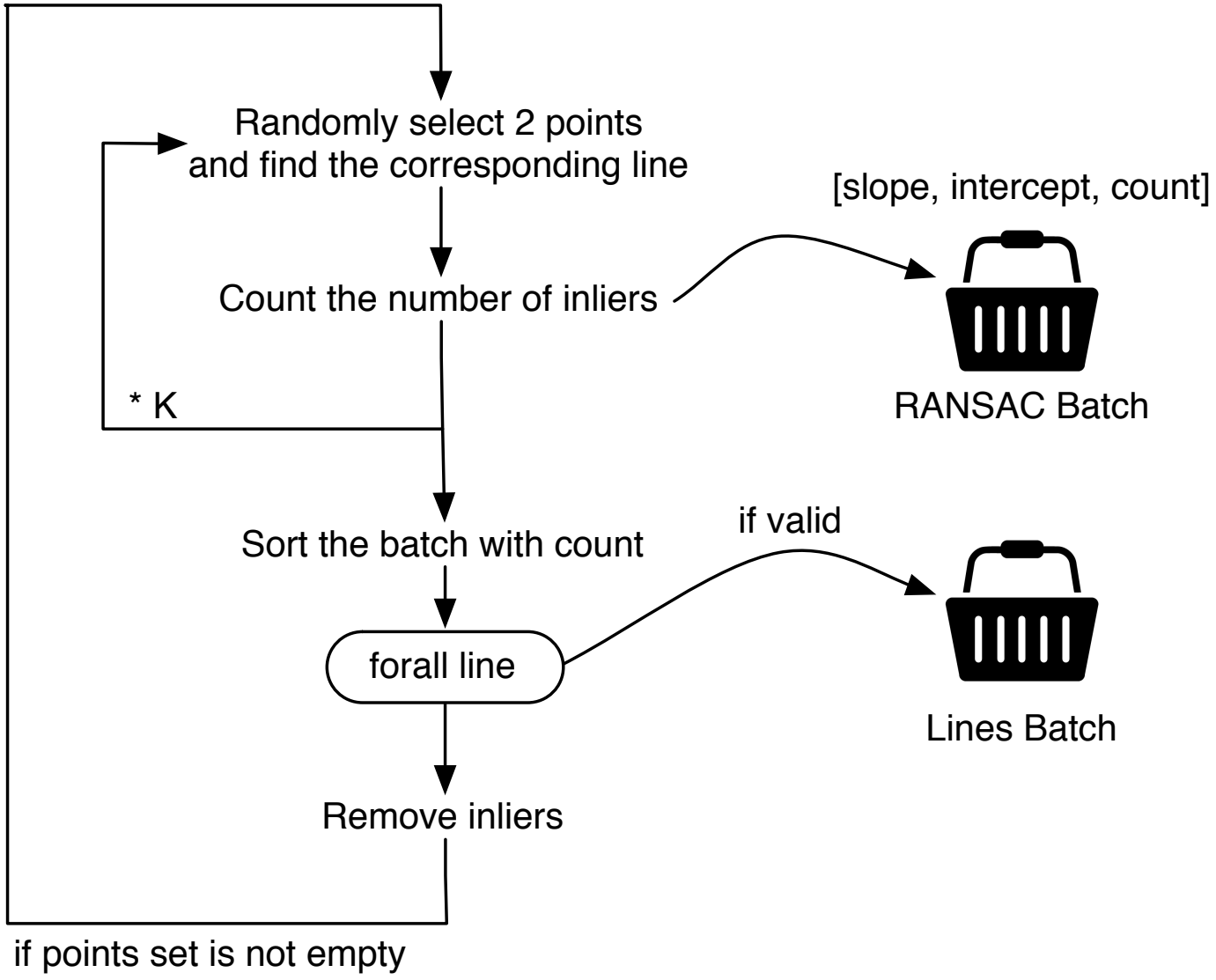


RANSAC: Example

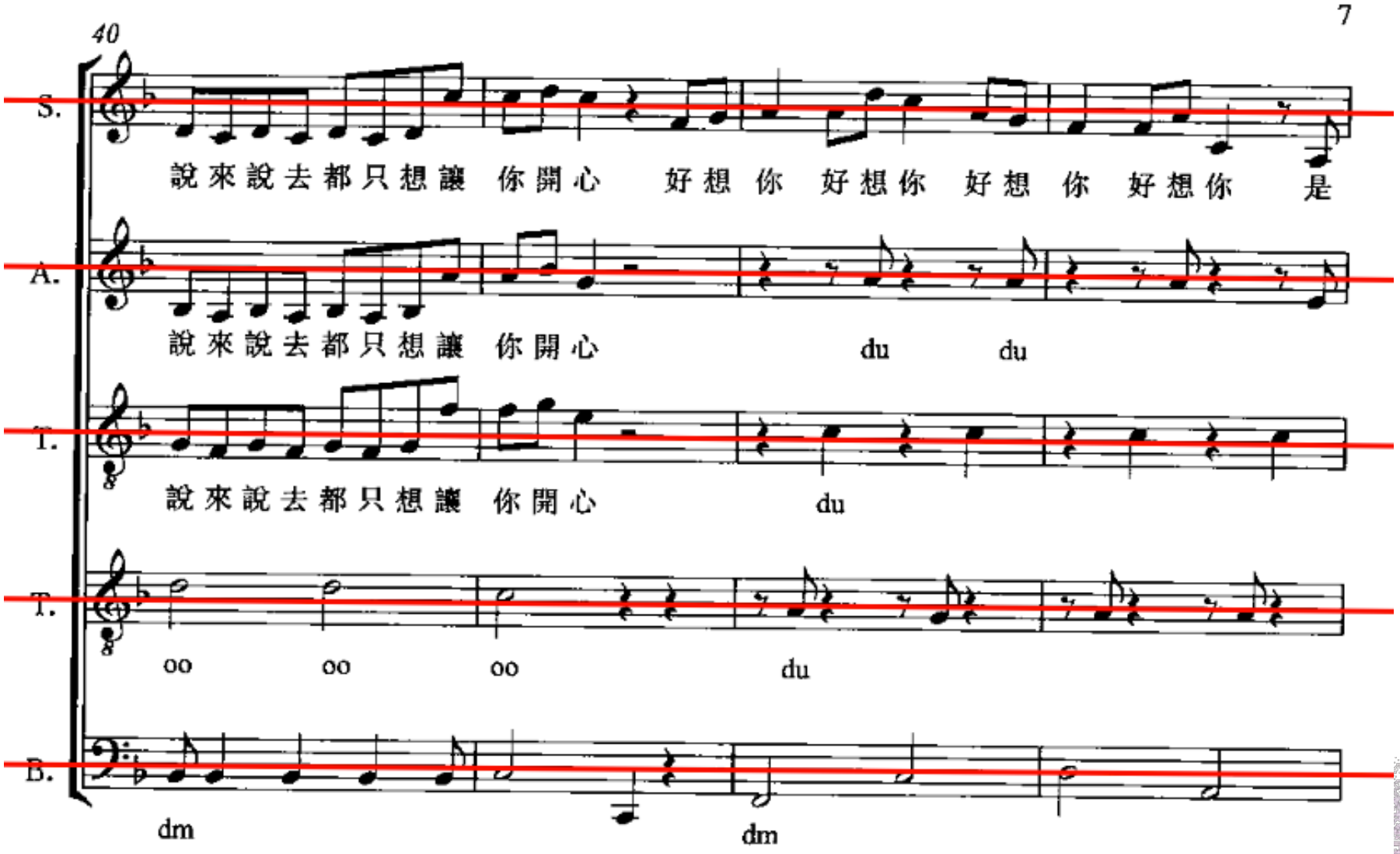


7

Iterative RANSAC

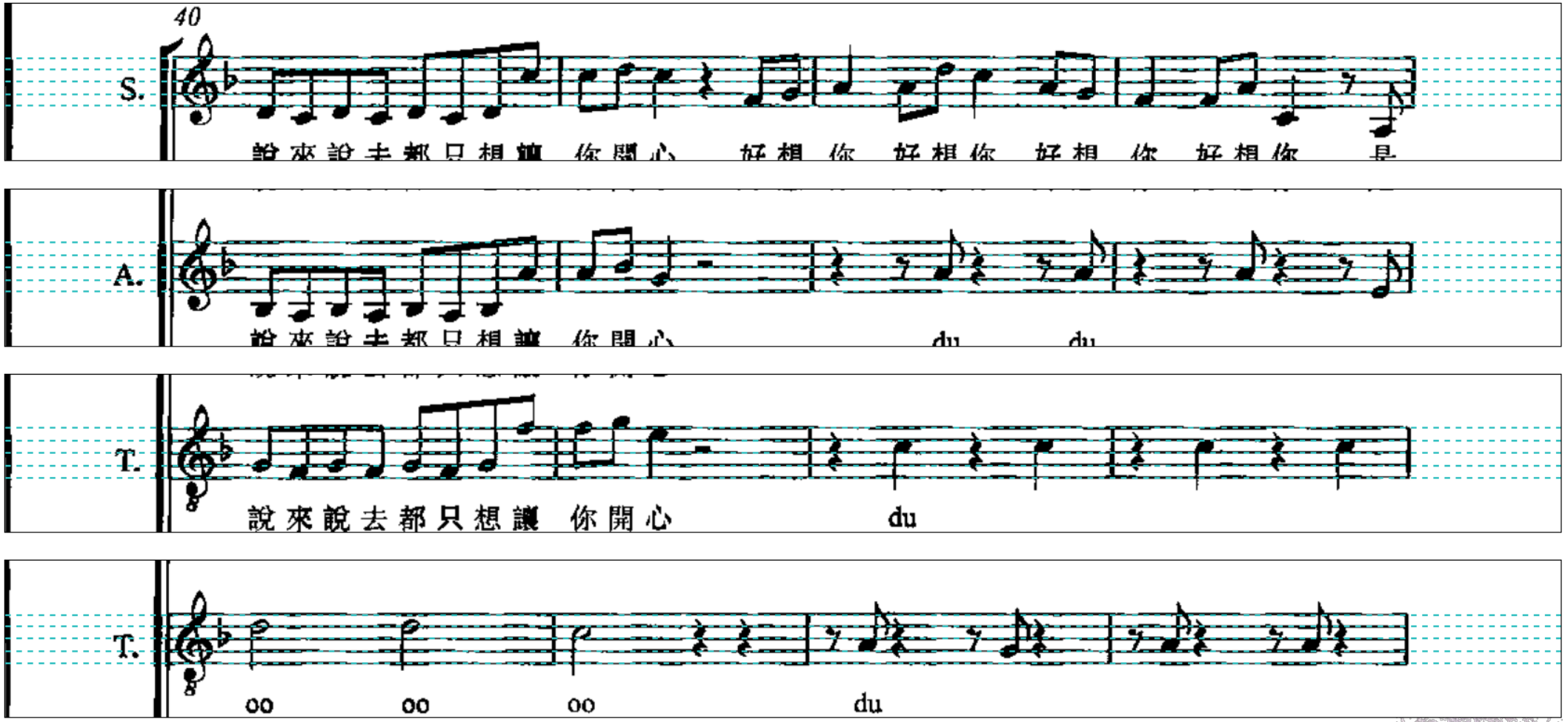


Detected Staves



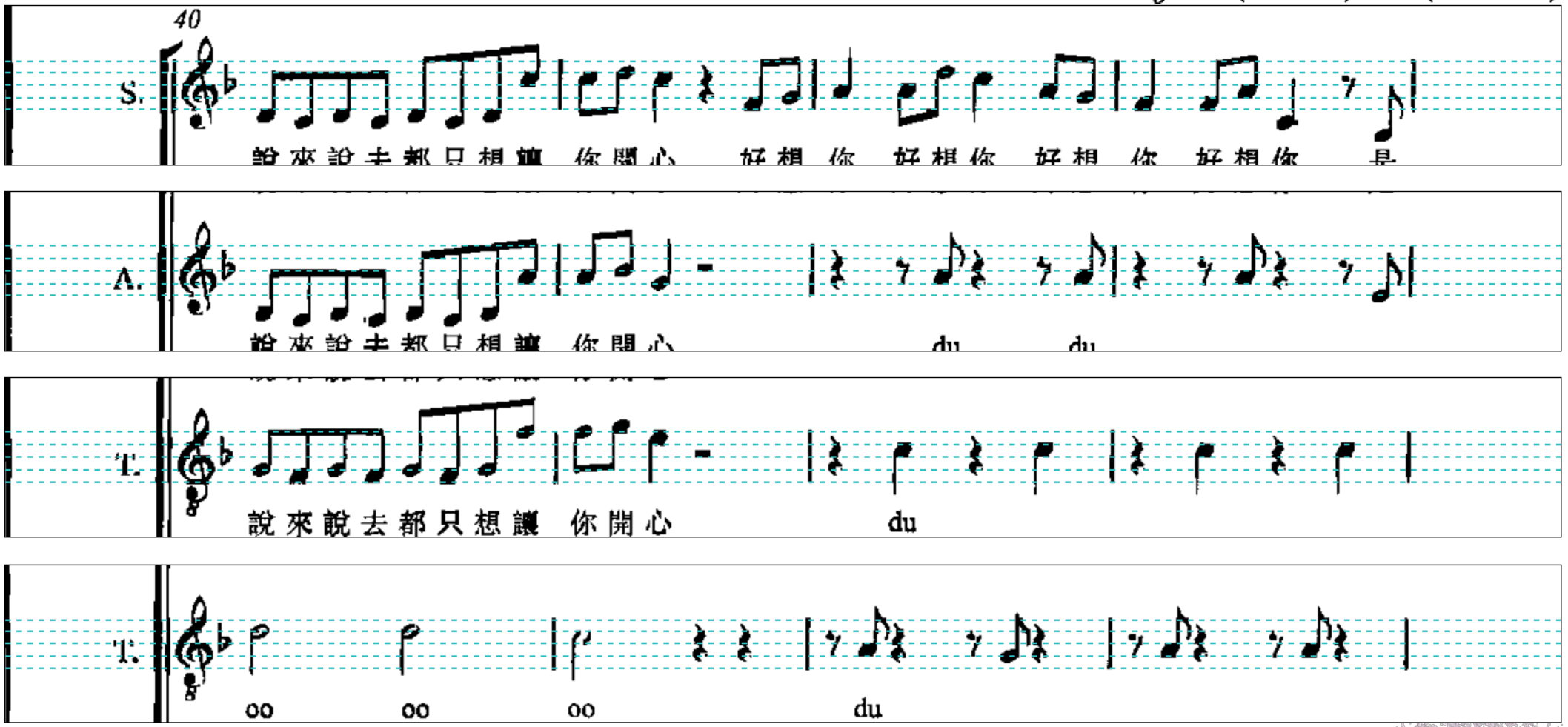
Staff Images (Before Staff Removal)

$$l_i = c_y + (i-3) \times (w+s)$$



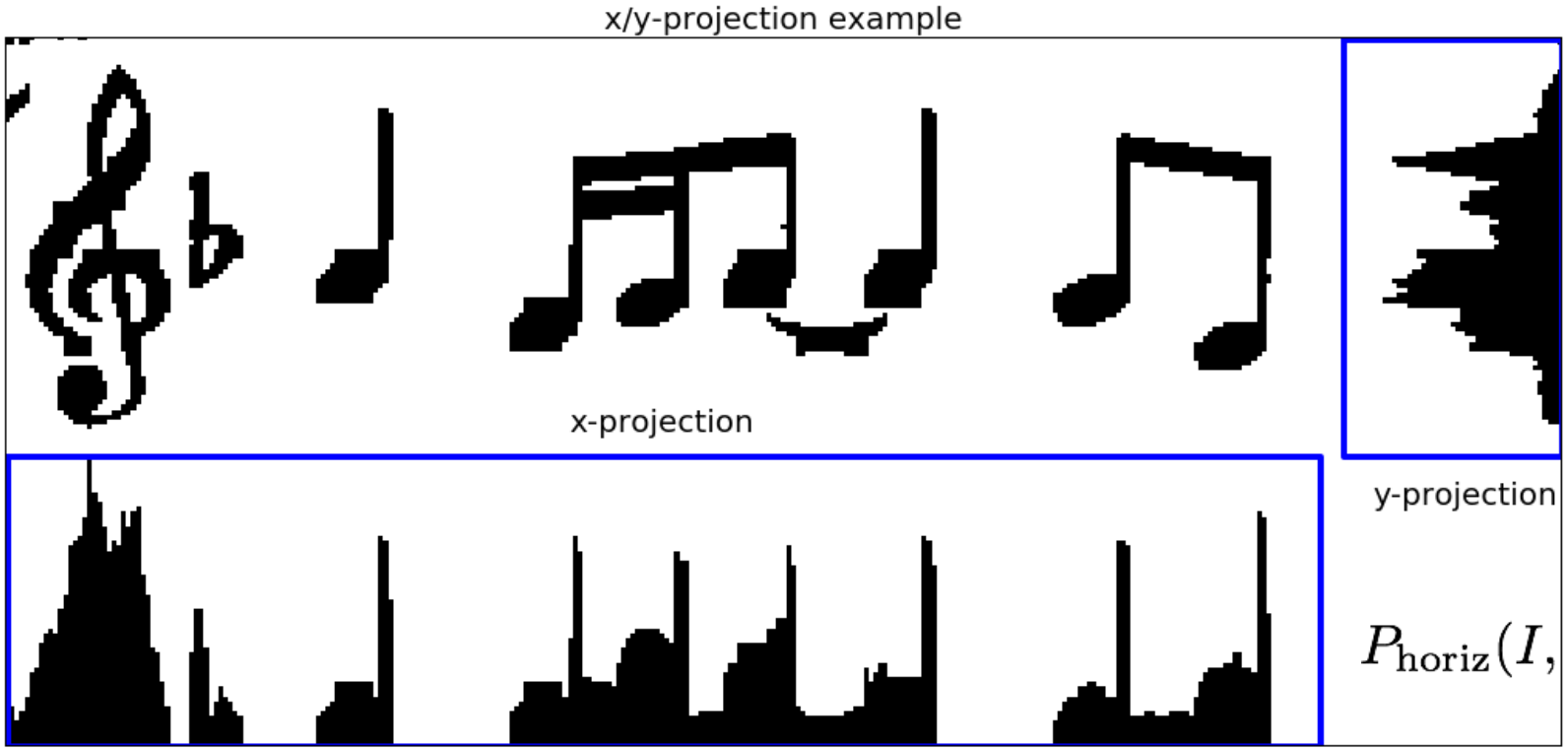
Staff Images (After Staff Removal)

$$l_i = c_y + (i-3) \times (w+s)$$



Recognition

Projection

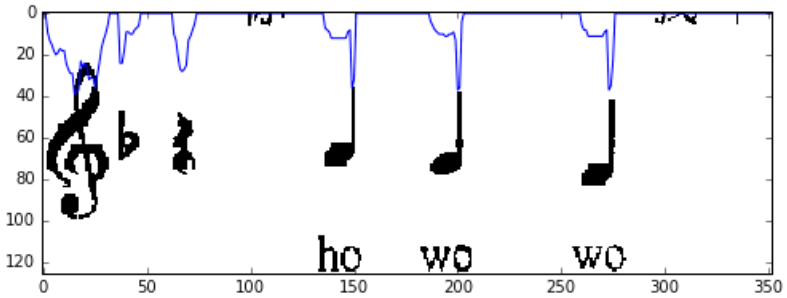


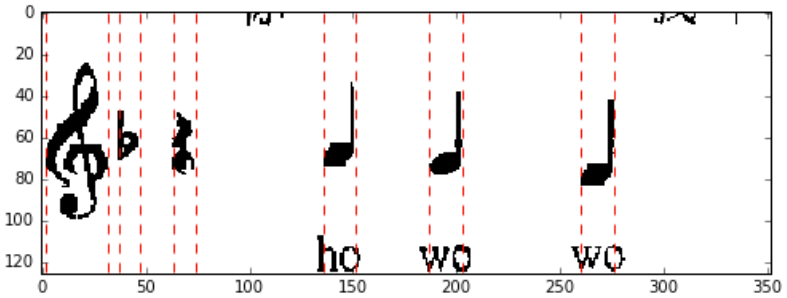
$$P_{\text{horiz}}(I, x_0) = \sum_y I(x_0, y)$$

