

Handwritten Character Recognition Using Piecewise Linear Two- Dimensional Warping

○ Mohammad Asad RONEE

内田 誠一

迫江 博昭

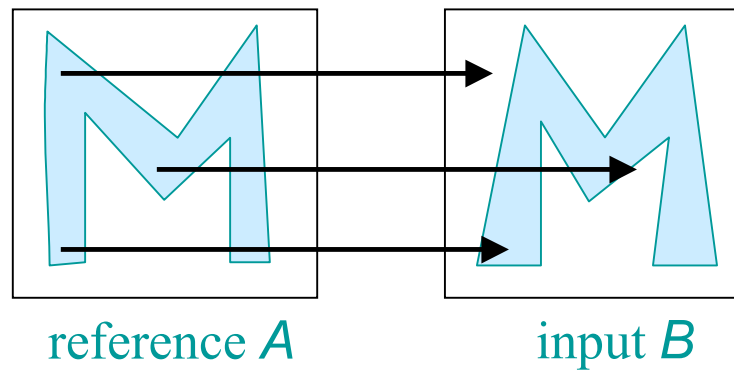
Kyushu University, Fukuoka

1 Pattern matching in handwritten character recognition

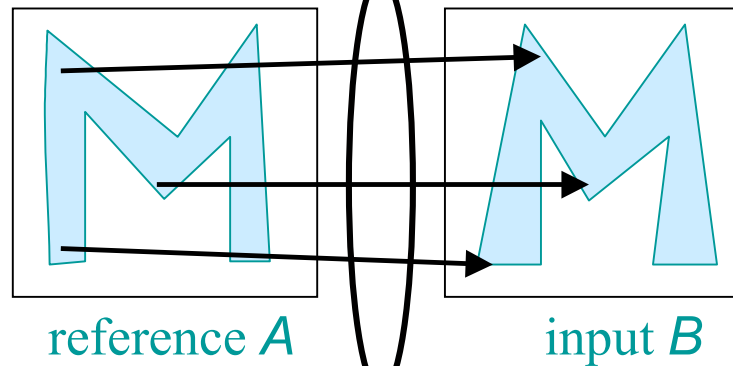
Template matching

solution

Elastic matching
(2D warping)



deformations
in
handwritten
patterns



2D-2D mapping

Optimize

2 Optimization of 2DW using dynamic programming (DP)

Advantages of using DP

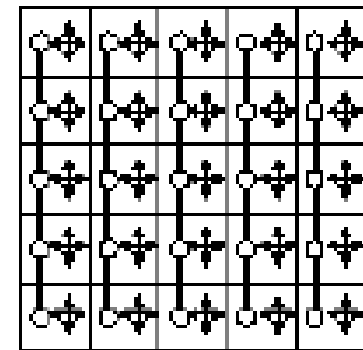
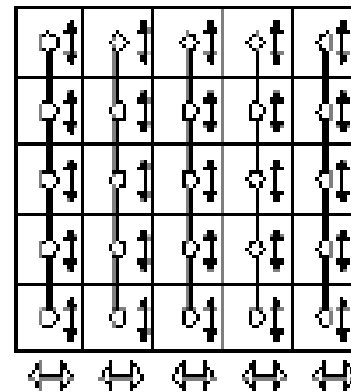
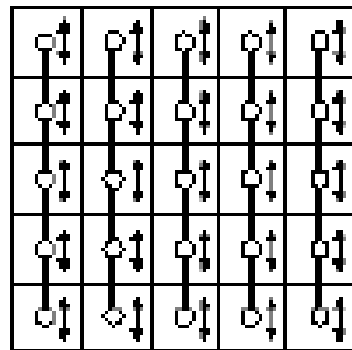
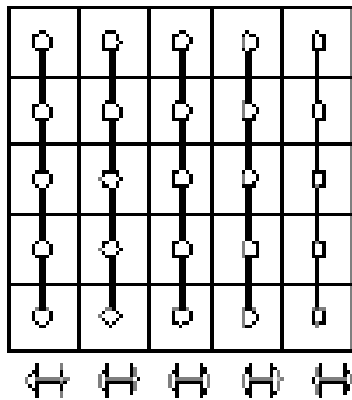
- Versatility with criterion functions and constraints
- Global optimality
- Computational stability

