DEEP RECURRENT-CONVOLUTIONAL MODEL FOR AUTOMATED SEGMENTATION OF CRANIOMAXILLOFACIAL CT SCANS

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Motivation

- Craniomaxillofacial malformations due to abnormal development comprise over one-third of all congenital birth defects.
- CT and CBCT are the most common imaging modalities for diagnosis and treatment of CMF disorders.
- Segmentation and Landmarking are the upstream steps for any subsequent clinical evaluation

Motivation

- Challenge of automatically CMF CT segmentation:
  - Multiple structures
  - Irregular and complex shape patterns
  - Lack of contrast in joints
  - Significant morphological variations among different patients

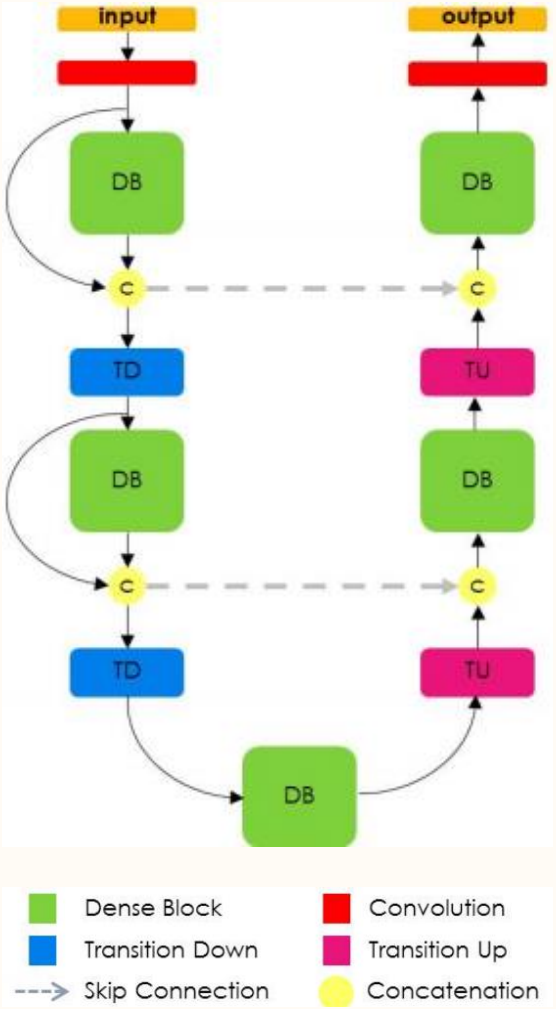
State of the art

- Before DL: atlas-guided methods, with a preliminary registration step
- After DL: Encoder-decoder fully convolutional networks (several variants)

Problems

- Large appearance variability of CMF CT scans
- Limited generalization capabilities

The Tiramisu Network [1]



[1] S. J´egou, M. Drozdzal, D. Vazquez, A. Romero, and Y. Bengio, "The one hundred layers tiramisu: Fully convolutional dense nets for semantic segmentation," in CVPRW 2017. IEEE, 2017, pp. 1175–1183.