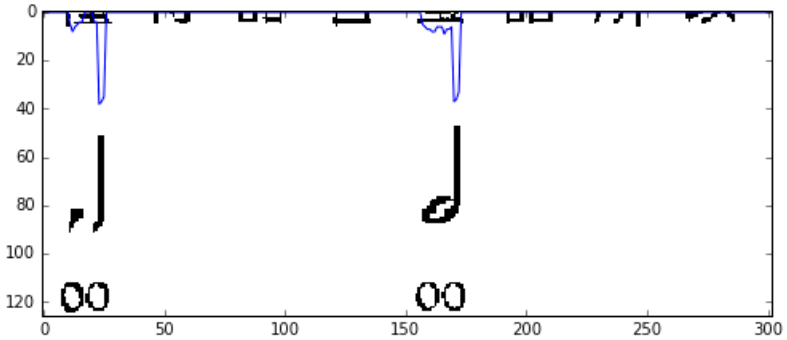
$$P_{\text{vert}}(I, y_0) = \sum_x I(x, y_0)$$

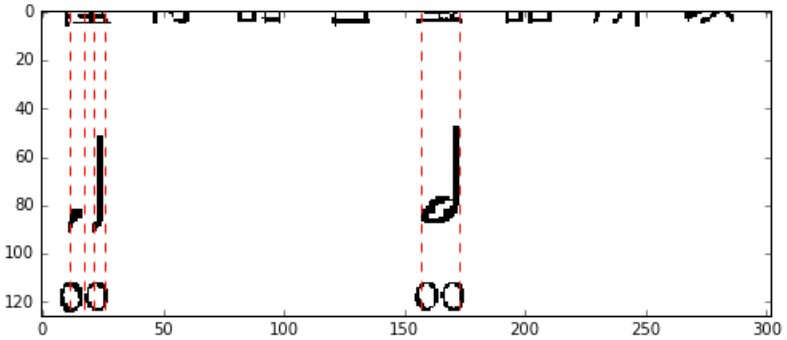
Onset Detection

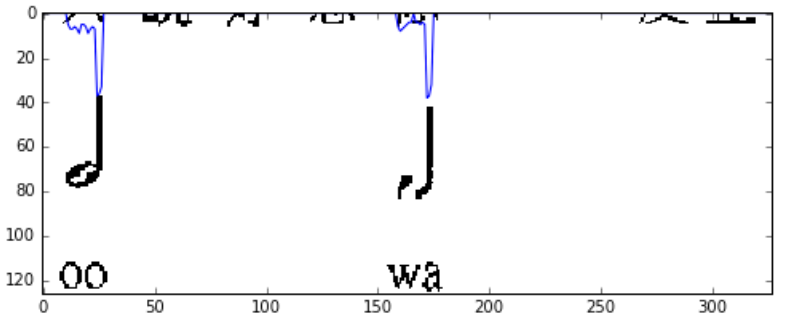
merge_thresh=0

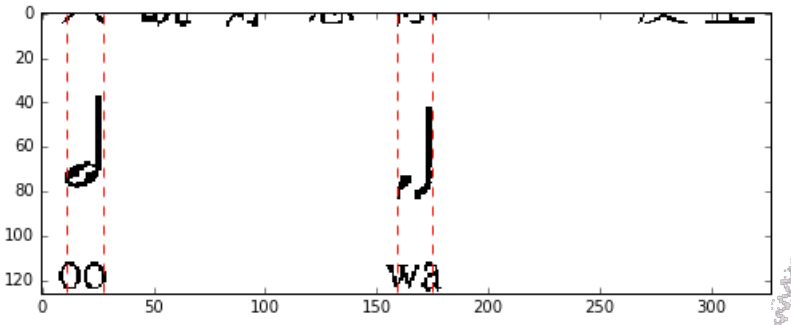






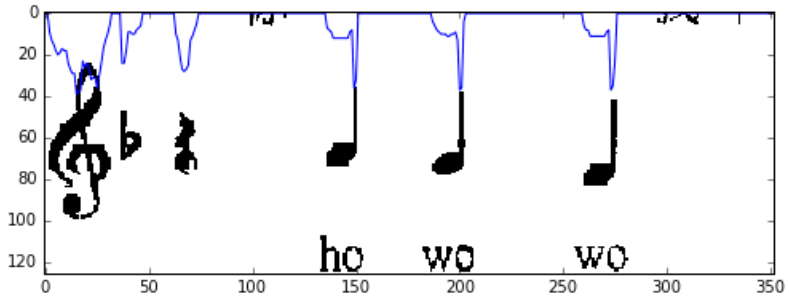


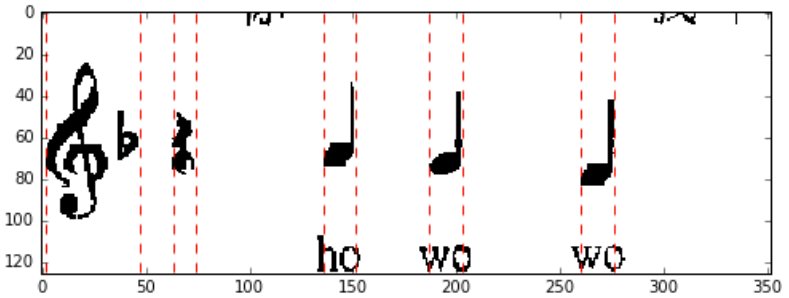


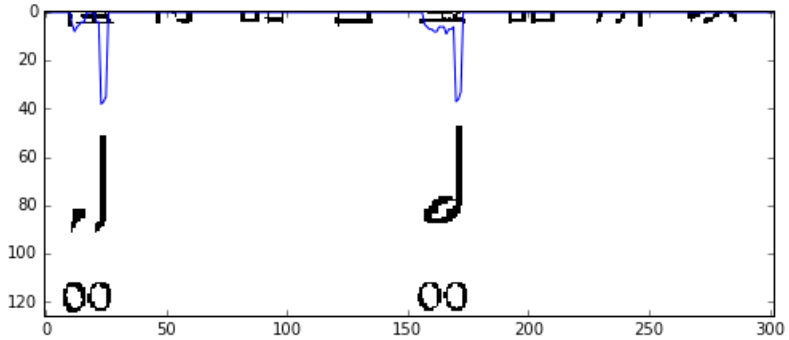


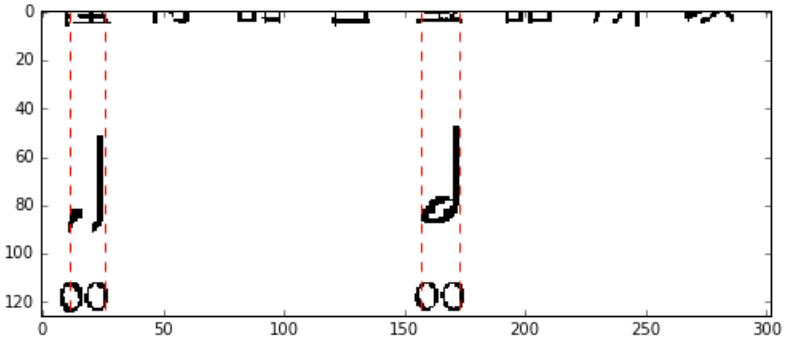
Onset Detection

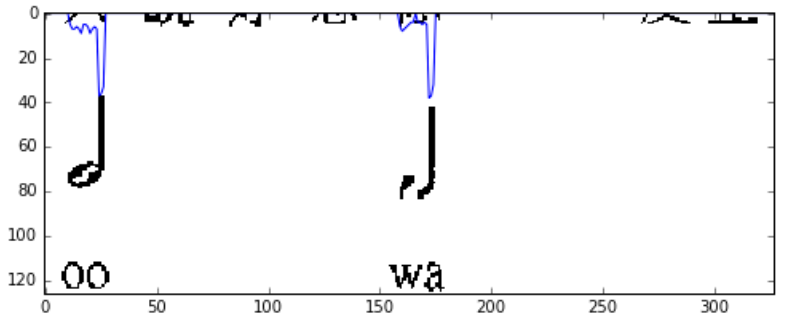
`merge_thresh=10`

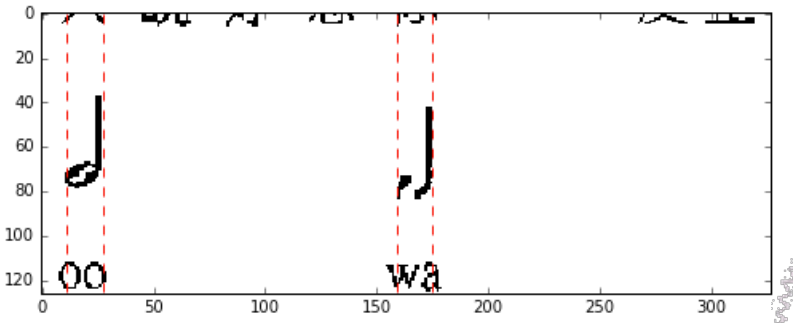






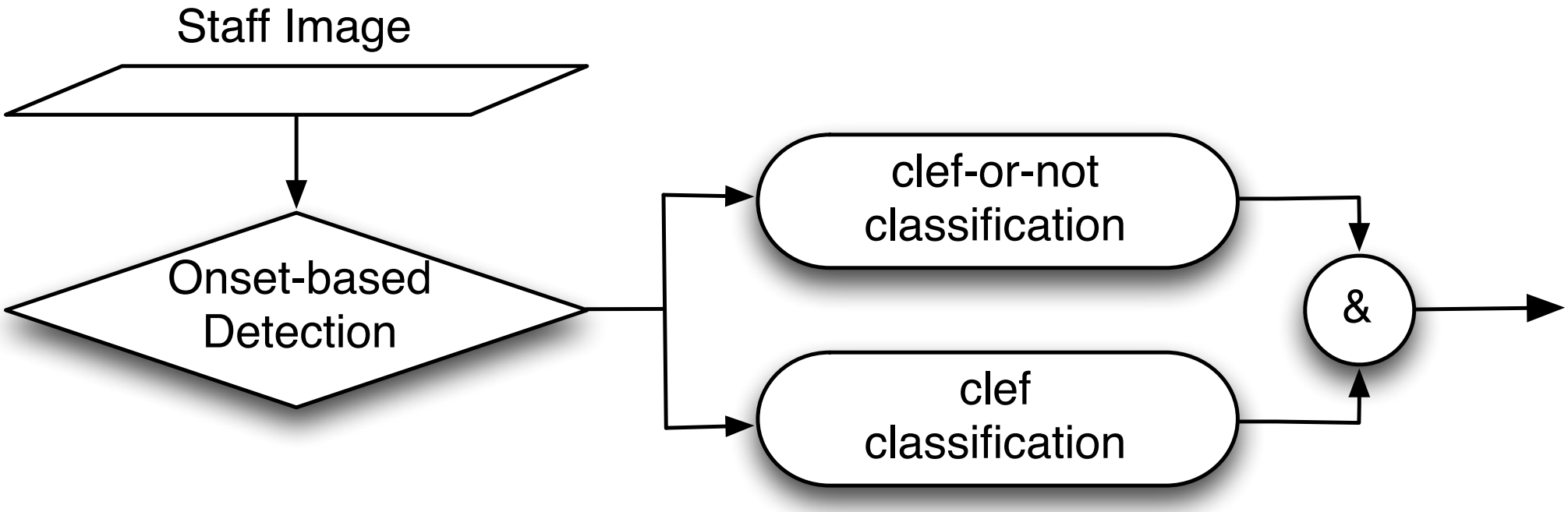