3 DP-based previous 2DW methods for handwritten character recognition

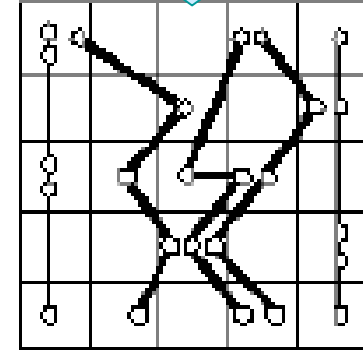
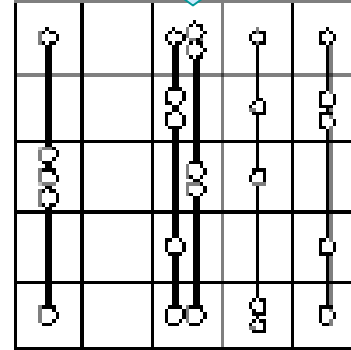
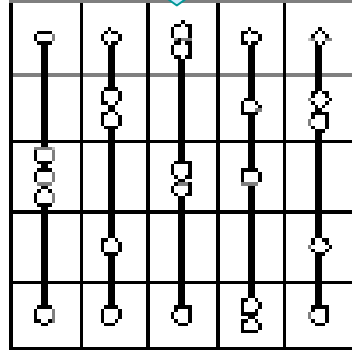
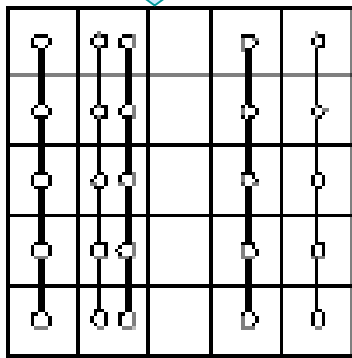
Column-wise restricted 2DW