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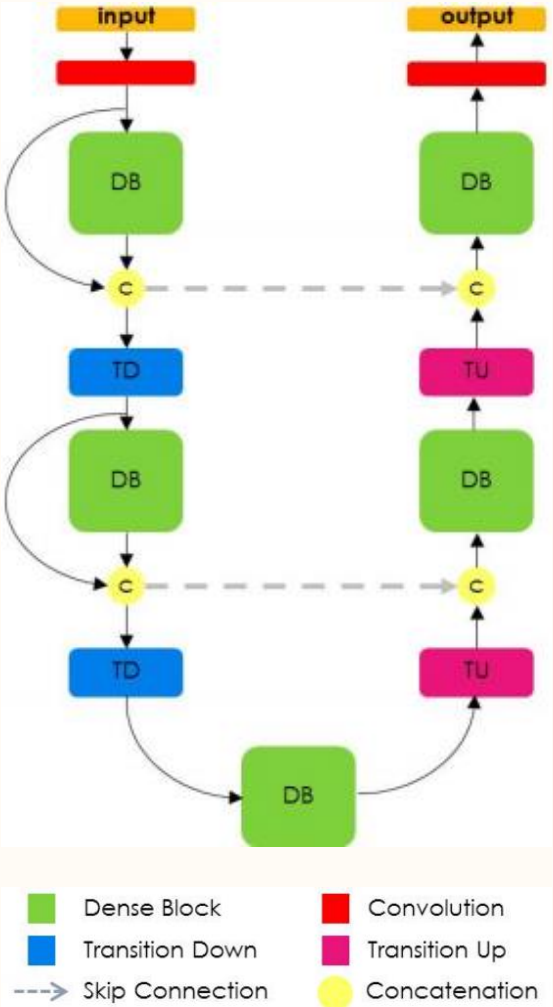