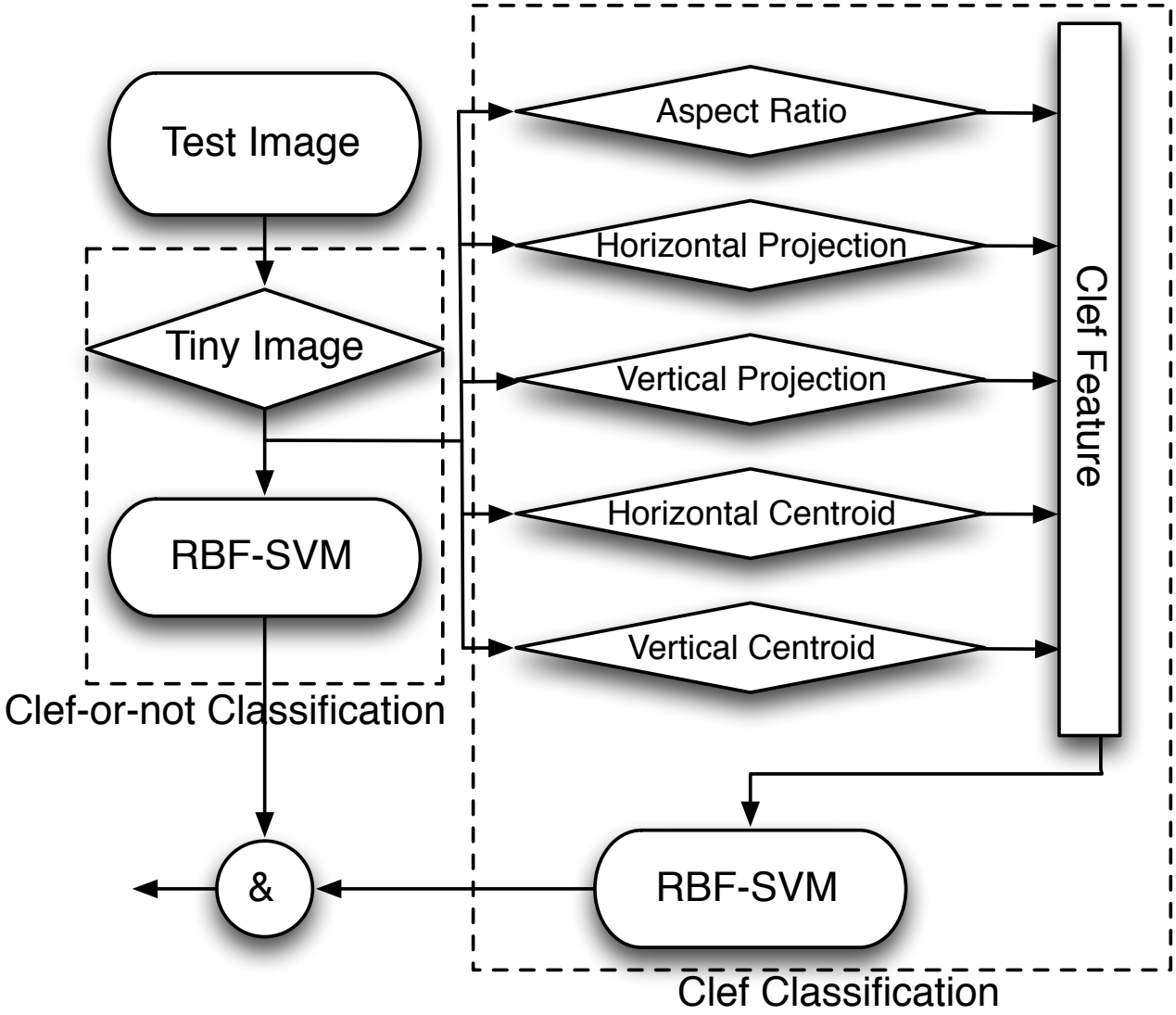


Recognition
Pitch-unrelated Symbols

Clef Detection



Clef Detection: Feature



Centroid

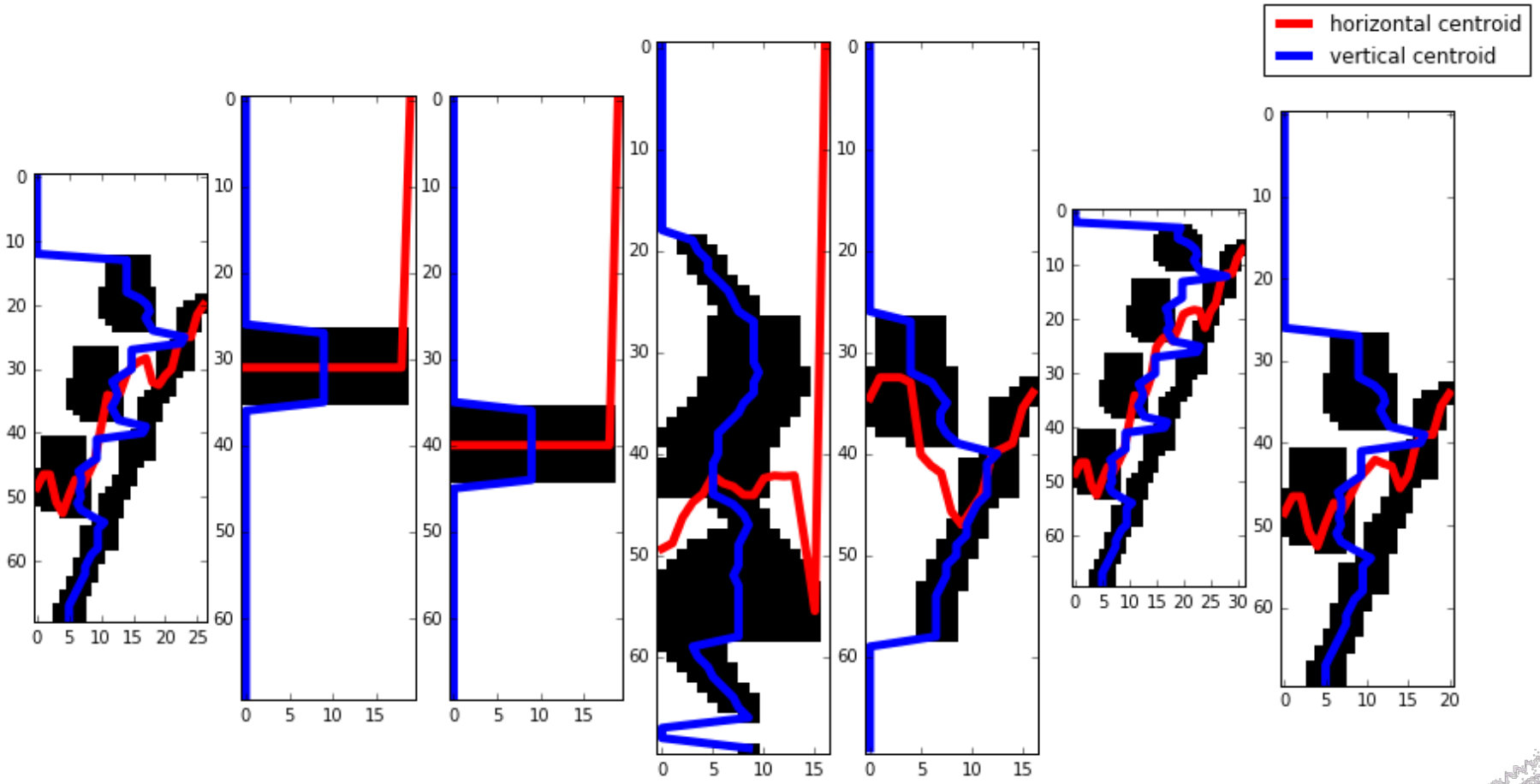
$$C_{\text{horiz}}(x_0) = \frac{\sum_y I(x_0, y) \times y}{\sum_y I(x_0, y)}$$

$$C_{\text{vert}}(y_0) = \frac{\sum_x I(x, y_0) \times x}{\sum_x I(x, y_0)}$$

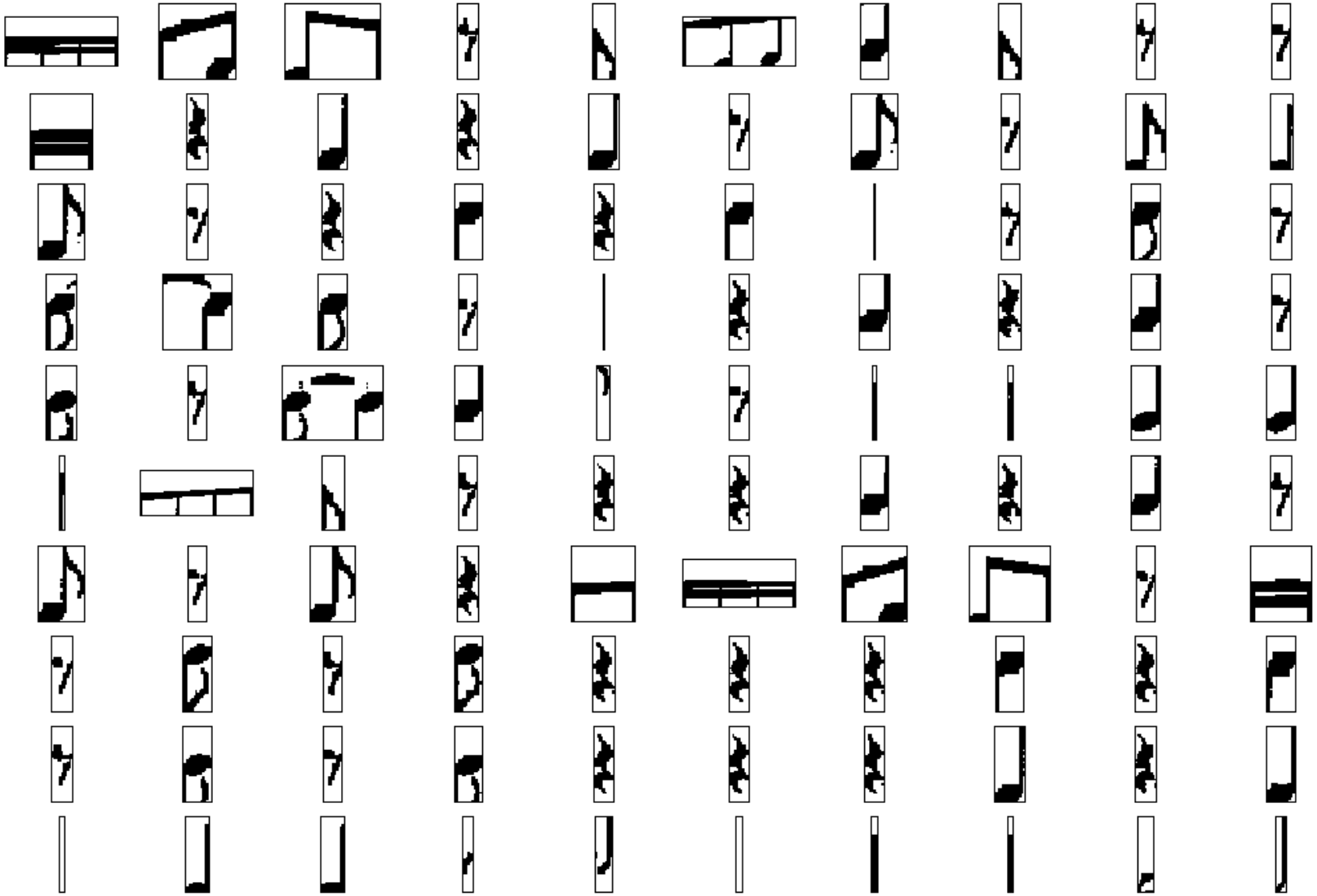
Centroid

$$C_{\text{horiz}}(x_0) = \frac{\sum_y I(x_0, y) \times y}{\sum_y I(x_0, y)}$$

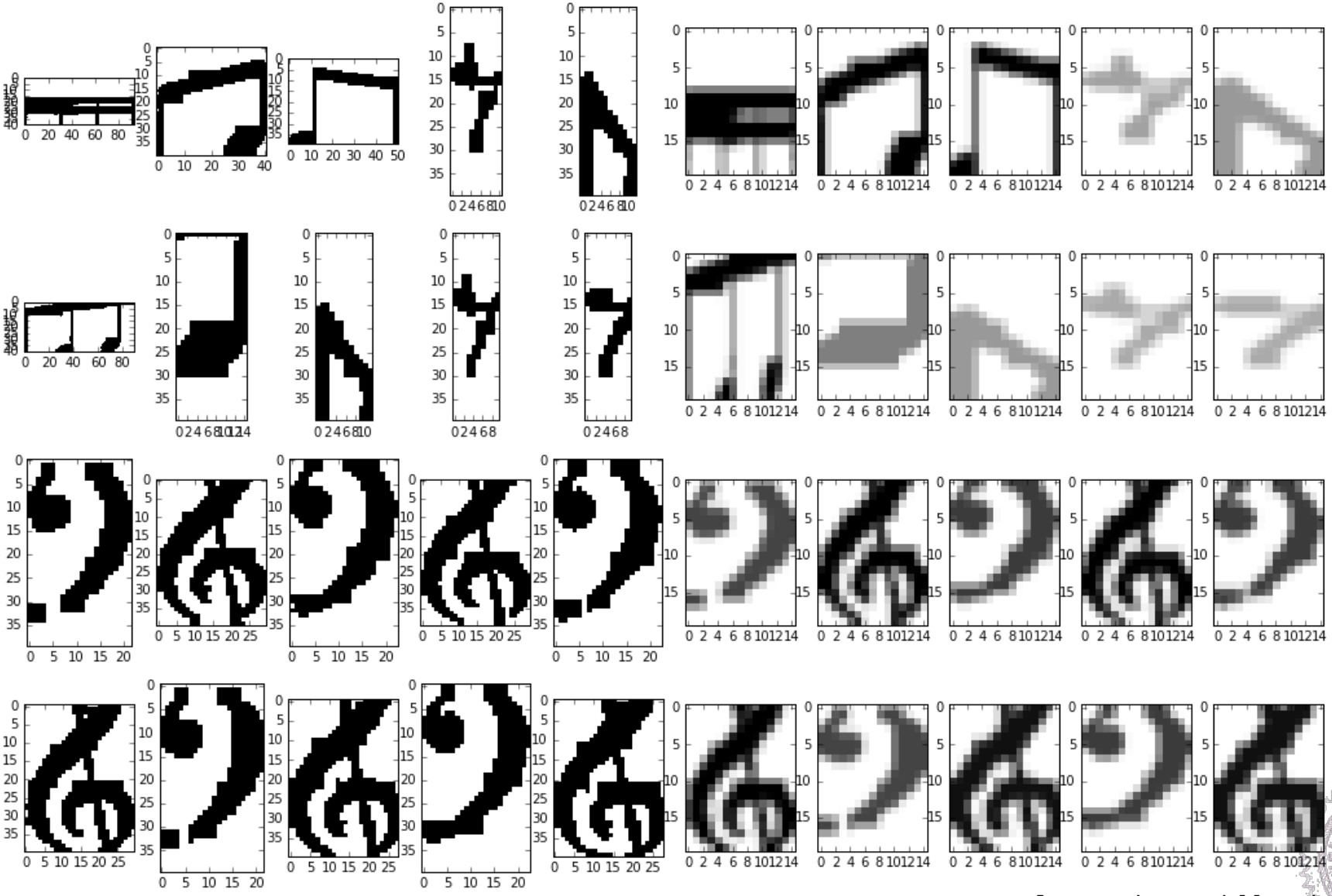
$$C_{\text{vert}}(y_0) = \frac{\sum_x I(x, y_0) \times x}{\sum_x I(x, y_0)}$$