Monotonic and continuous 2DW

A



B



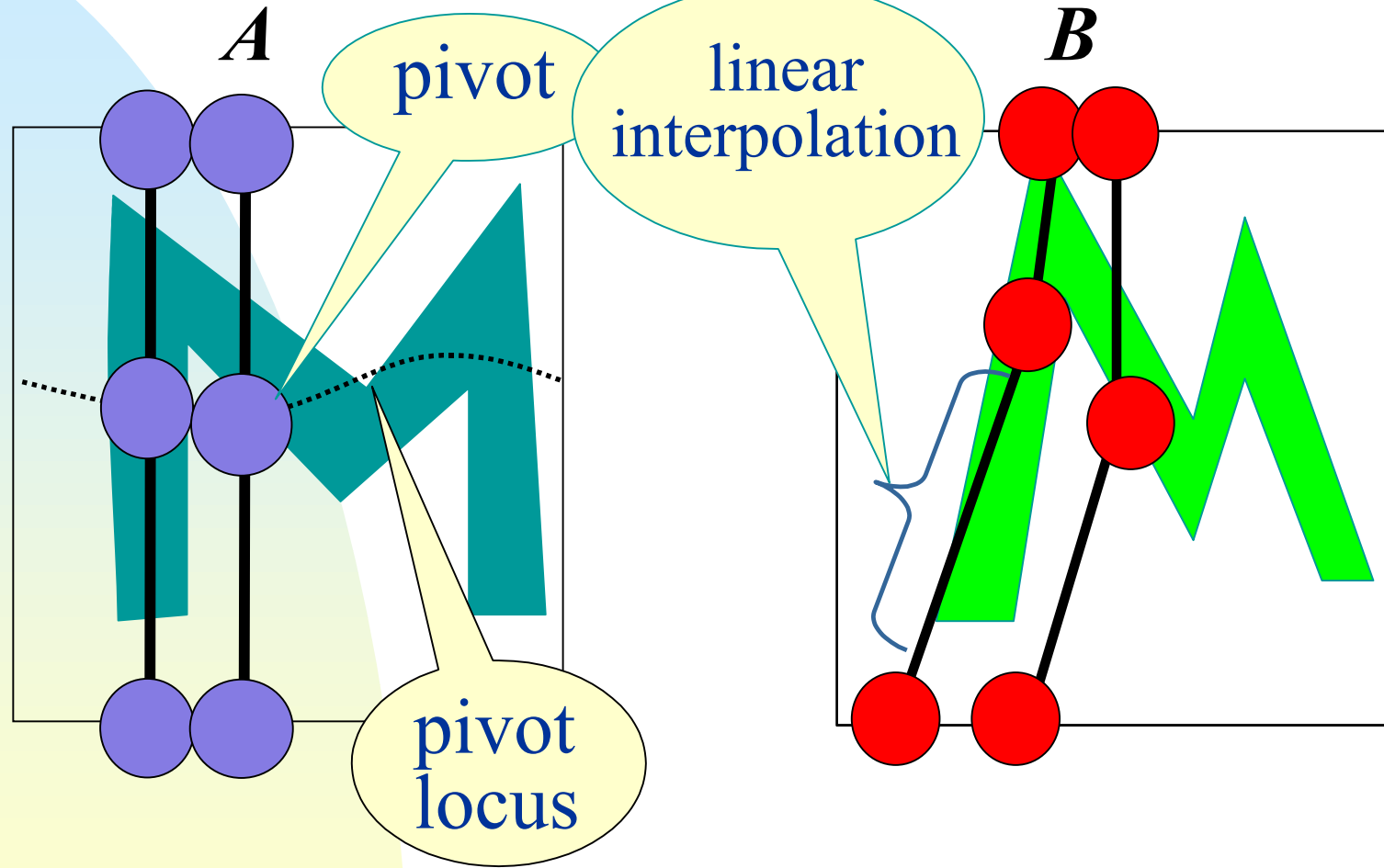
✗ insufficient flexibility

✗ large complexity

4 Objective of the present research

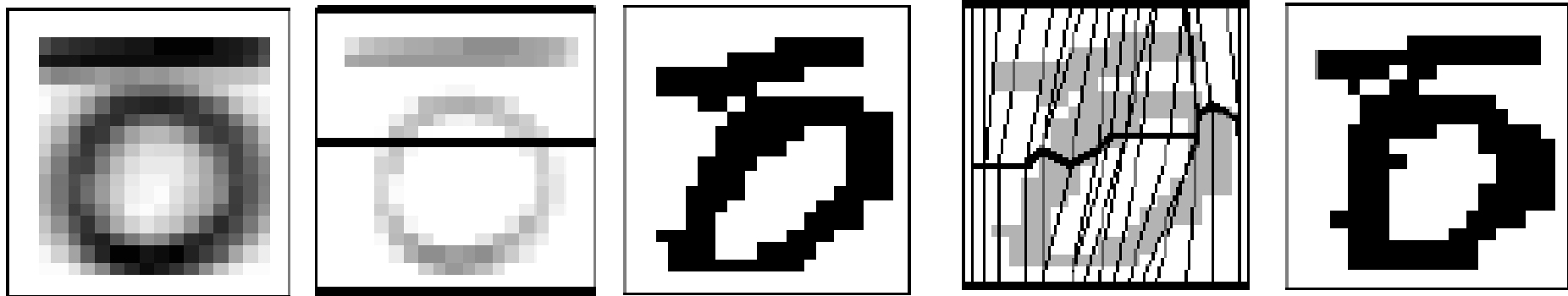
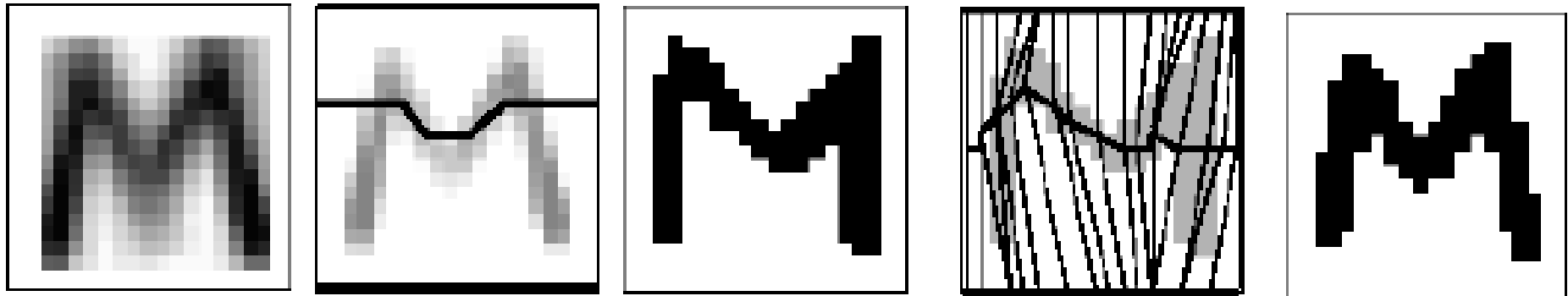
Investigation of piecewise linear 2DW(PL2DW)
in handwritten character recognition

5 Piecewise linear 2-dimensional warping (PL2DW)



Optimization of pivot mapping

6 Examples of matching using PL2DW



reference
A

pivots on
A

input
B

warp on
B

warped
B

given

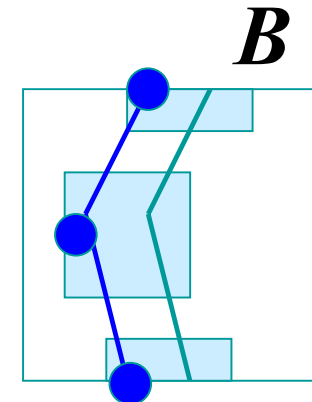
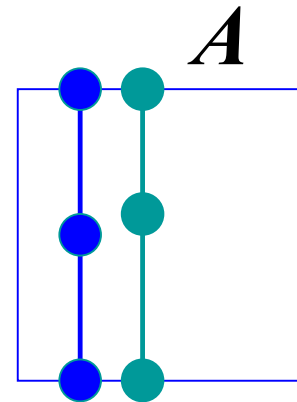
results