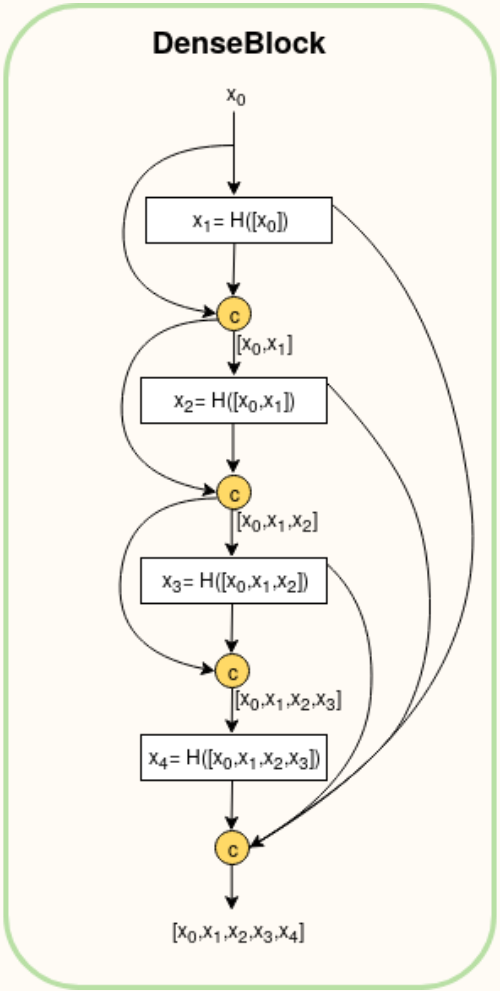

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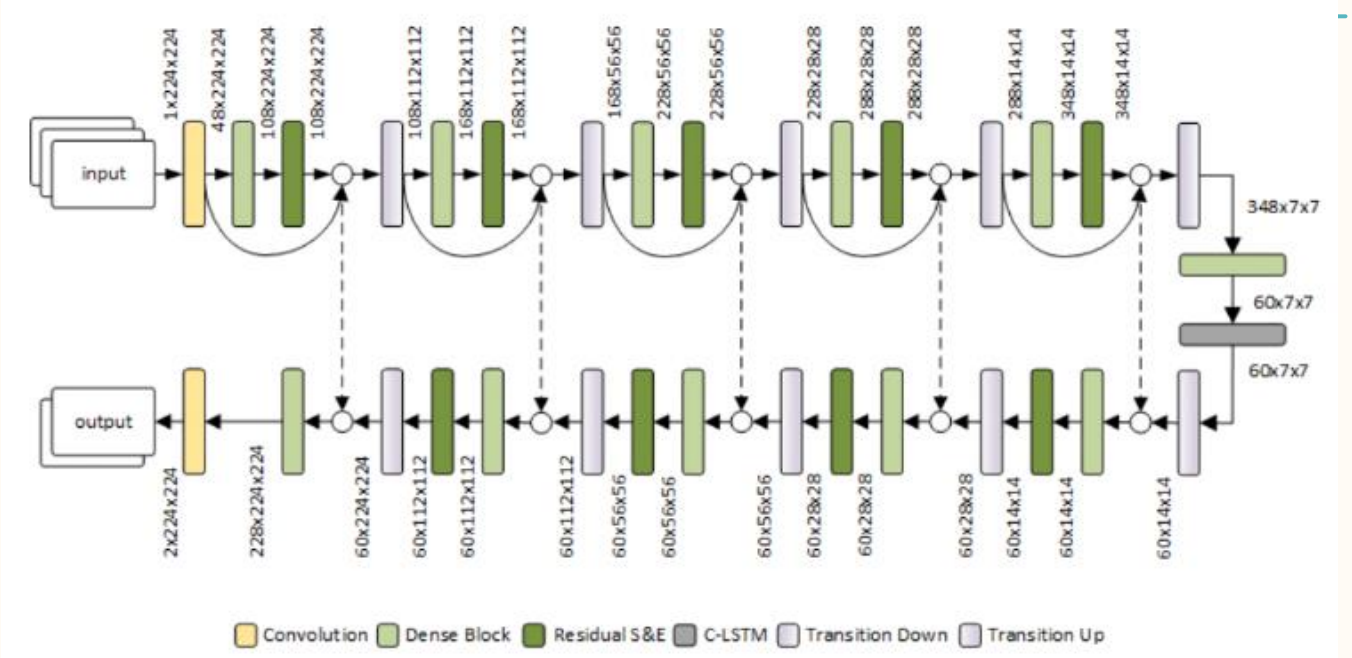
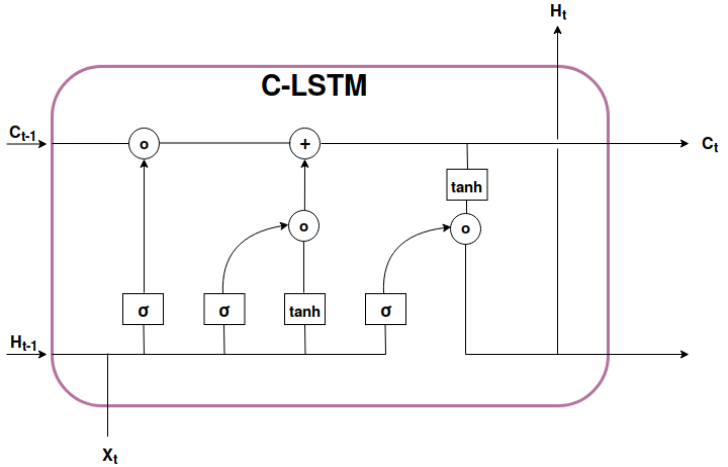
Method

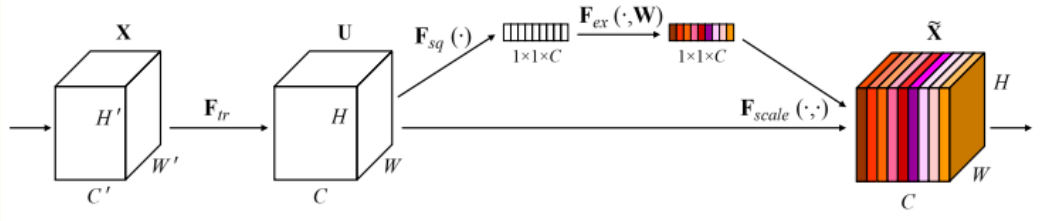
- Fully convolutional DenseNet following U-Net architecture
- C-LSTMs at bottleneck to exploit spatial axial correlation of consecutive scan slices
- Residual squeeze-and-excitation layers to emphasize relevant features and improve representational power