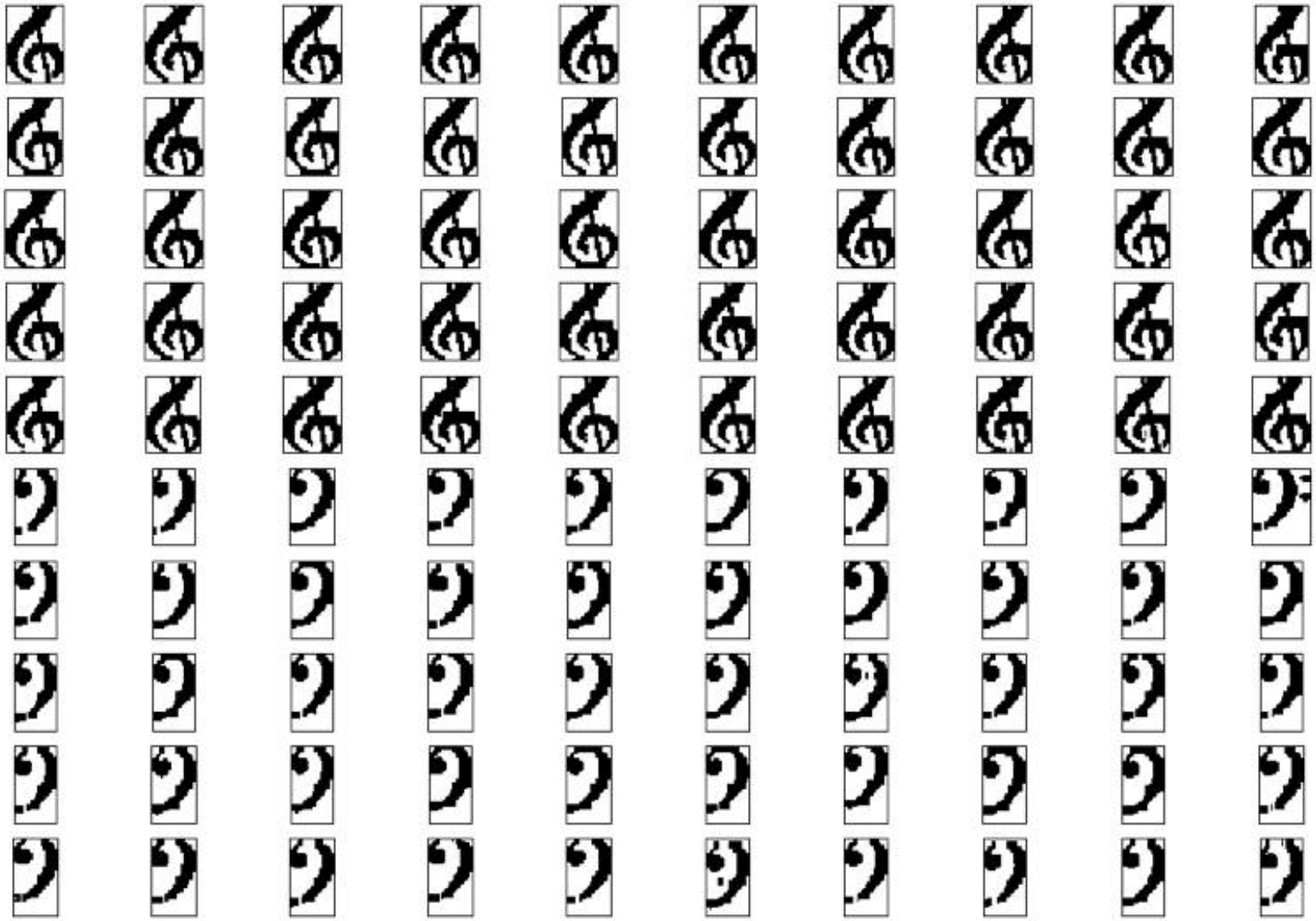
Clef-or-not Samples



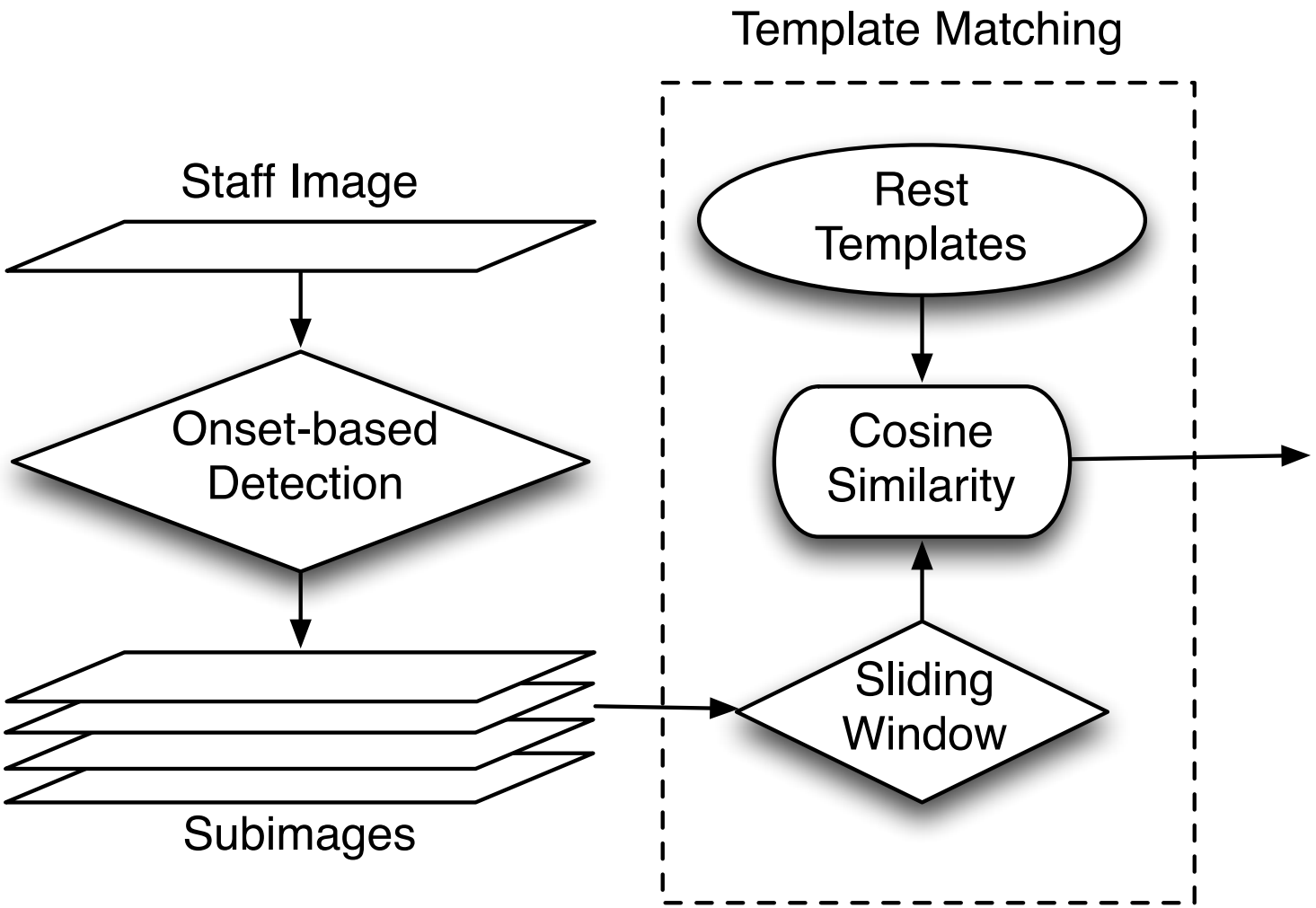
Clef-or-not Feature



Clef Samples

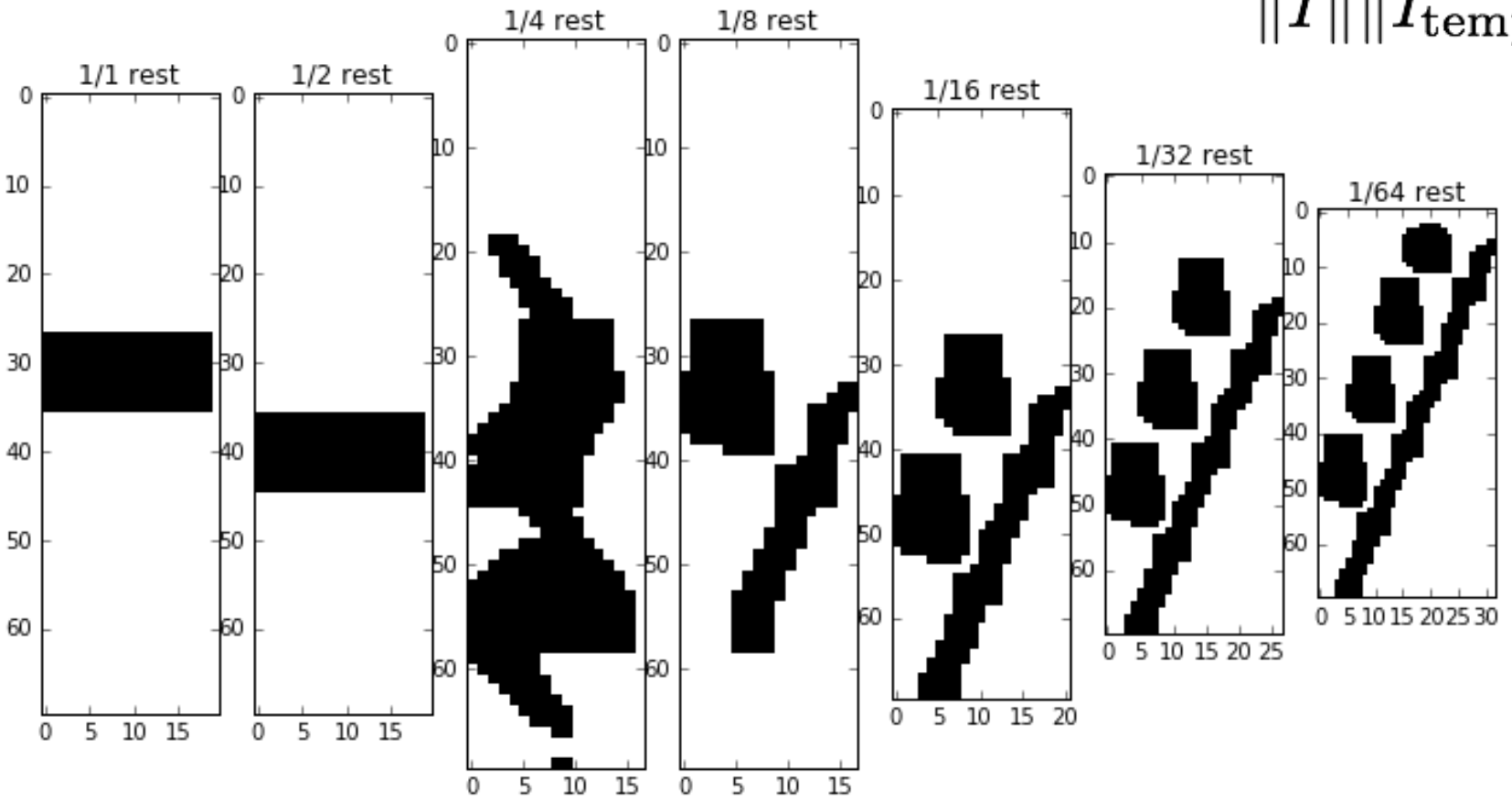


Rest Detection

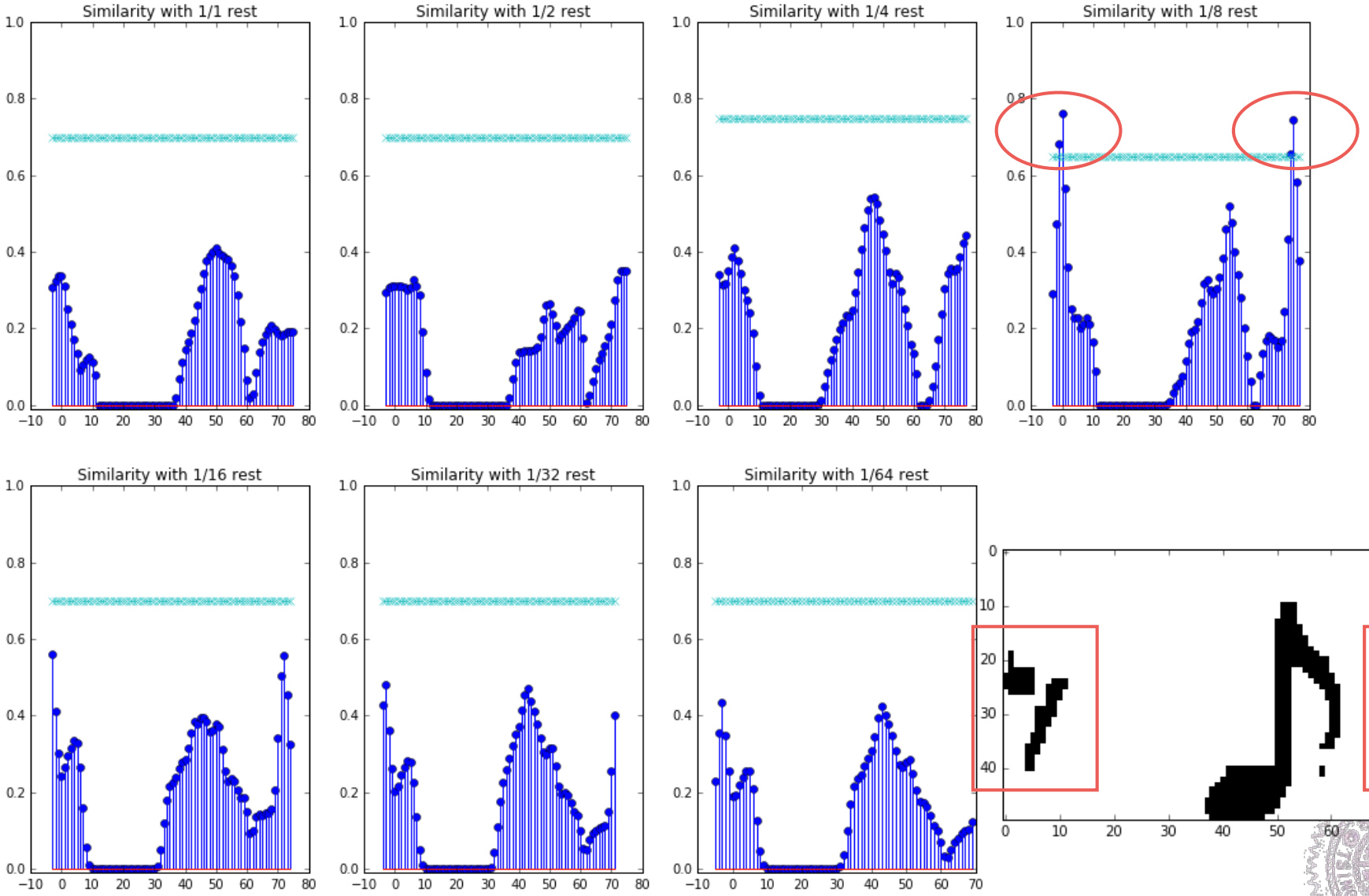


Rest Templates

$$\text{score} = \frac{\langle I,\ I_{\text{template}} \rangle}{\|I\| \|I_{\text{template}}\|}$$