7 Constraints on mapping

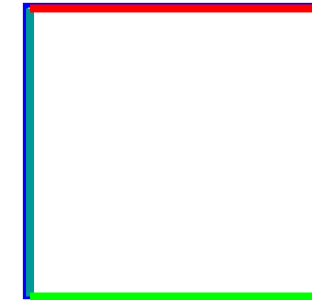
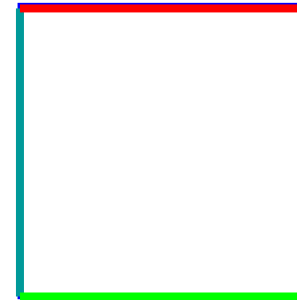
- **Monotonicity and continuity conditions**



Realize isomorphic mapping



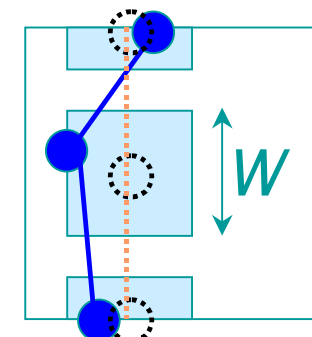
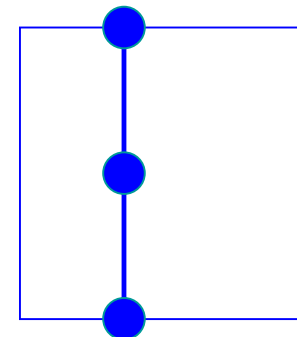
- **Boundary conditions**



