

Supplementary Material for NCA-Morph: Medical Image Registration with Neural Cellular Automata

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1 Flow from CNN harms performance

Our default NCA-Morph generates flows directly from its channels, while an alternative involves using an additional CNN layer after the NCA. Different fire rate during inference as shown in Appendix 2 leads to different shifts in the deformation field during both training and inference. Table 1 captures the quantitative results of the flow generation and fire rate variations.

Method	Fire rate	Flow	SSIM \uparrow	$ J_\phi \leq 0 \downarrow$	Dice \uparrow [%]
<i>VoxelMorph</i>	–	CNN	82.84 (1.36)	254217 (20553)	90.82 (1.03)
$NCA_{7 \times 7}^{10}$	25%	NCA	81.67 (1.66)	339712 (33034)	91.65 (1.09)
$NCA_{7 \times 7}^{10}$	50%		82.70 (1.66)	257241 (24826)	92.14 (1.09)
$NCA_{7 \times 7}^{10}$	75%		79.25 (1.48)	170418 (17172)	88.55 (1.37)
$NCA_{7 \times 7}^{10}$	100%		66.65 (1.15)	166 (158)	66.33 (2.59)
$NCA_{7 \times 7}^{*10}$	25%	CNN	64.38 (1.10)	93308 (7070)	61.23 (2.61)
$NCA_{7 \times 7}^{*10}$	50%		82.05 (1.57)	336983 (23095)	91.29 (1.18)
$NCA_{7 \times 7}^{*10}$	75%		65.21 (1.16)	6520 (921)	62.15 (2.61)
$NCA_{7 \times 7}^{*10}$	100%		65.64 (1.16)	0.14 (0.4)	63.12 (2.61)

Table 1: Comparison of the two main variants predicting the flow directly using the NCA or an additional CNN layer, with different fire rates during inference; for every set of experiments the best values are marked bold, whereas number channels is set to 32 and hidden size to 128.

Table 1 demonstrates the superior performance of directly generating the deformation field from the NCA compared to using an additional CNN layer, Appendix Figure 1.

2 Impact of fire rate on deformation field

Figure 1 shows the deformation fields for different variations and visually confirms the results from Table 1 of our main manuscript. The best setup is the NCA-Morph using a 7×7 kernel size with 10 steps, 32 channels, a hidden dimension of 128 using a fire rate of 50%. NCA-Morph with an additional CNN layer to generate flows do not generate meaningful shifts anymore with increasing fire rates which harm the registration performance, Table 1).

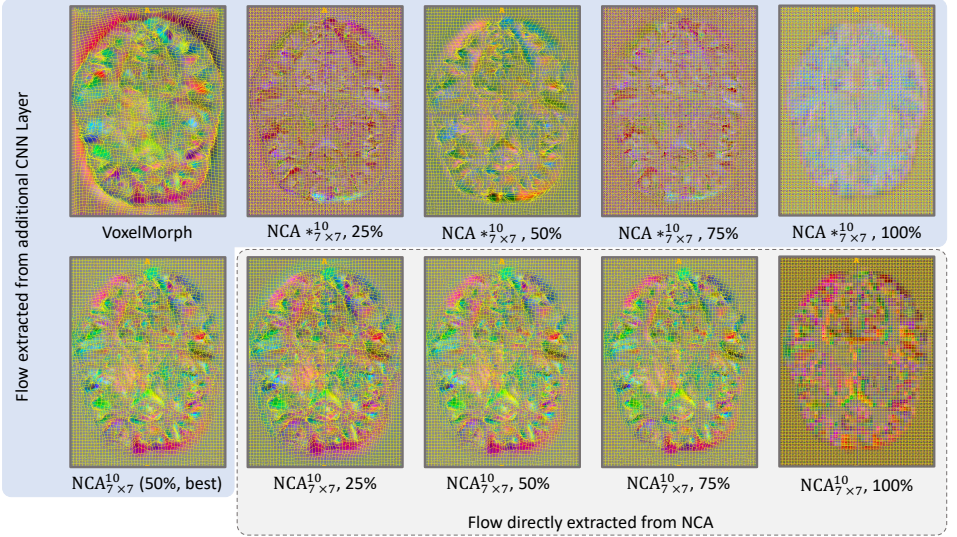


Figure 1: Qualitative analysis of deformation fields for different NCA-Morph variations showing the influence of fire rates on the flow adjustments; Notation: $NCA-Morph_{kernel}^{steps}$ fire rate %.

3 More on Neural Cellular Automata (NCA)

The adaptation of NCAs to a 3D registration problem was done in several steps. First, adapting the NCA from 2D to 3D is fairly straightforward, as the 2D convolution is replaced by a 3D convolution while the internal architecture remains the same. The more difficult problem is that 3D significantly increases the VRAM required for training, which requires further adjustment of the pipeline. We ensure this by performing a downsampling step before applying NCA, followed by another upscaling step. In addition, the pipeline requires careful adaptation of the underlying architecture, as it must be optimized to require as few parameters as possible. We achieve this by drastically simplifying the architecture, ultimately using only a single 3D convolution and very small linear layers. Lastly to enable the optimized architecture to perform registration it has to be integrated into the VoxelMorph training pipeline.