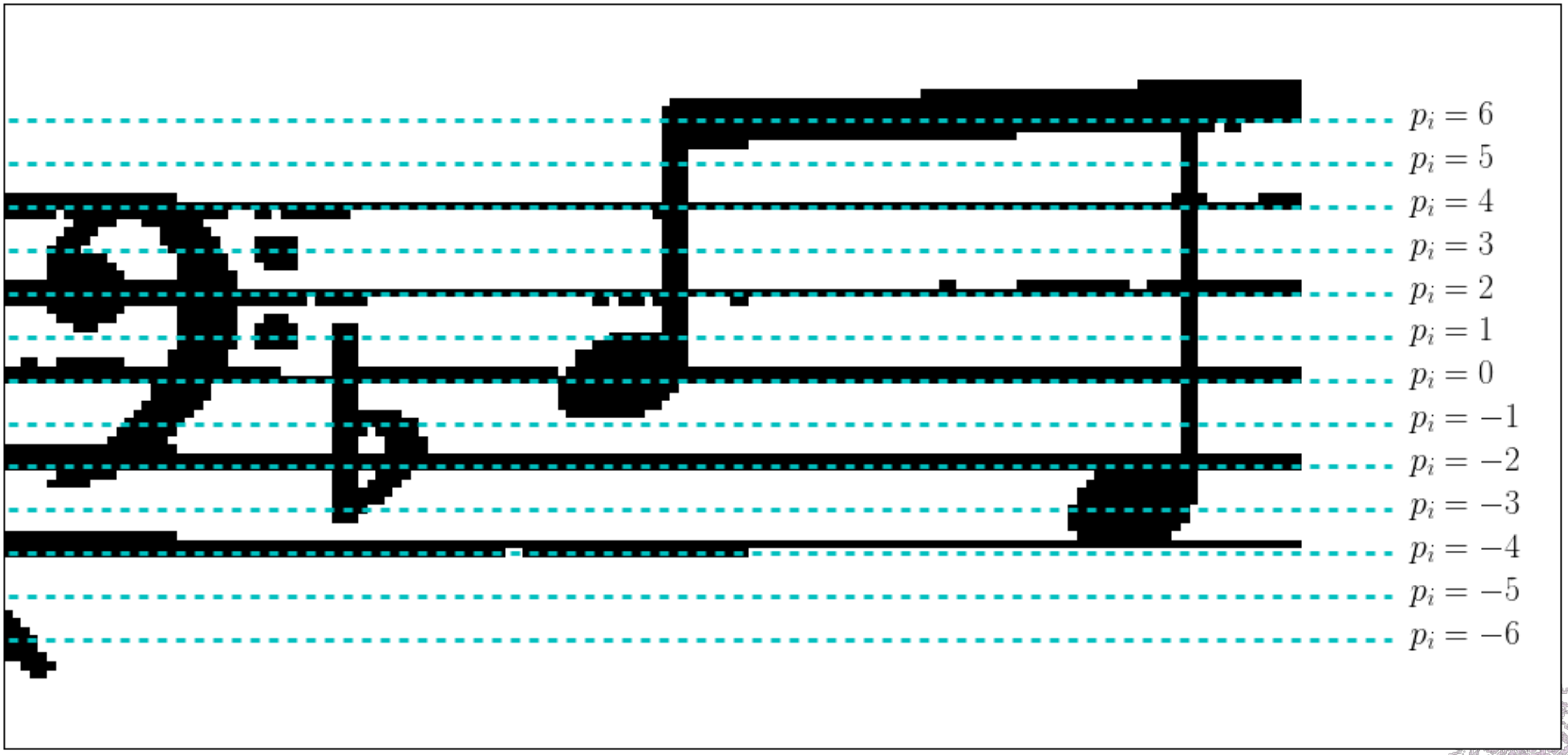
Rest Detection
Template Matching



Recognition
Pitch-related Symbols

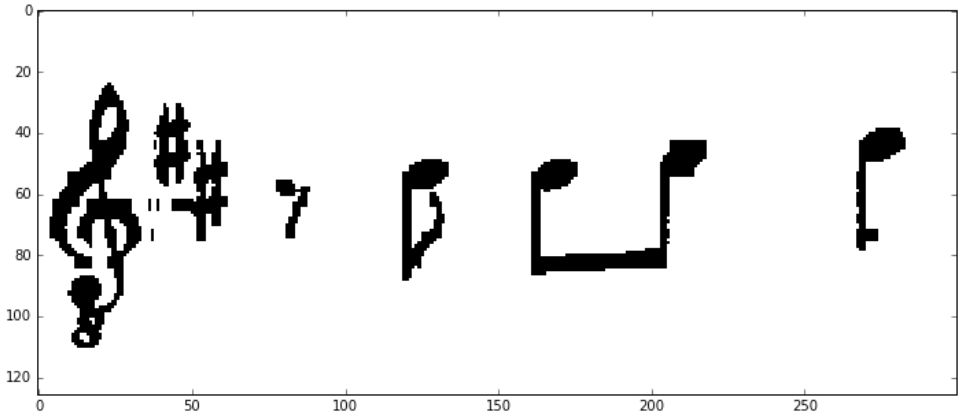
Pitch Cropping

$$y_{p_i} = l_3 - p_i \times 0.5(w + s)$$

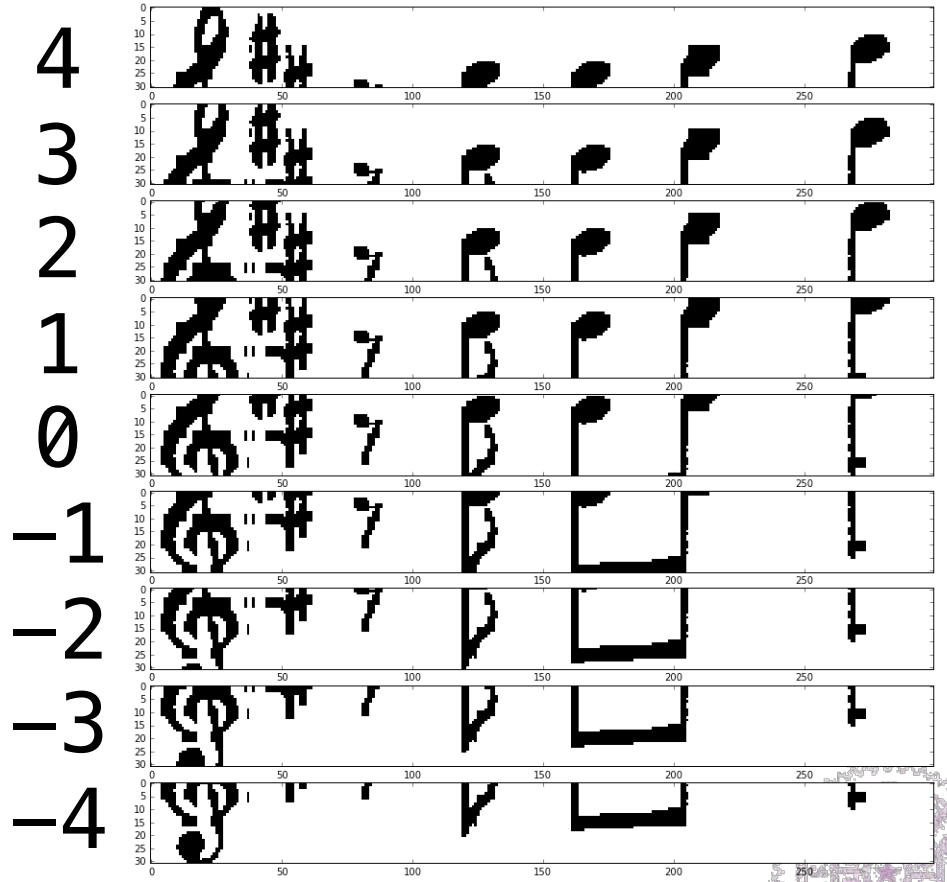


Pitch Cropping

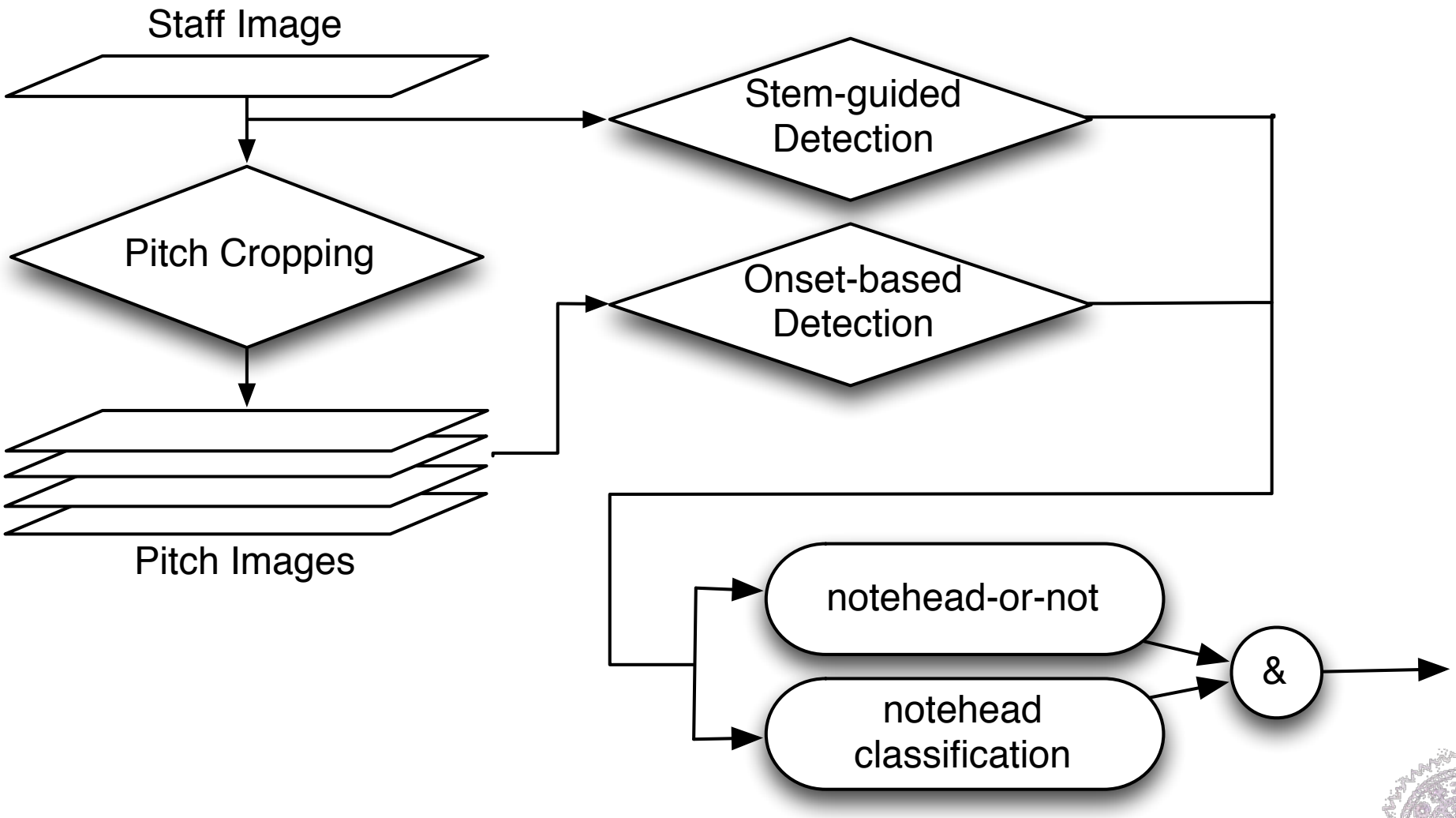
$$\rho_{\text{seg}}(I,\, p_{\text{range}},\, r) = \{I(:,\, y_{p_i} - r : y_{p_i} + r) \mid p_i = -p_{\text{range}},\, \cdots,\, p_{\text{range}}\}$$



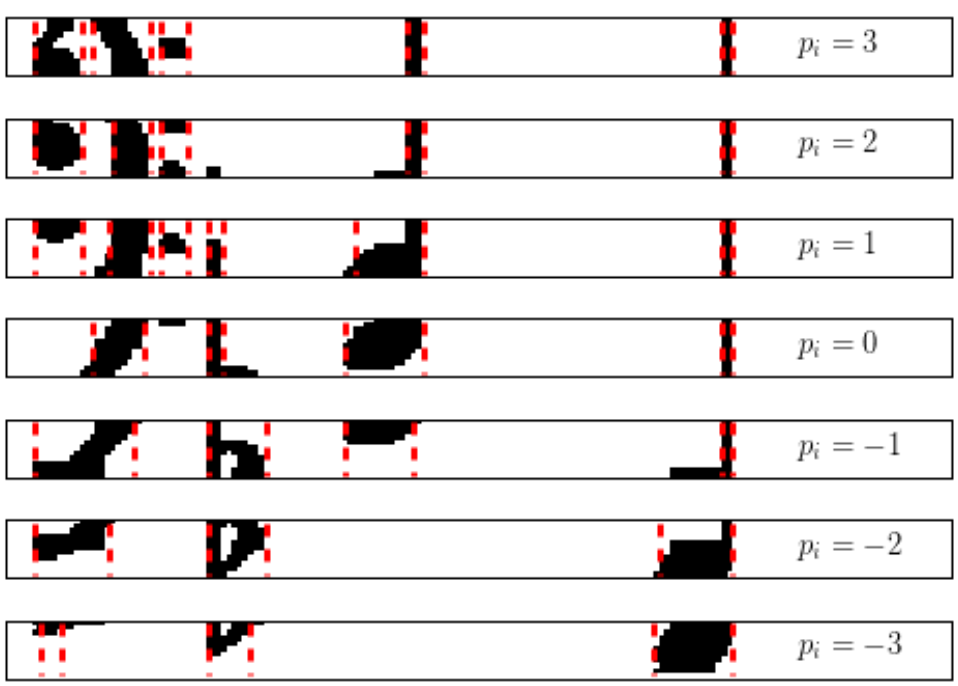
$p_{\text{range}} = 4,\ r = 1.5(w + s)$

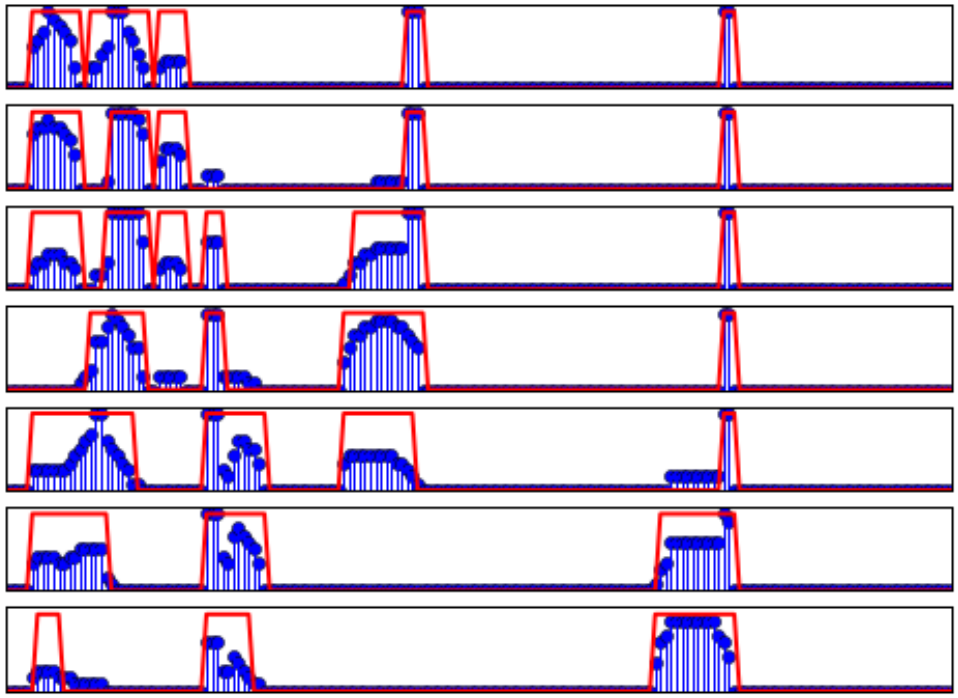


Notehead Detection

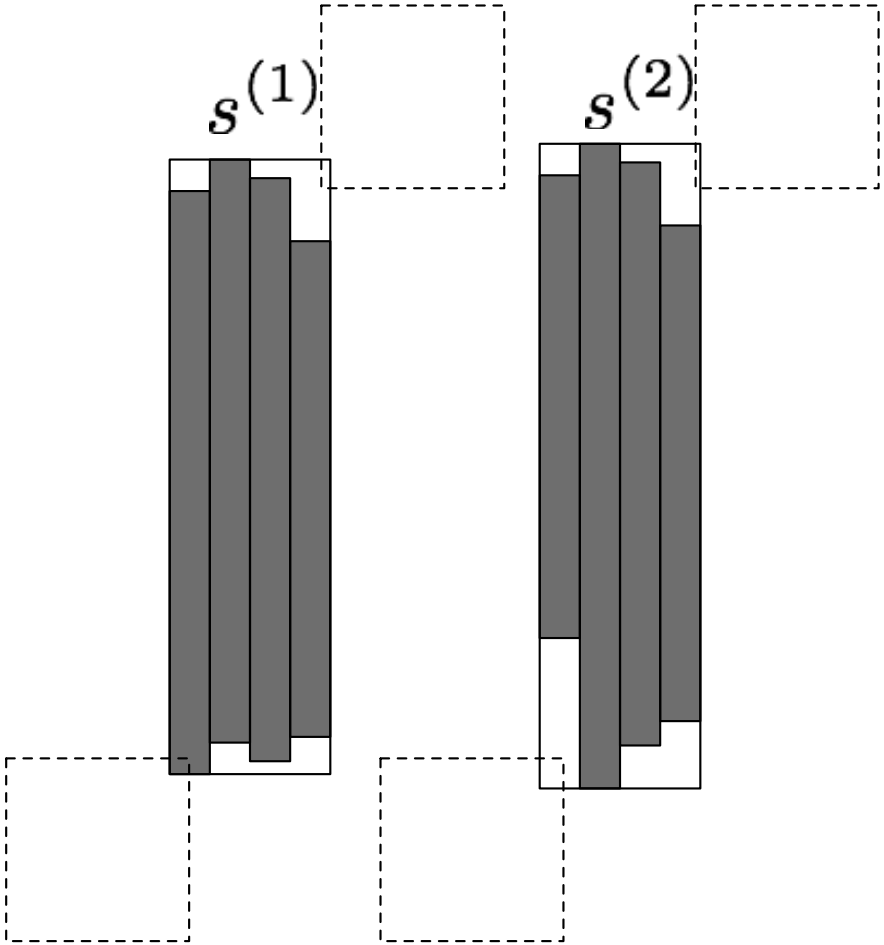


Notehead Detection
Onset-based





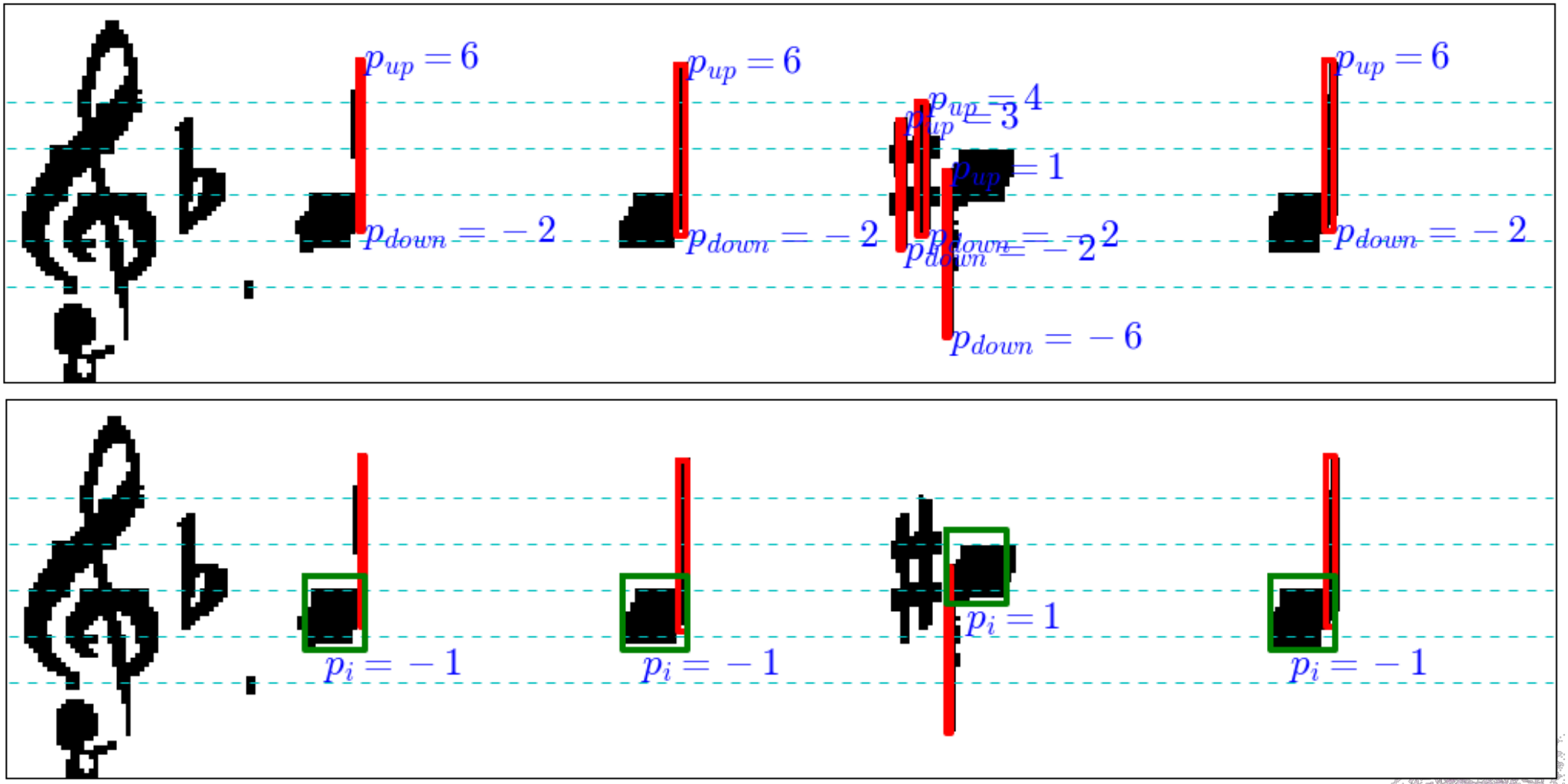
Notehead Detection
Stem-guided



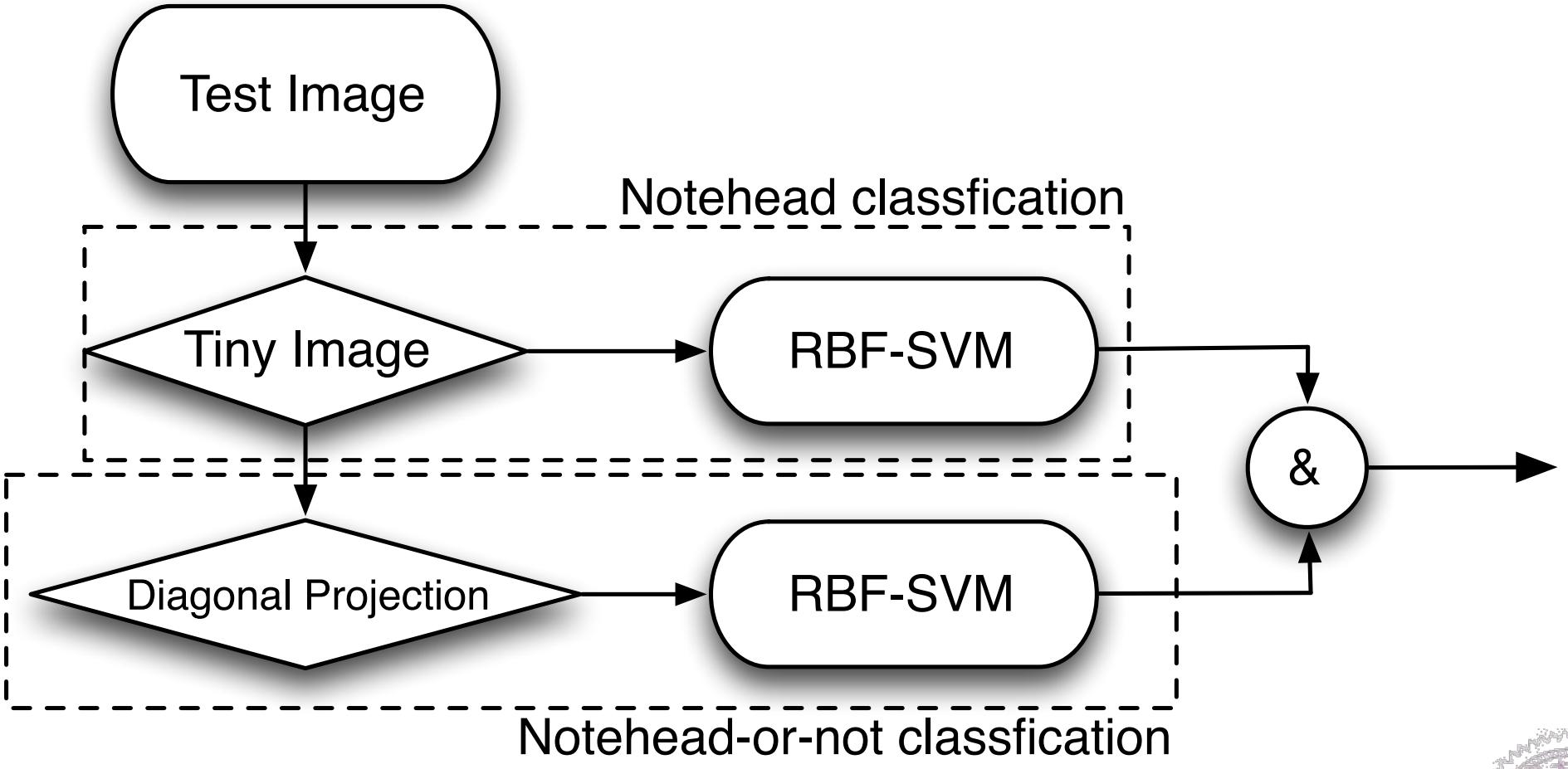
$$p_{\mathrm{u}} = \mathrm{round}\left(\frac{l_3 - y_{\mathrm{min}}}{0.5(w+s)}\right)$$

$$p_{\mathrm{d}} = \mathrm{round}\left(\frac{l_3 - y_{\mathrm{max}}}{0.5(w+s)}\right)$$