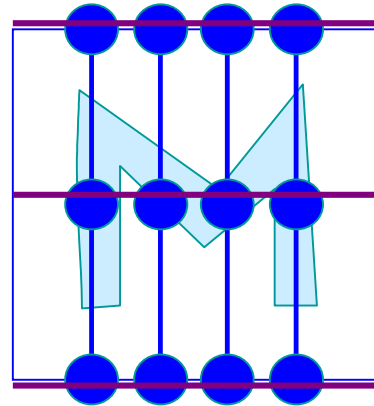
- **Warp range limitation**



Prevents excessive warping

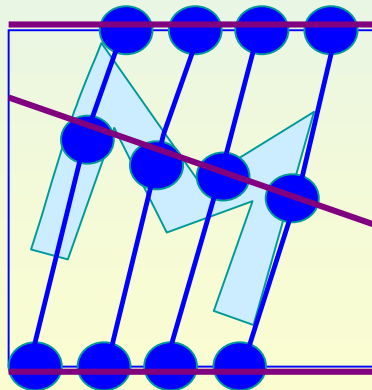


8 Compensation for variations using PL2DW

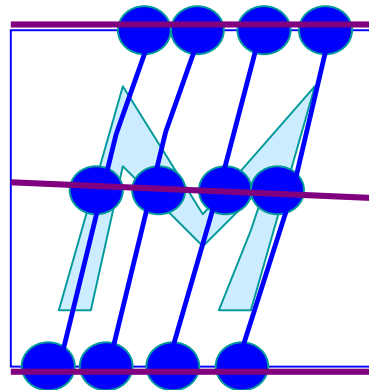


reference

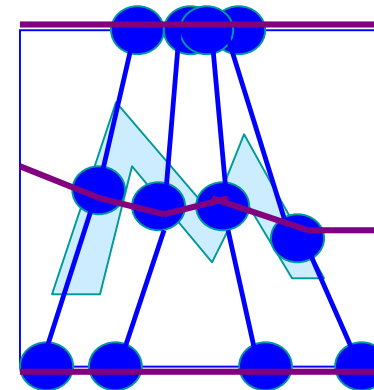
rotation



skewness

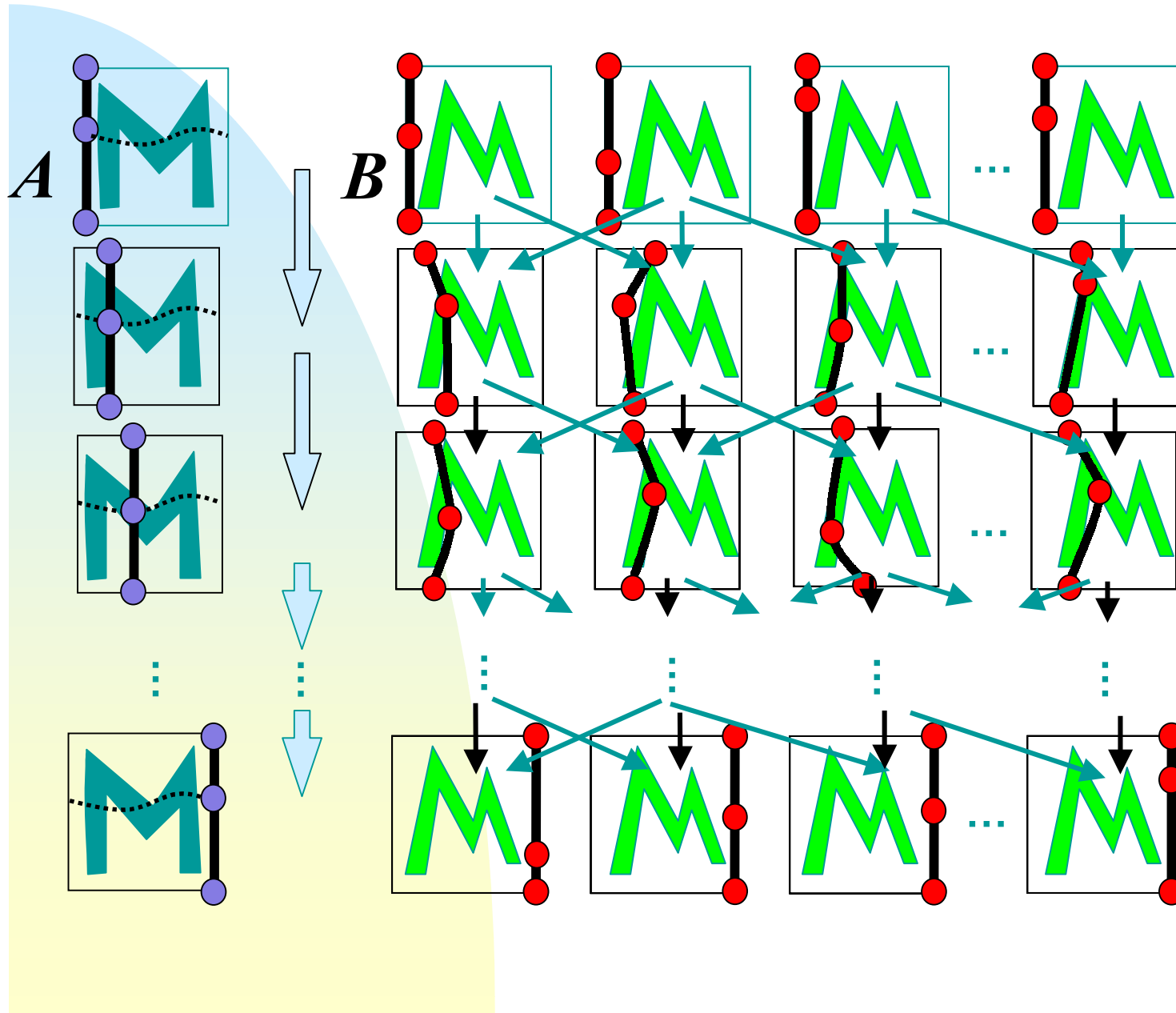


uneven local deformation



input

9 DP Algorithm for PL2DW



2DW optimization problem

Row-wise organization

Best path problem

Efficiently solvable by DP

10 Complexity of the DP algorithm for PL2DW

polynomial order of the image size

Computation time: **130 ms/matching**

(SUN Ultra2, int_95:12.3, fp_95:20.2;

20 × 20 image size)

MC2DW

complexity: **exponential order**, time: 4.26 sec

11 Experimental setup

- Data set:

ETL6 English alphabet
(capital letters)

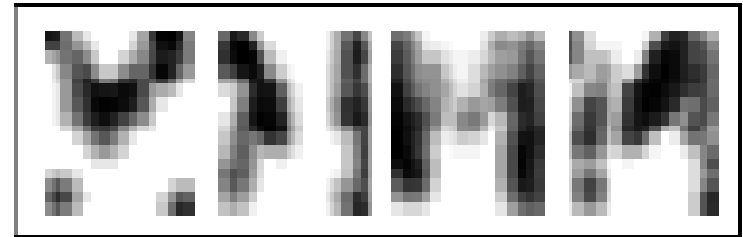
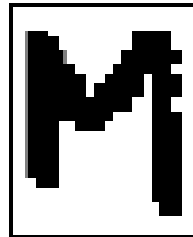
preprocessing

- Image size: 20×20

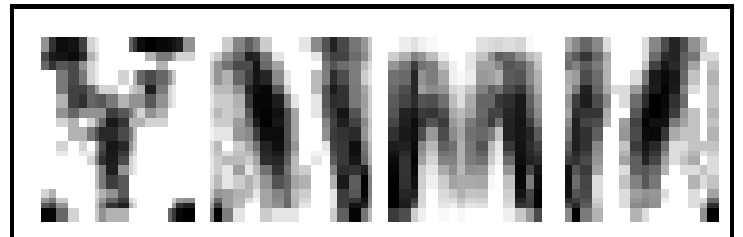
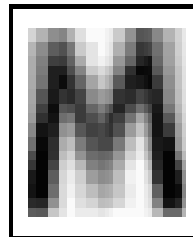
intensity
patterns