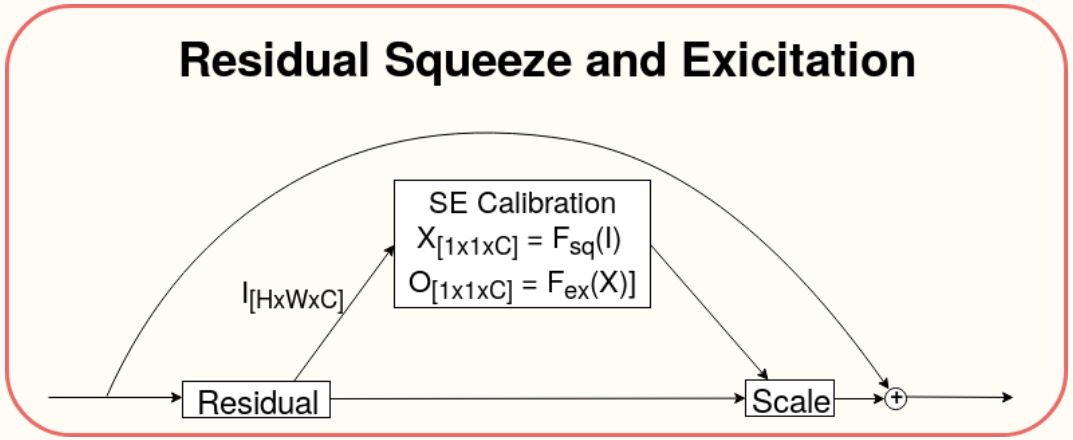


Method

Unidirectional Convolutional LSTM







Squeeze-and-Excitation block [2]

[2] J. Hu, L. Shen, and G. Sun, "Squeeze-and-excitation networks," arXiv preprint arXiv:1709.01507, vol. 7, 2017

Performance Evaluation - Datasets

- **MandibleSet**
  - 32 CT scans and 20 CBCT scans
  - Mandible segmentation
  - Patients with no clinically obvious facial asymmetries and no prior surgery in the head and neck
- **MICCAI Head and Neck 2015 Challenge dataset**
  - CT scans of 48 patients with manual segmentations of several anatomical regions
  - Challenging because of image artifacts and different disease
- **AirwaysSet (proposed in this paper)**
  - Subset of MandibleSets
  - 19 CT scans (one per subject)
  - Nasal cavity and pharyngeal areas segmentation

Performance Evaluation

Metrics

- Dice Similarity coefficient

$$DSC = \frac{2\sum_i^N p_i g_i}{\sum_i^N p_i^2 + \sum_i^N g_i^2}$$

N number of pixels

p_i and g_i output of the model and ground truth at pixel i

Training procedure

- 3 consecutive slices as input processed individually, normalized to 0 mean and unitary standard deviation
- Training for 50 epochs on the MandibleSet and optimized with RMSProp
- Dice Score Coefficient computed on the central slice was used for backpropagation

Performance Evaluation

Model	Pure DL	DSC (%)
3D-UNet [24]	Yes	87.34
Tiramisu [7]	Yes	91.20
Ours	Yes	93.41
Robust segmentation [26]	No, post-processing	91.00
AnatomyNet [3]	No, post-processing	92.50
Best MICCAI 2015 [27]	No, landmark-guided	93.90
Hierarchical Vertex [25]	No, shape prior	94.00

- Performance on MICCAI Head and Neck 2015 Dataset

- DSC performance when fine-tuned(second columns) and trained from scratch on the CBCT part of MandibleSet and on the AirwaysSet

Model	Fine-Tuned (%)	Trained from scratch (%)
	CBCT - Mandible set	
3D-UNet [24]	80.32	73.36
Tiramisu [7]	83.74	76.78
Ours	89.25	80.31
	Airways	
3D-UNet [24]	81.82	77.30
Tiramisu [7]	84.02	80.21
Ours	93.31	85.12