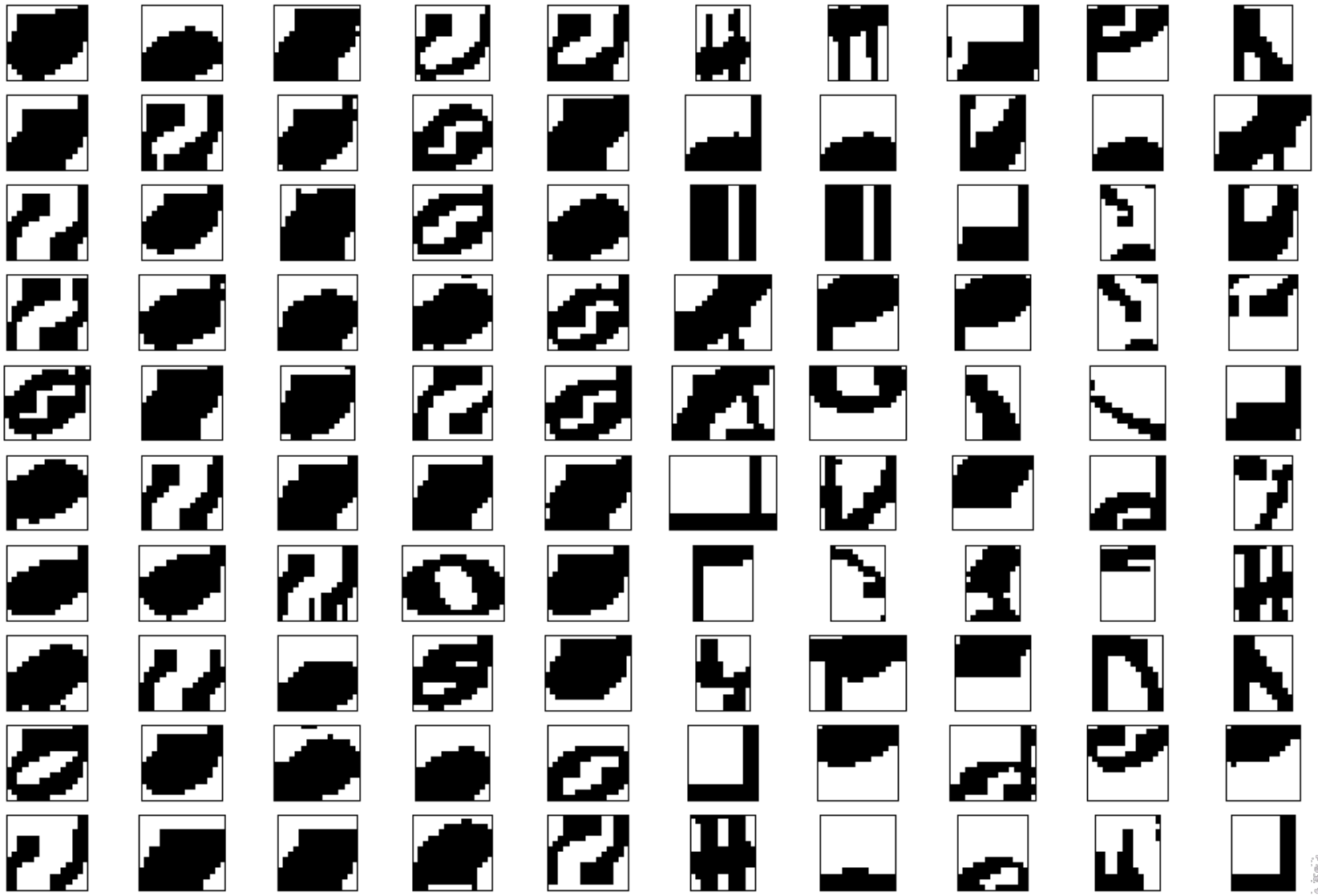
Notehead Detection
Stem-guided



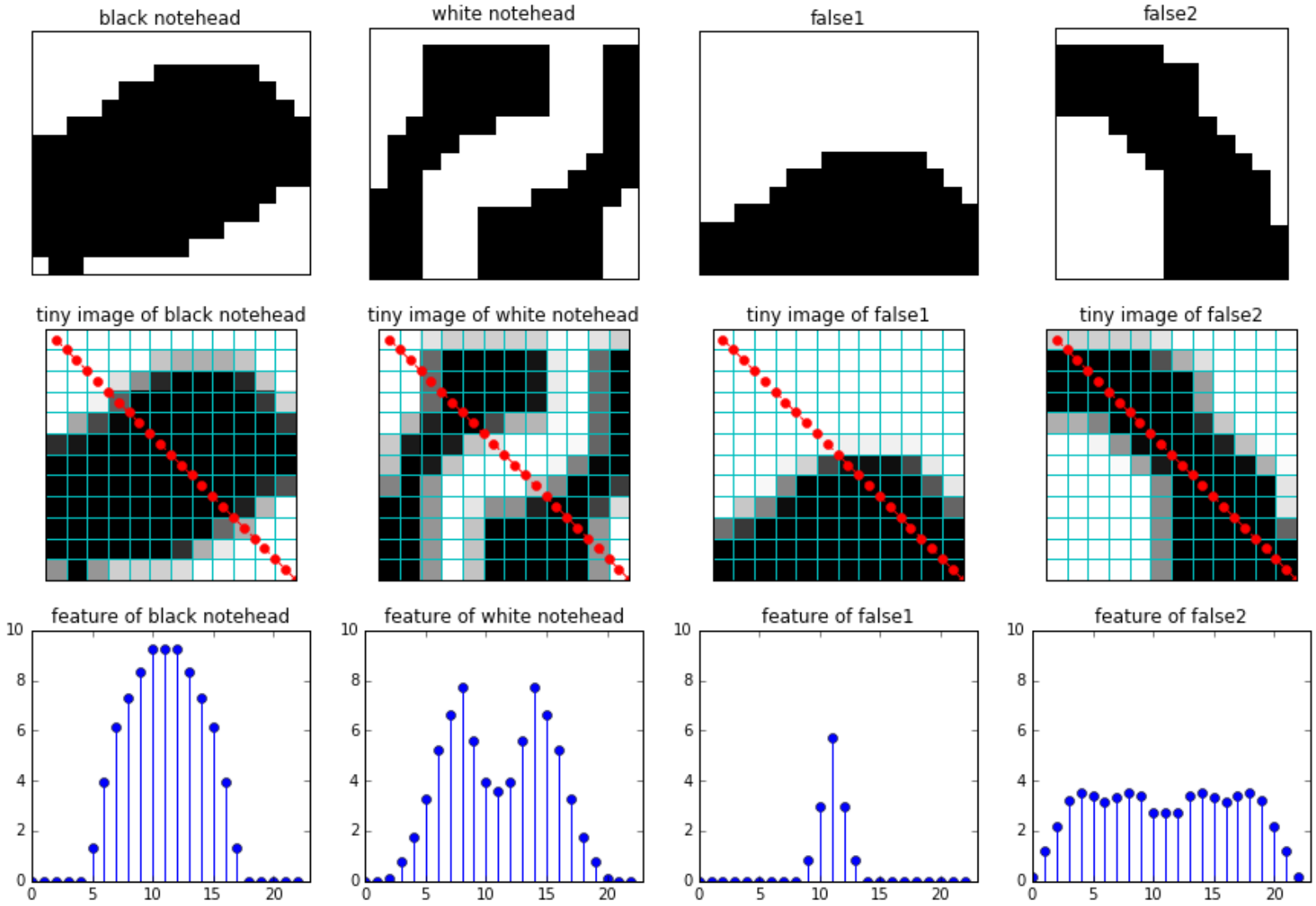
Notehead Detection: Feature



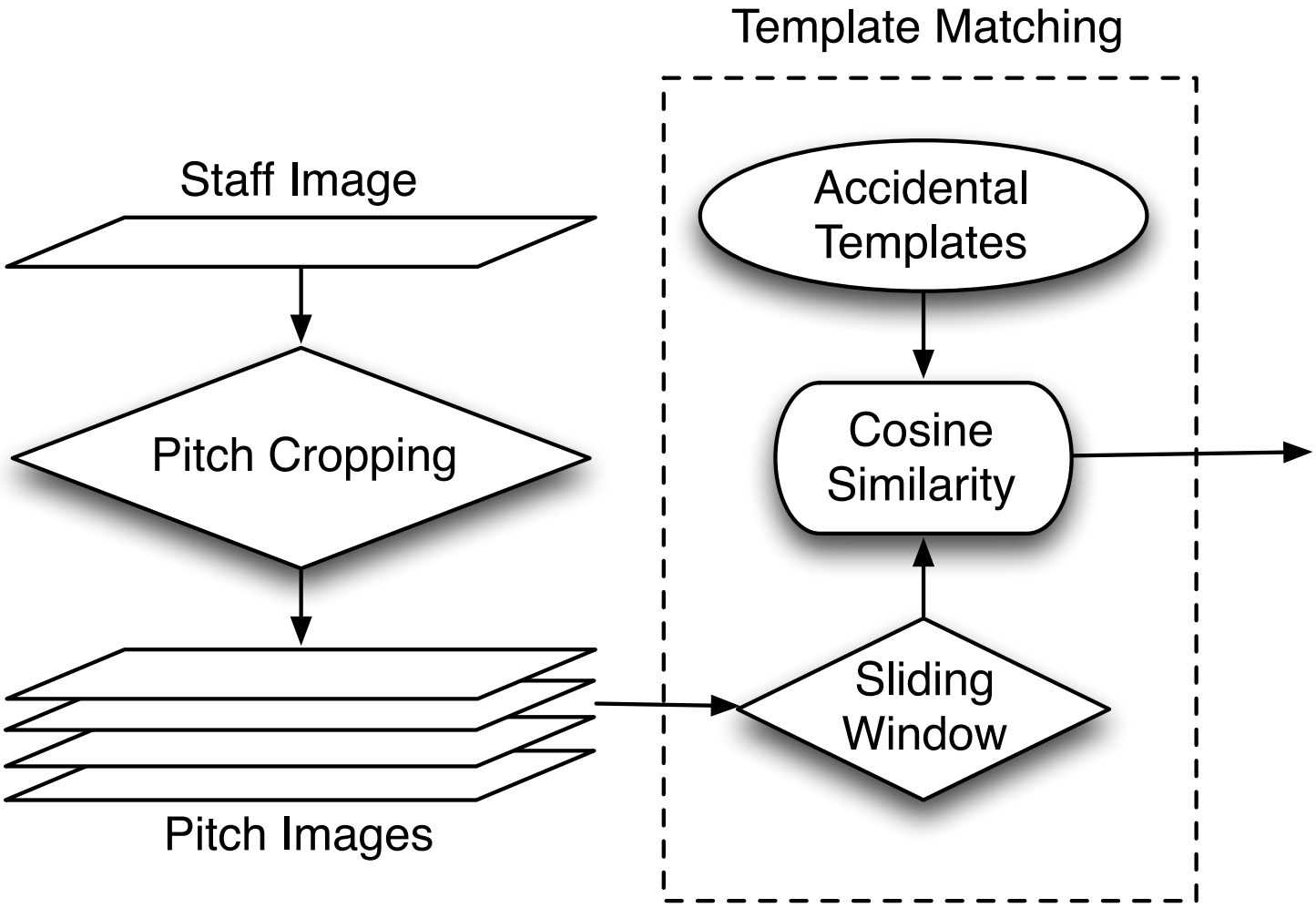
Notehead-or-not Samples



Notehead-or-not Feature

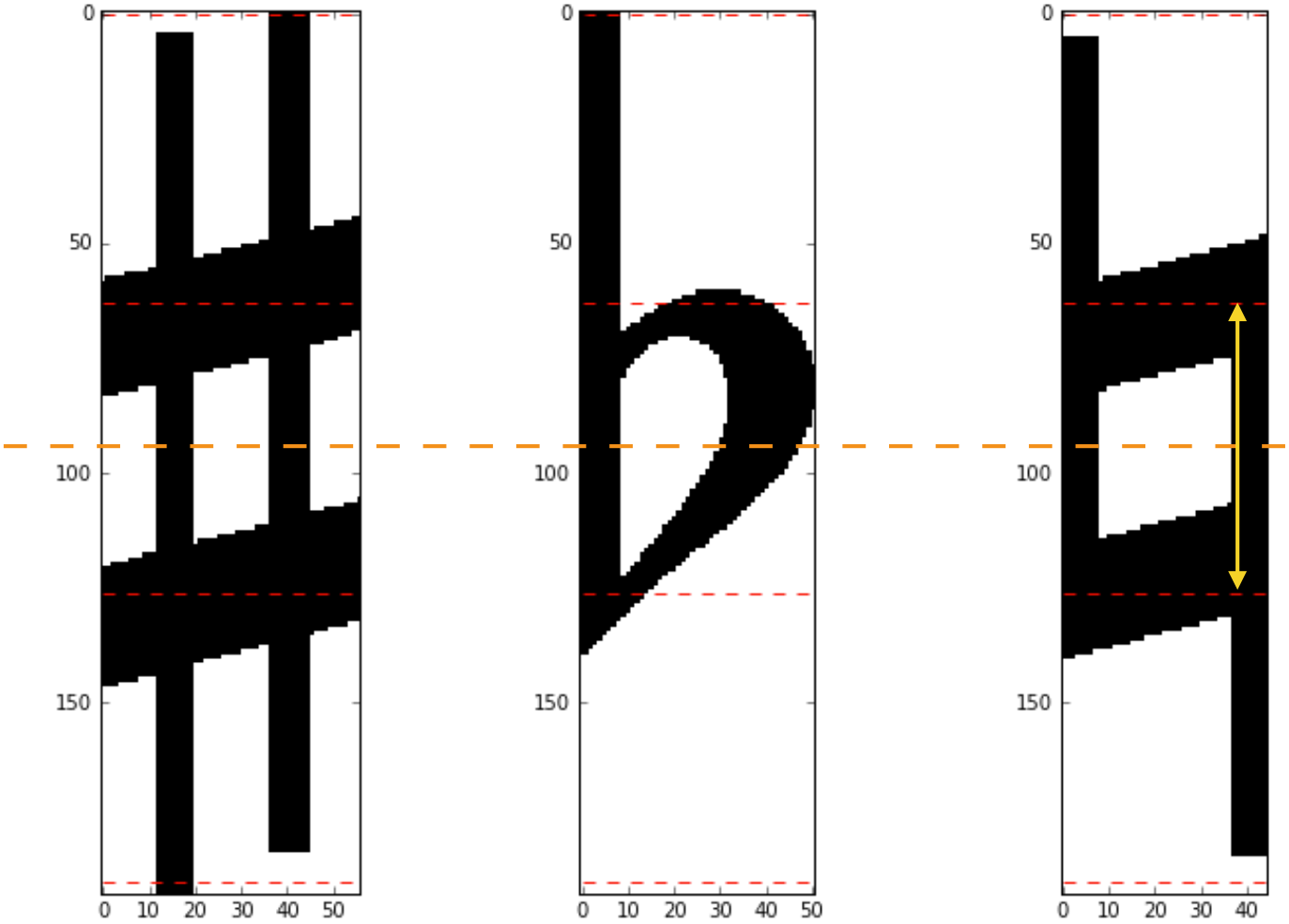


Accidental Detection



Accidental Templates

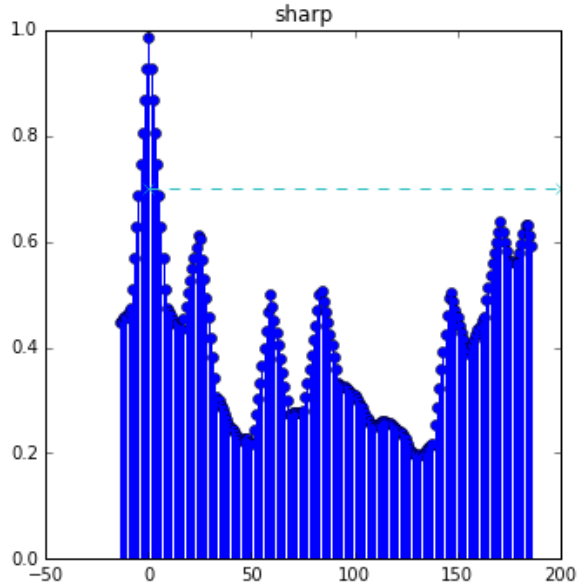
$$\text{score} = \frac{\langle I,\ I_{\text{template}} \rangle}{\|I\| \|I_{\text{template}}\|}$$