directional
patterns

- Input: 25895 samples

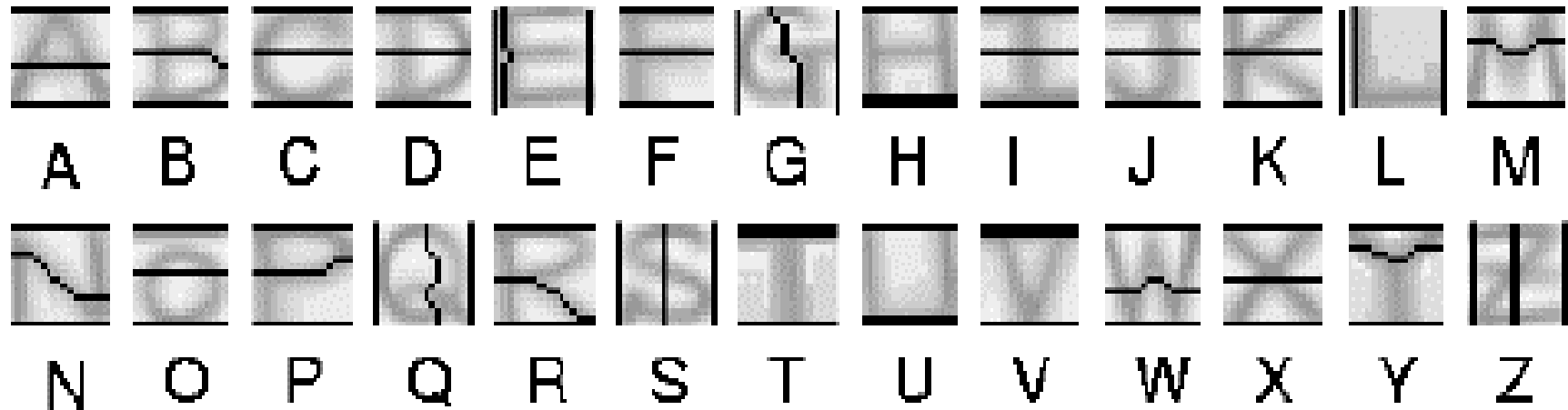


- Reference: average of 100
samples/category



12 Arrangement of pivots

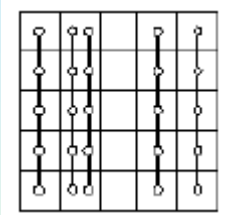
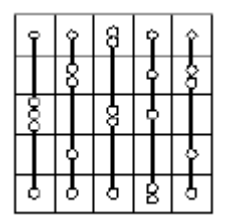
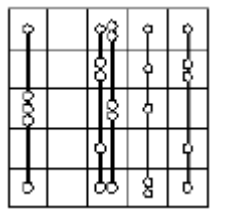
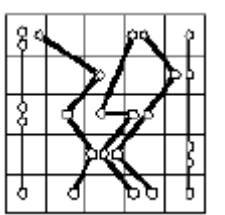
- Artificially arranged
- Layout determined by preliminary experiments