Performance Evaluation

Ablation studies

Model	DSC (%)	
[7]	92.81	Tiramisu Network
Res-SE	95.32	Tiramisu Network + SE
C-LSTM	95.04	Tiramisu Network + C-LSTM
Bi-C-LSTM	94.81	Tiramisu Network + Bi C-LSTM
Res-SE + C-LSTM	96.52	Tiramisu Network + SE + C-LSTM
Res-SE + Bi-C-LSTM	95.03	Tiramisu Network + SE + Bi C-LSTM

Performance Evaluation

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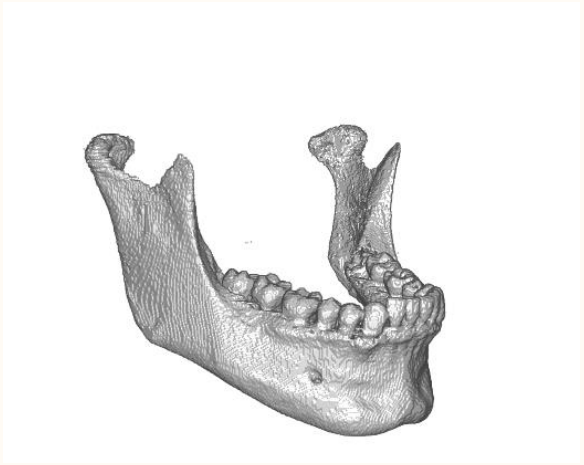
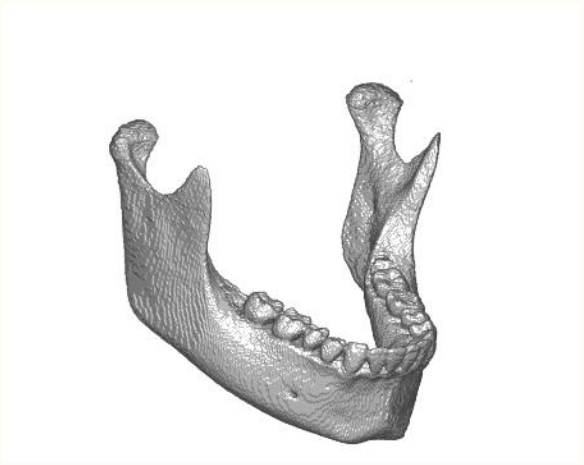
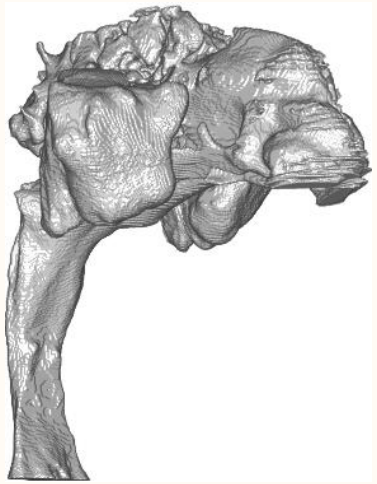
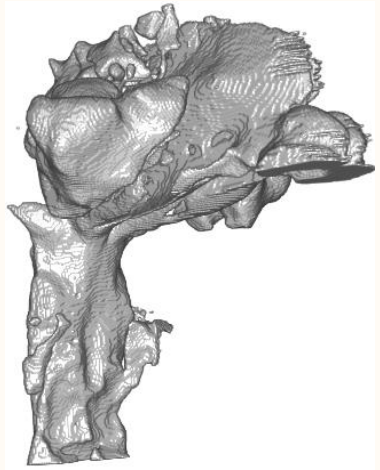
Segmentation examples









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Conclusion

We propose:

- A Deep encoder-decoder network for automated segmentation of CMF structures
  - Improved segmentation performance
  - Enhanced generalization capabilities to multiple CMF structures
- Two new Datasets
  - MandibleSet containing multiple mandible segmentations
  - AirwaysSet containing multiple nasal cavity and pharynges segmentations