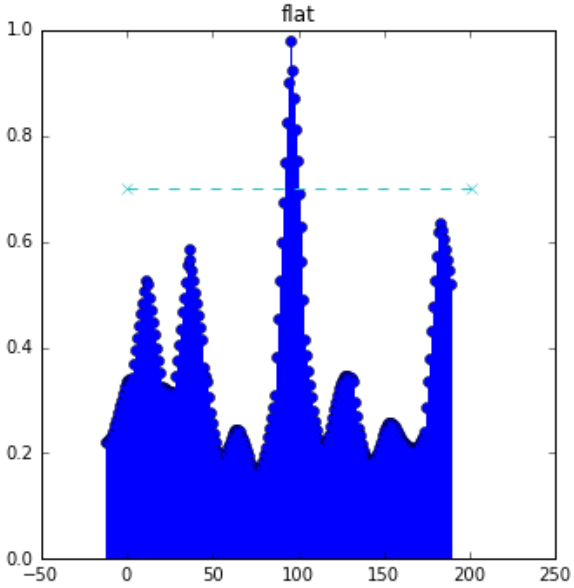


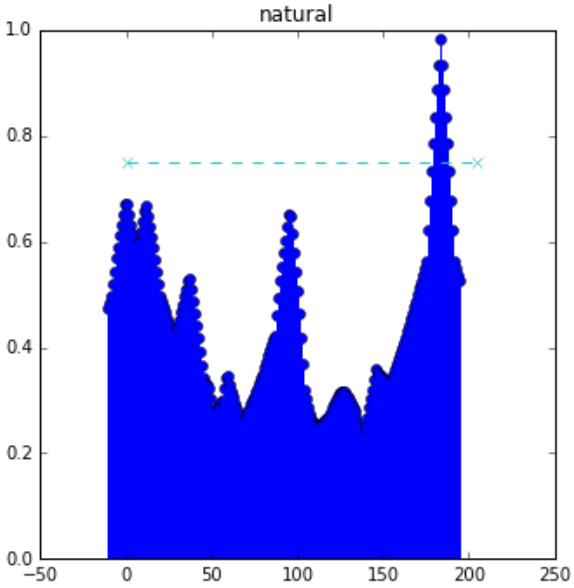
the margin between adjacent stafflines

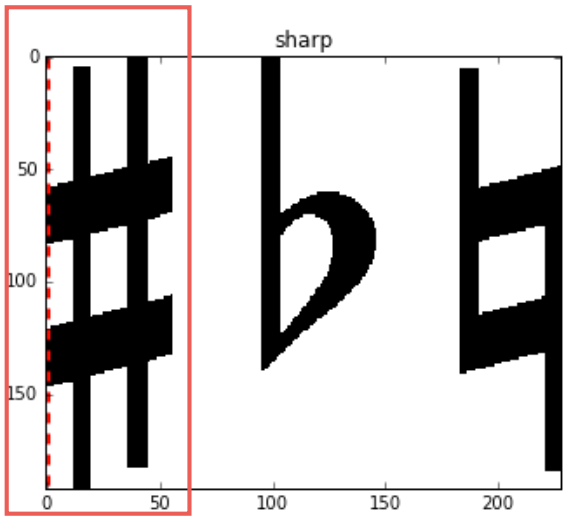
pitch

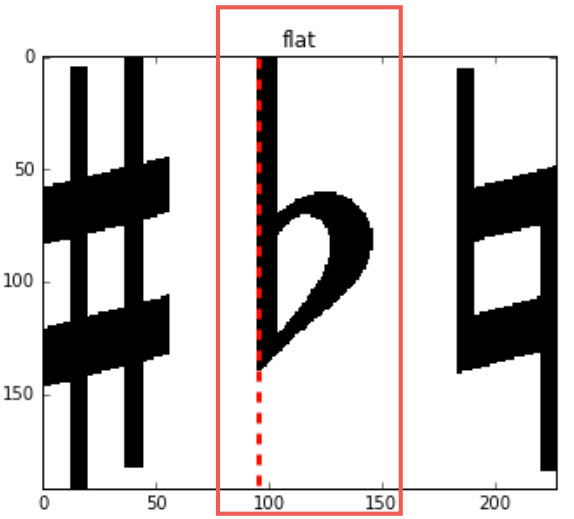
Accidental Detection
Template Matching

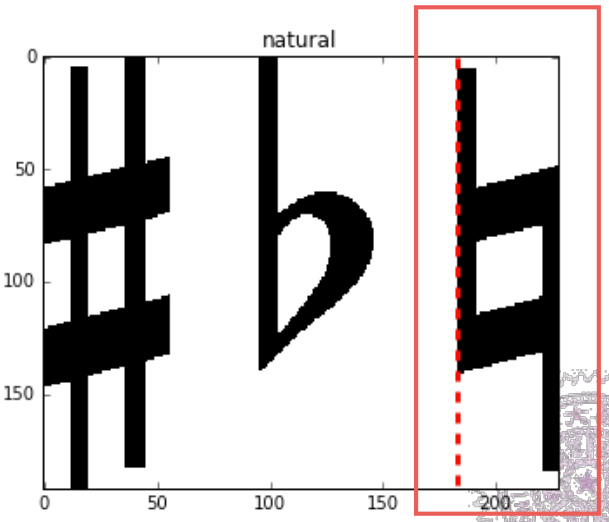






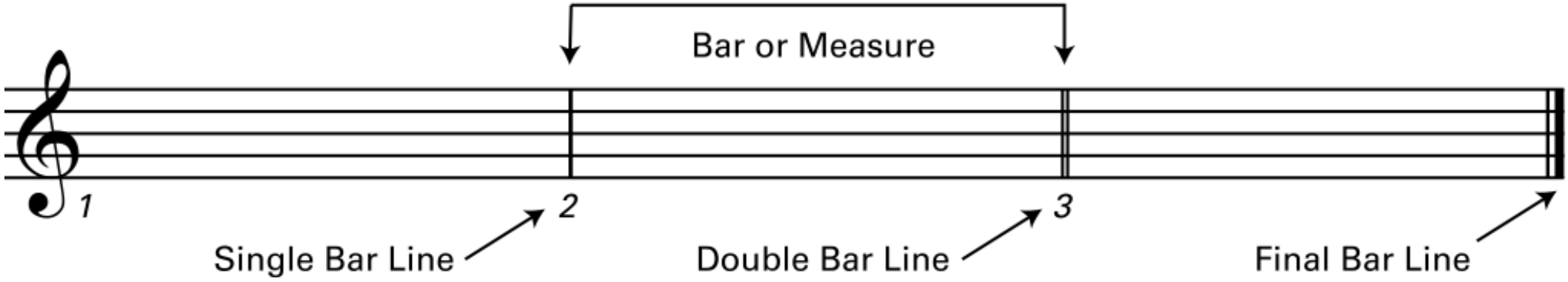


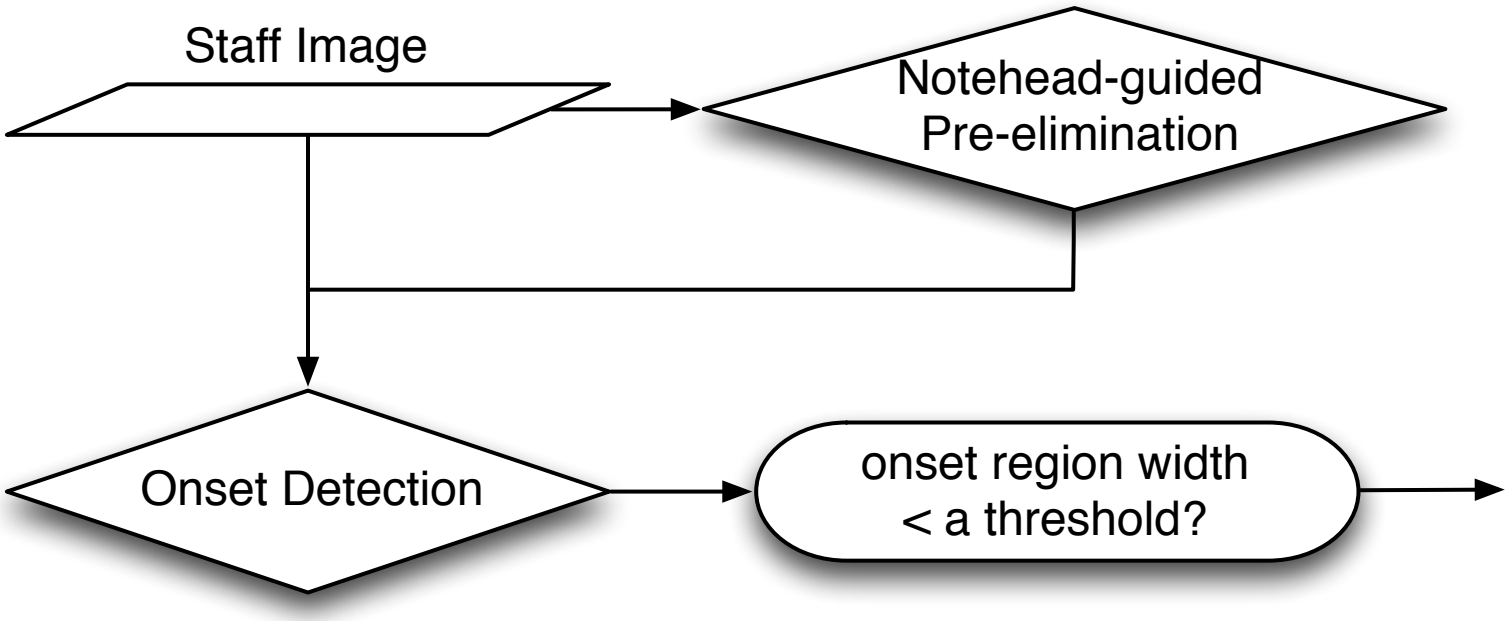




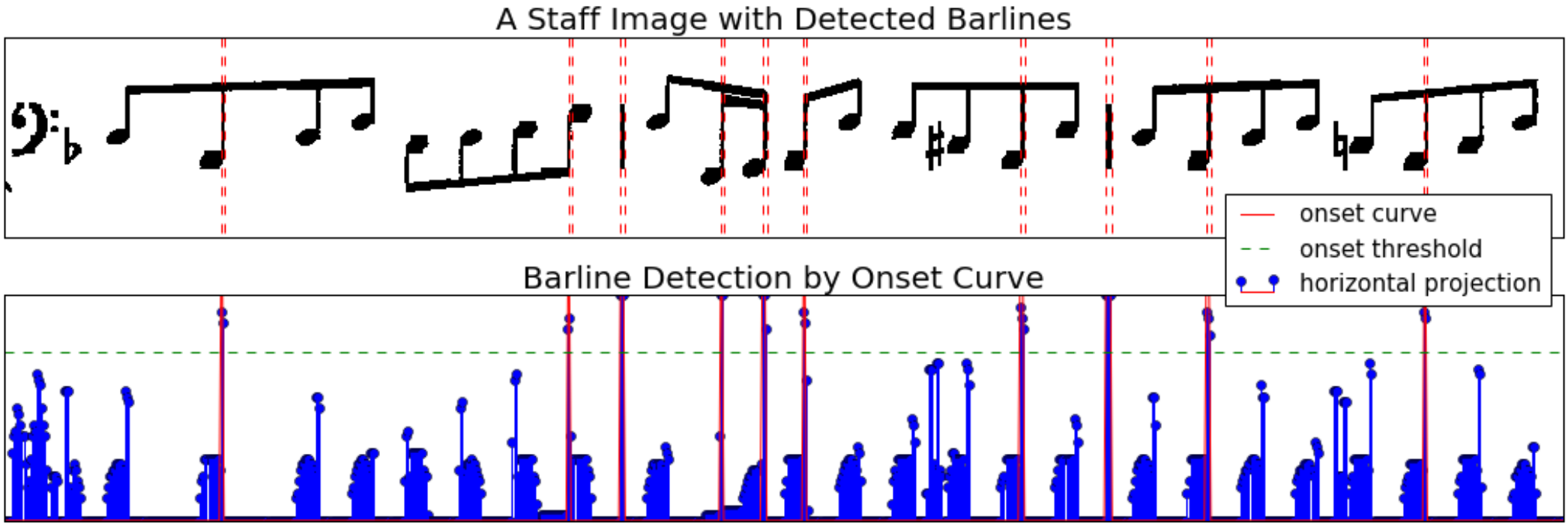
Recognition
Other Symbols

Barline Detection

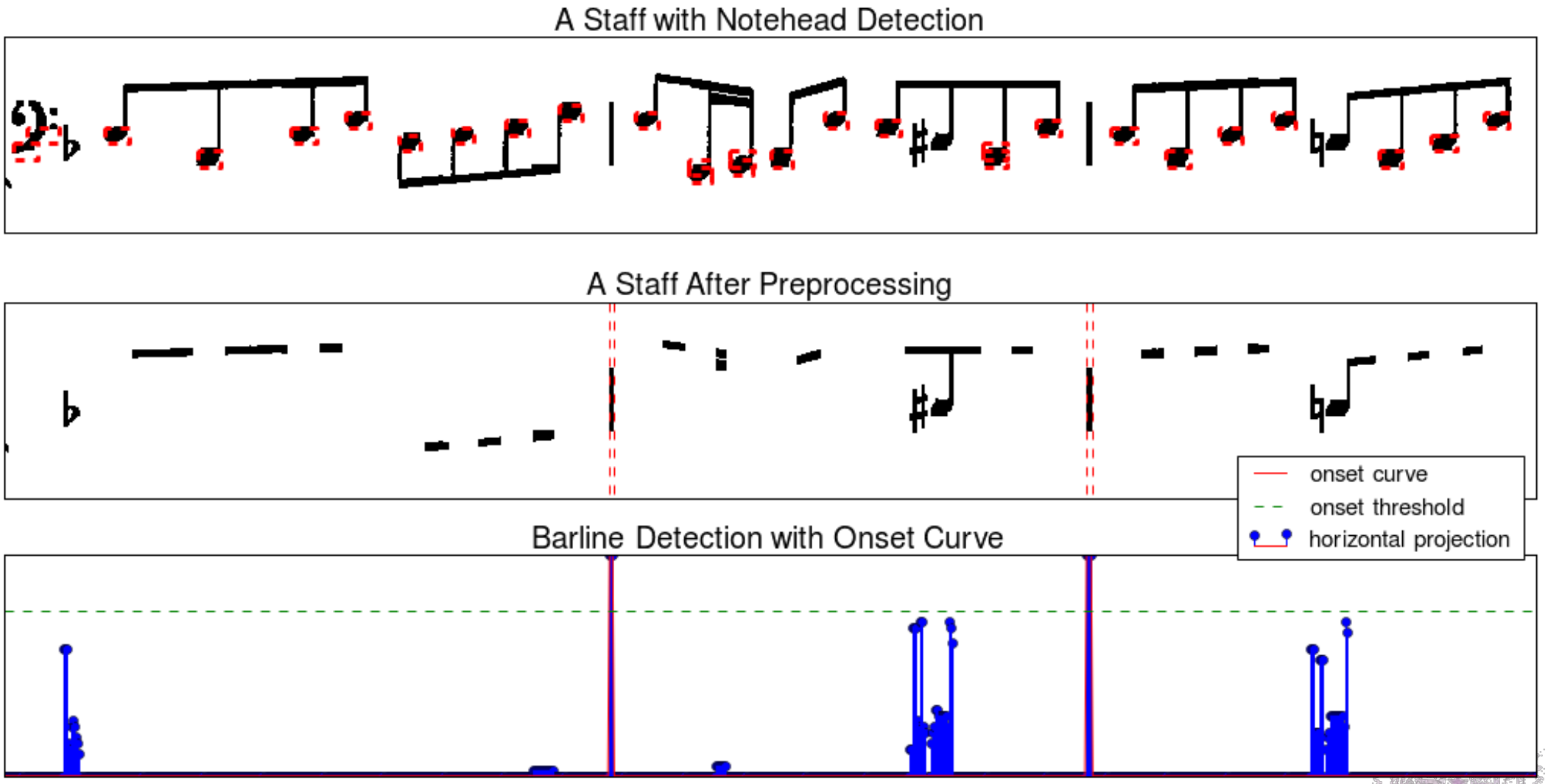




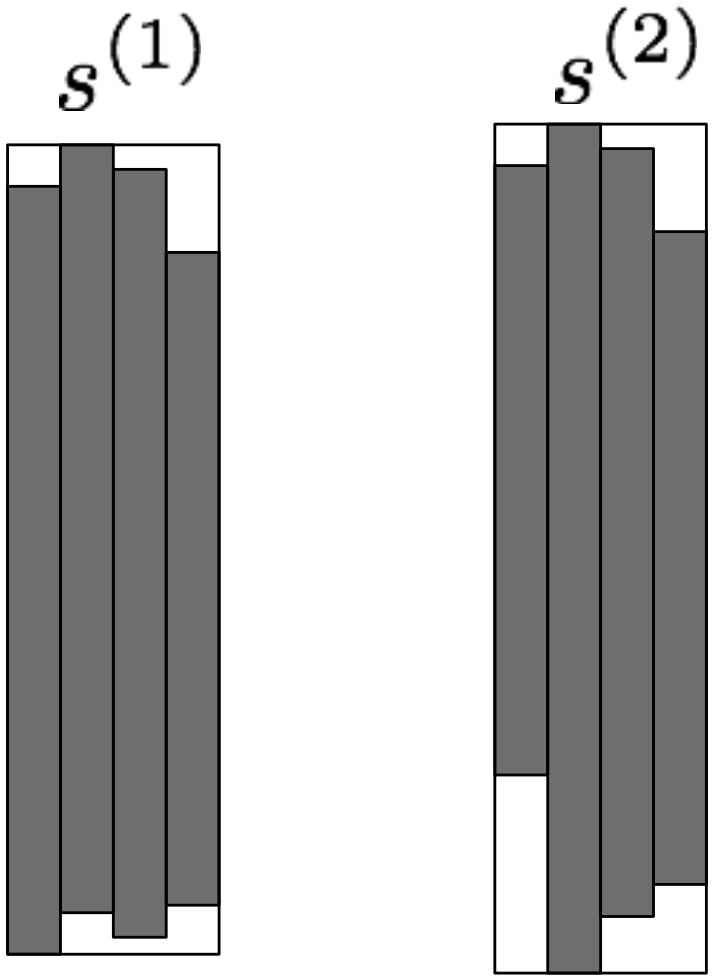
Barline Detection



Barline Detection with Preprocessing



Stem Detection



Algorithm 1 Procedure of finding vertical lines

Input: A gray-scaled image I
Output: A set of 4-tuples

$\mathscr{V} \leftarrow []$
for each $c \leftarrow$ the x^{th} column of I **do**
  if $c(y) = 1, \forall y = y_{\min}, y_{\min}+1, \cdots, y_{\max}$ and $y_{\max} - y_{\min} \geq 2(w+s)$ **then**
    Append $(x, y_{\min}, y_{\max})$ to $\mathscr{V}$
  end if
end for
$\mathscr{R} \leftarrow []$
for each $(x, y_{\min}, y_{\max}) \in \mathscr{V}$ **do**
  if $\mathscr{R}$ is empty **then**
    Append $(x, x, y_{\min}, y_{\max})$ to $\mathscr{R}$
    Continue
  end if
  $r \leftarrow$ the reference of the last element of $\mathscr{R}$
  if $r_2 = x - 1$ **then**
    Update $r_2 \leftarrow x$
    Update $r_3 \leftarrow \min(r_3, y_{\min})$
    Update $r_4 \leftarrow \max(r_4, y_{\max})$
  else
    Append $(x, x, y_{\min}, y_{\max})$ to $\mathscr{R}$
  end if
end for
Return $\mathscr{R}$