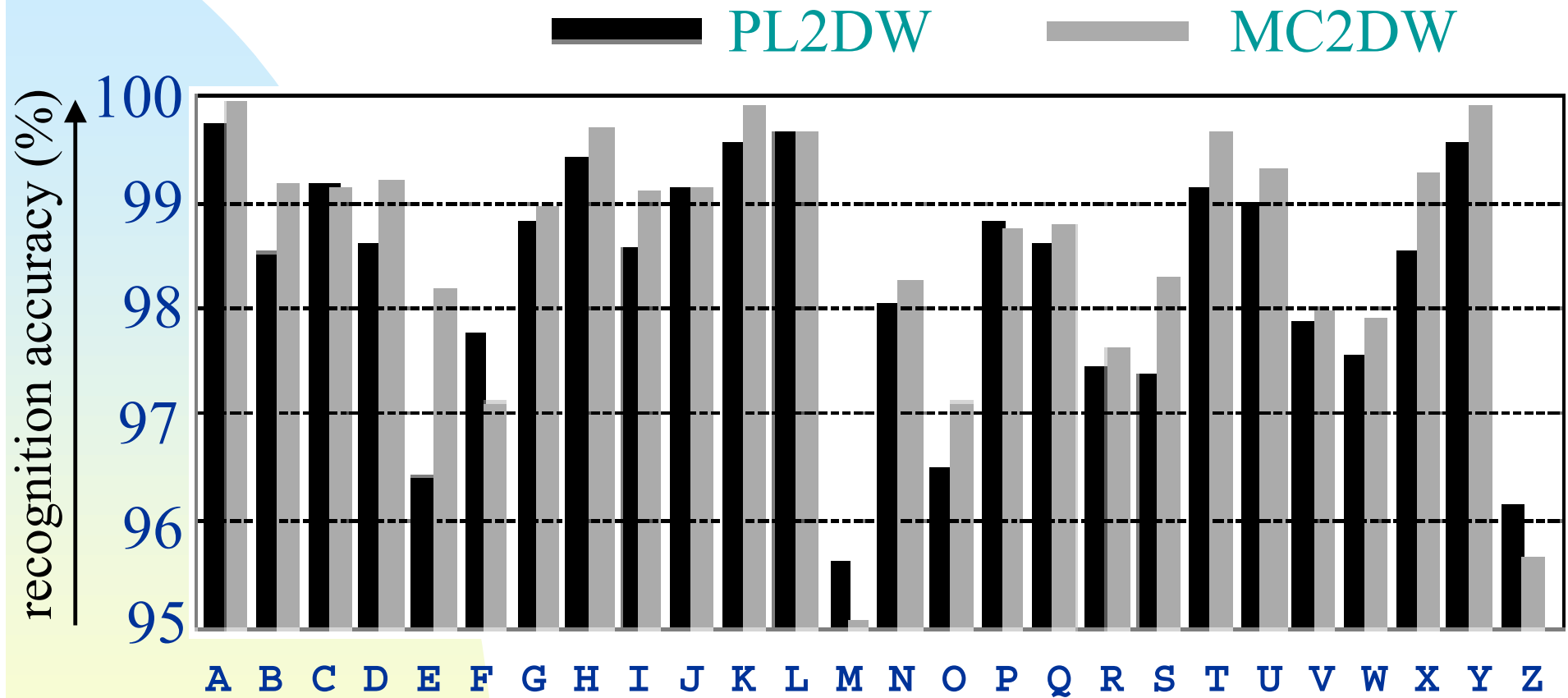
13 Recognition result with PL2DW

warp range w				
0 (template matching)	1	2	3	4
97.4	98.3	98.6	98.3	98.0

14 Comparison with other DP-based 2DW methods

column-wise restricted 2DW			PL2DW	MC2DW
				
97.6	97.5	97.8	98.6	98.9

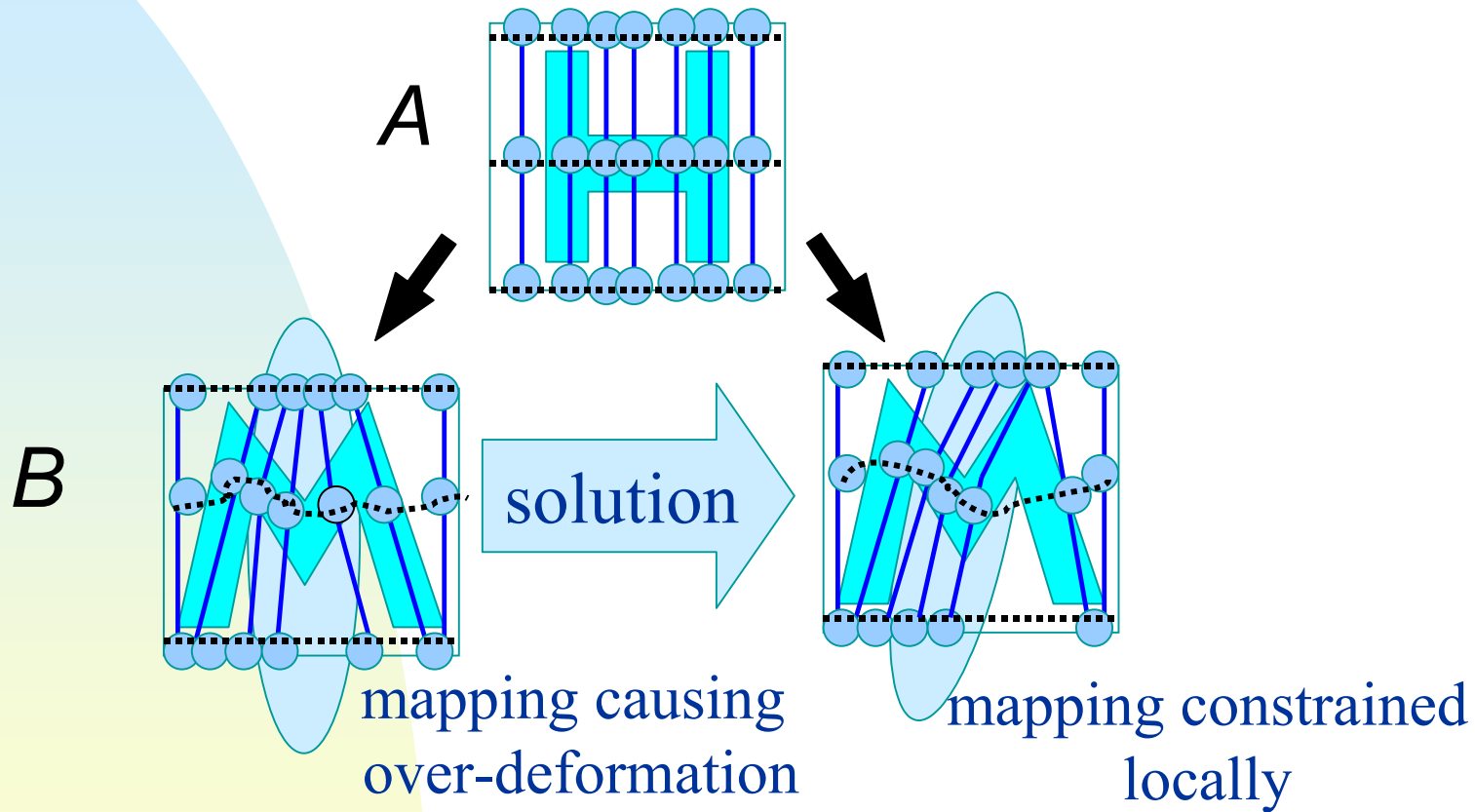
15 Category-wise comparison with MC2DW



16 Error analysis of PL2DW results

over deformation	59%
insufficient matching	41%

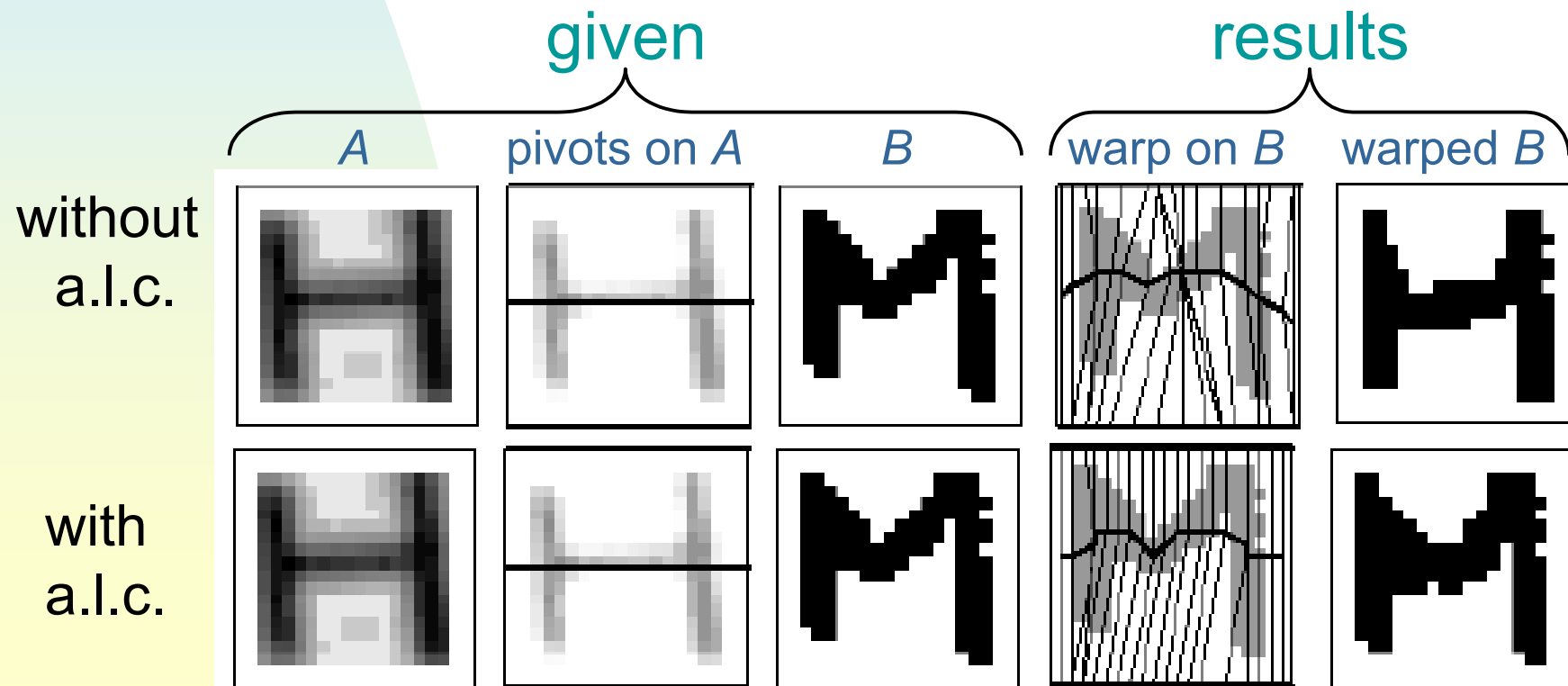
17 Additional local constraints to reduce over-deformations



DP allows to incorporate such constraints

18 Recognition result with Additional local constraints

	recognition rate (%)
without a.l.c.	98.6
with a.l.c.	98.8



19 Conclusion

- The effectiveness of PL2DW in handwritten character recognition is justified experimentally upon comparison with several other DP-based 2DW methods.
- Additional local constraints have been applied successfully to control over-deformations.