Beam Grouping

Algorithm 2 Procedure of beam grouping

Input: the image I and the matrix M_{vl}

Output: A set of $(\mathscr{S}, \delta)$'s where $\mathscr{S}$ is the collection of stems that belong to the same beam and $\delta = \begin{cases} 0, & \text{the beam runs through } y_{\min}\text{'s} \\ 1, & \text{the beam runs through } y_{\max}\text{'s} \end{cases}$ is a binary symbol referring to the beam is upper or lower.

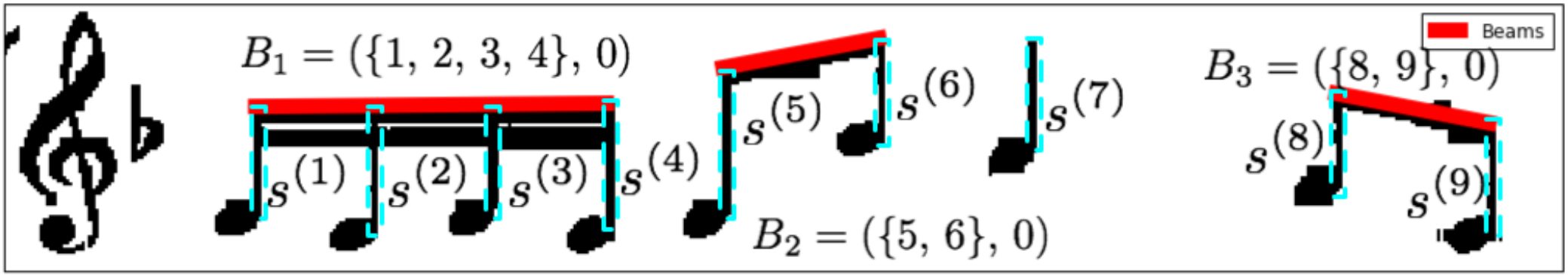
$\mathscr{G} \leftarrow []$
for $i \leftarrow 1, \cdots, |\mathscr{R}_{\text{vl}}|$ **do**
  $s^{(i)} \leftarrow$ the i^{th} column of M_{vl}
  for $j \leftarrow i+1, \cdots, |\mathscr{R}_{\text{vl}}|$ **do**
    $s^{(j)} \leftarrow$ the j^{th} column of M_{vl}
    $p_1 \leftarrow (s_1^{(i)}, s_3^{(i)}), p_2 \leftarrow (s_1^{(j)}, s_3^{(j)})$
    if $L_I(p_1, p_2) \geq 0.9(p_{2x} - p_{1x})$ **then**
      Append $(i, j, 0)$ to $\mathscr{G}$
      Break
    end if
    $p_1 \leftarrow (s_1^{(i)}, s_4^{(i)}), p_2 \leftarrow (s_1^{(j)}, s_4^{(j)})$
    if $L_I(p_1, p_2) \geq 0.9(p_{2x} - p_{1x})$ **then**
      Append $(i, j, 1)$ to $\mathscr{G}$
      Break
    end if
  end for
end for

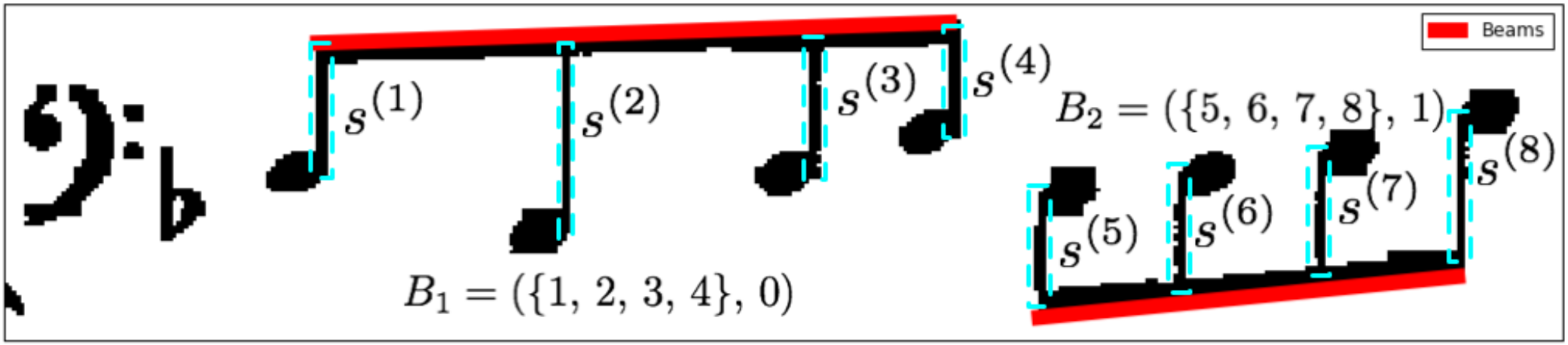
$\mathscr{S}_{\text{beam}} \leftarrow []$
for each $(i, j, \delta) \in \mathscr{G}$ **do**
  if $\mathscr{S}_{\text{beam}}$ is empty **then**
    Append $(\{i, j\}, \delta)$ to $\mathscr{S}_{\text{beam}}$
    Continue
  end if
  $(\mathscr{S}_{\text{last}}, \delta_{\text{last}}) \leftarrow$ the last element of $\mathscr{S}_{\text{beam}}$
  $j_{\text{last}} \leftarrow \max(\mathscr{S}_{\text{last}})$
  if $j_{\text{last}} = i$ **then**
    Add j to $\mathscr{S}_{\text{last}}$
    Update the last element of $\mathscr{S}_{\text{beam}}$
  else
    Append $(\{i, j\}, \delta)$ to $\mathscr{S}_{\text{beam}}$
  end if
end for
Return $\mathscr{S}_{\text{beam}}$

$$l_{p_1,p_2}(x) = y,$$

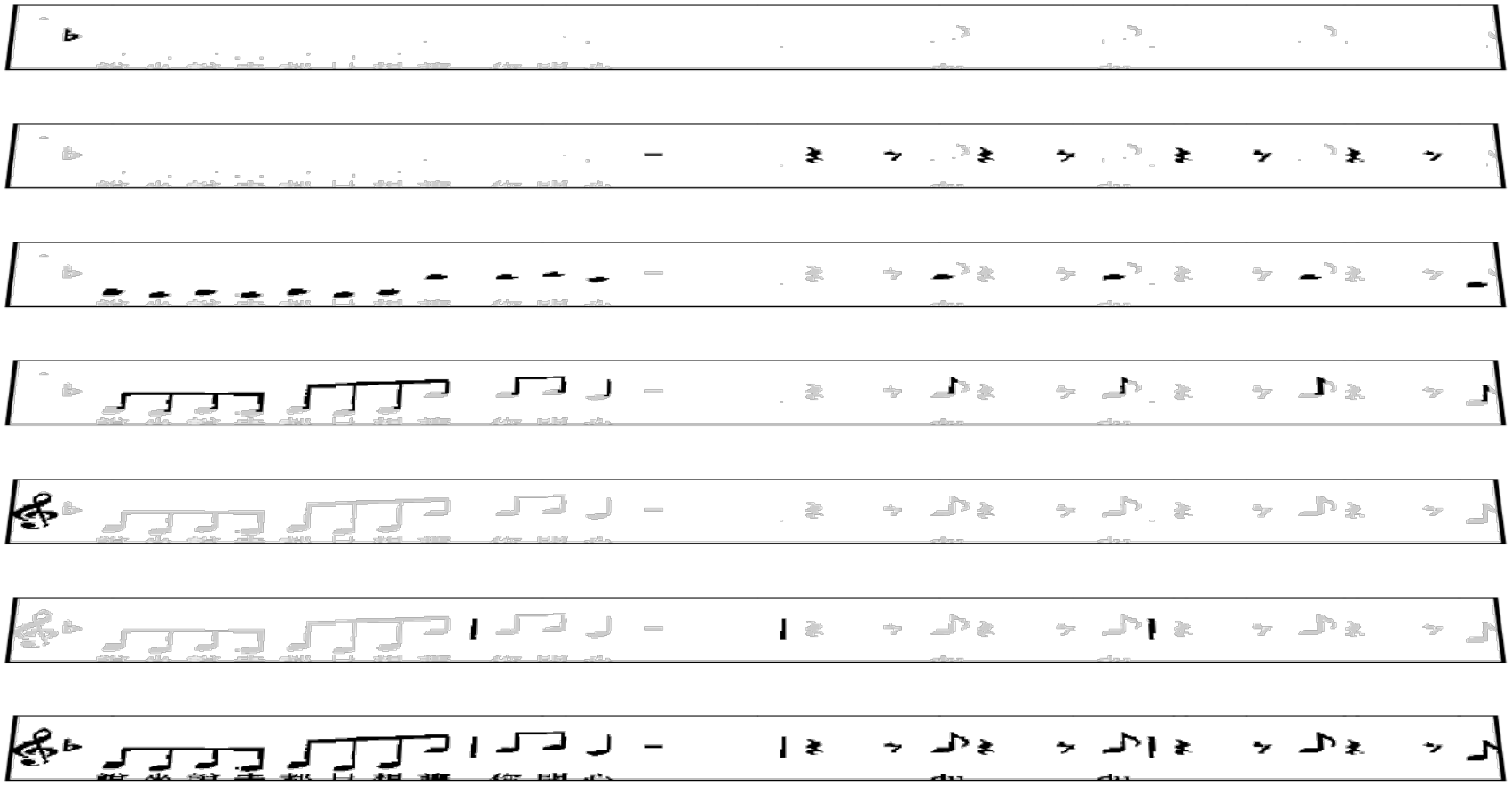
$$L_I(p_1, p_2) = \sum_{x=p_{1x}}^{p_{2x}} I(x, l_{p_1,p_2}(x)),\ p_{1x} \leq p_{2x}$$

Beam Grouping





Hierarchical Detection



Summary of Detection on Different Symbols

	Detection Approach	Locating Symbols	Parameters	Working Images
Barlines	Horizontal Projection	Onset Curve	width, onset threshold	Staff
Clefs	Double-stage SVM	Onset Curve	merge, onset threshold	Measure
Rests	Template Matching	Onset Curve	similarity, onset threshold	Measure
Accidentals	Template Matching	Sliding Window	similarity threshold	Pitch
Noteheads	Double-stage SVM	Onset Curve	onset threshold	Pitch
		Stem-guided	N/A	Measure
Stems	RLE	Sliding Window	length threshold	Measure
Beams	Line Integral	Stem-guided	line integral threshold	Measure

Summary of Features on Different Symbols

	Features
Barlines	RLE of Horizontal Projection
Clefs	Tiny Image, Horizontal/Vertical Projection and Centroid
Rests	Cosine Similarity
Accidentals	Cosine Similarity
Noteheads	Tiny Image, Diagonal Projection
Stems	RLE
Beams	Rectangles of Stems

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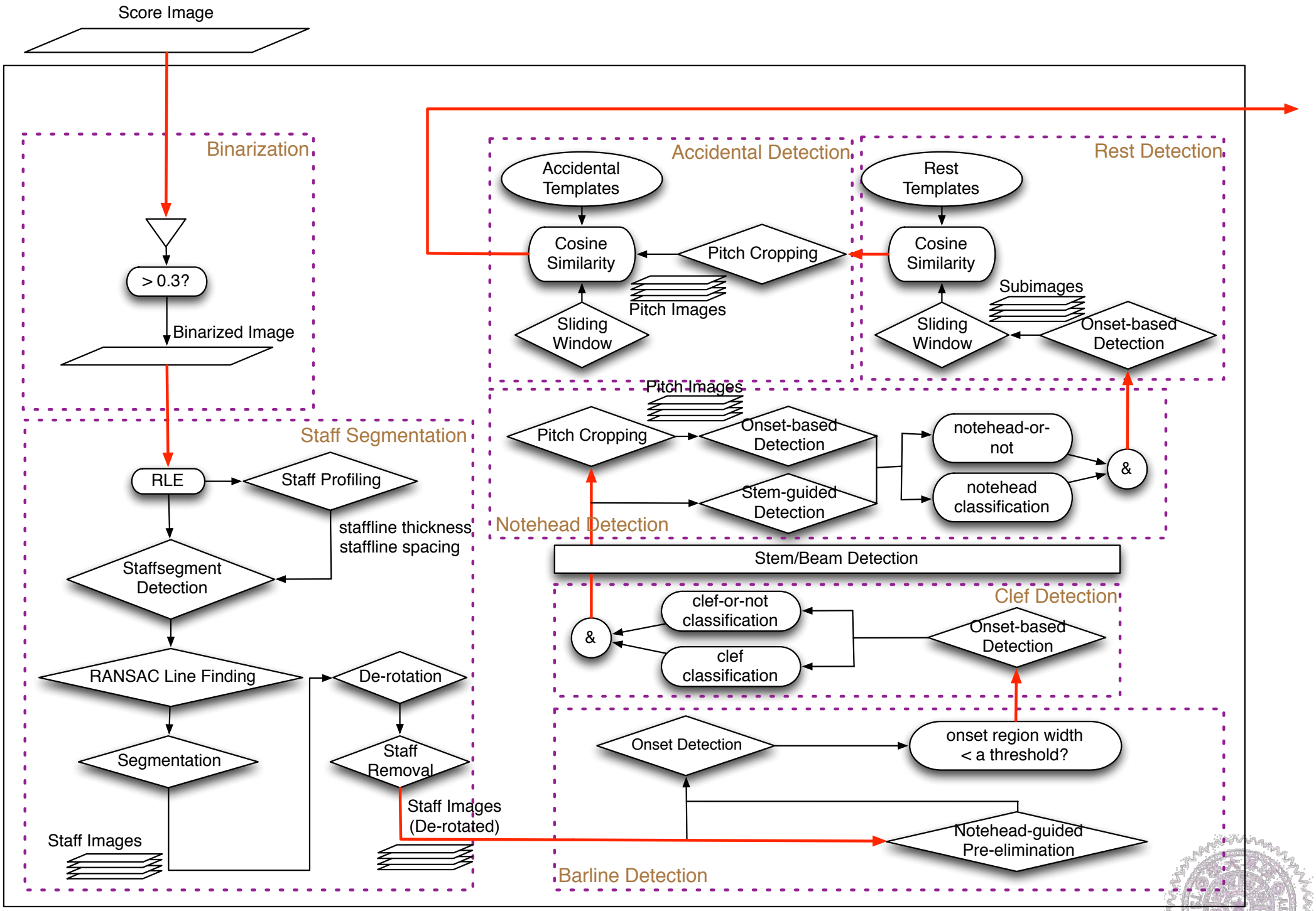
Score Image
Binarization
> 0.3?
Binarized Image
Staff Segmentation
RLE
Staff Profiling
staffline thickness
staffline spacing
Staffsegment Detection
RANSAC Line Finding
De-rotation
Segmentation
Staff Removal
Staff Images
Staff Images (De-rotated)
Accidental Detection
Accidental Templates
Cosine Similarity
Pitch Cropping
Pitch Images
Sliding Window
Rest Detection
Rest Templates
Cosine Similarity
Subimages
Sliding Window
Onset-based Detection
Pitch Images
Pitch Cropping
Onset-based Detection
Stem-guided Detection
notehead-or-not
notehead classification
&
Notehead Detection
Stem/Beam Detection
Clef Detection
&
clef-or-not classification
clef classification
Onset-based Detection
Barline Detection
Onset Detection
onset region width < a threshold?
Notehead-guided Pre-elimination