

Meta-registration of the EMPIRE10 data set

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Abstract. We propose a meta-algorithm for registration improvement by combining deformable image registrations (MetaReg). It consists of two main components. A strategy for composing an improved registration by combining transformations obtained by different registration algorithms, and a method for regularization of transformations post registration. In order to compare and combine different registrations, MetaReg utilizes a supervised regressor for assessment of local registration quality. We test two interesting meta-registrations employing the three publicly available registration algorithms: ANTS gsyn, NiftyReg, and Elastix. The corresponding evaluation results are listed on the EMPIRE10 website as MetaReg(NifElx) and MetaReg(ANTNifElx).

Keywords: Deformable image registration, meta-registration, combination, meta-algorithm, machine learning, pattern recognition

1 Introduction

Accurate registration of medical images is a key technology to medical image analysis. Many different registration algorithms have been presented in the last decade, yet accurate and reliable image registration remains a challenging task [1]. Within intensity based registration algorithm a distinction is made between parametric (mostly B-Spline based) and non-parametric (mostly variational or optic flow like) algorithms. Both approaches have been shown to perform on average very well and to be versatile as well. Yet both approaches, while being versatile, have disadvantages and yield insufficient results for certain tasks (certain organs, inter-intra-patient or multi-modal registration) and at particular image regions. One way to improve image registration is to develop specialized registration algorithms for each application. That is formulating the core of the registration algorithm to match particular application requirements. We propose another way of improving image registration by combining different algorithms for deformable image registration. Here, we present a refined version of the algorithm we previously proposed in [4].

2 Methods

Note that an extensive description of our method is prepared for a journal publication. For that reason, the following sections only give a brief description of the basic principles of our algorithm.

2.1 Registration

The rationale of our meta-registration framework (MetaReg) is inspired by a well-established method from machine learning, the combination of classifiers. MetaReg composes an improved registration by combining locally superior regions from different base registrations. In order to compare different registrations, MetaReg utilizes a landmark-based supervised regressor for assessment of local registration quality. Based on this assessment, the displacement field is partitioned [4] and a quantitative accuracy estimate is assigned to each partition. Next, a linear weighting scheme is applied to compose a combined registration. Displacement vectors of each base registration are weighted dependent on the accuracy estimated by the regressor. Finally, a post-registration regularization method is employed to revise irregularities that might arise from the local fusion of different transformation sources. The regularization method is based on a fast B-Spline reconstruction scheme [7]. Folding regions are corrected by substituting the field locally by an interpolation from the uncorrupted vicinity of the field.

We employ three (publicly available) deformable image registration methods which differ mainly in following characteristics:

ANTS gsyn [5]: diffeomorphic symmetric transformation, gradient descent optimizer, local normalized cross correlation metric.

NiftyReg [2]: B-Spline transformation with folding correction scheme, conjugate gradient ascent optimizer, approximate normalized mutual information metric.

Elastix [6]: B-Spline transformation, stochastic gradient descent optimizer, local normalized cross correlation metric.

We refer to [5], [2], [6] for further description of the registration method and details about the particular registration settings optimized for lung CT registrations. We conducted registrations accordingly with each registration method.

For the evaluation on the EMPIRE10 data set we test two interesting meta-registrations, denoted by MetaReg(NifElx) and MetaReg(ANTNifElx). In MetaReg(NifElx) we employ the NiftyReg and Elastix algorithms, which perform well on its own, however they are both inferior to the ANTS algorithm wrt lung registration, as indicated by the EMPIRE10 rankings. Because NiftyReg and Elastix employ different similarity measures and different optimizers, there is presumably potential that both algorithms can complement each other in a meta-registration. MetaReg(ANTNifElx) includes the best ranked algorithm and it is therefore interesting to evaluate whether the proposed meta-registration method can maintain or further improve the registration accuracy achieved by ANTS.

2.2 Supervised regression

A non-parametric regression method is employed to automatically assess and compare registrations locally. The method is based on supervised learning of local alignment patterns, which are captured by statistical image features at automatically detected landmarks [3]. Similar to [3], we employ a set of features consisting of Gaussian, correlation, entropy, texture, position, and deformation related measures. For the EMPRIE10 challenge, we trained the regressor on a set of pulmonary CT scan pairs from a lung cancer screening database [8]. Five breath-hold inspiration-expiration scan pairs and five follow-up scan pairs were chosen randomly.

2.3 Transformation

The transformations generated by MetaReg contain deformation characteristics of all base registrations, varying locally dependent on the weight with which each base registration contributes to a particular image region. The post-registration regularization method ensures bijective, folding-free transformations. Further, the smoothness of a transformation can be controlled by selecting a particular order of B-Spline in the post-registration regularization method.

2.4 Similarity measure

ANTs gsyn and Elastix employ the normalized cross correlation metric locally, i.e. compute the metric on image regions. NiftyReg employs an approximated mutual information metric, measured globally. Moreover, the MetaReg algorithm is steered by the supervised regression which includes a variety of multi-scale measures.

2.5 Lung masks

The provided lung segmentation were employed in all base registrations, in the feature extraction process, and in the post-registration regularization.

2.6 Computation times

The proposed MetaReg framework in the first place aims to improve registration accuracy. Minimization of computation times was not in the scope of this work, and the implementation has not been explicitly optimized for speed. On a PC with an Intel Core 2 Quad CPU (2.66GHz) and 8GB RAM, one meta-registration took on average about 70 minutes, in addition to the time required to compute the base registrations.

3 Results & Discussion

The evaluation results of the meta-registrations (ANTNifElx and NifElx) are shown in Tables 1, 2, and Tables 3, 4, 5 show the evaluation results of the base registrations employed in MetaReg. The rankings and final placements are from a total of 32 competing algorithms (April, 30, 2013).

The EMPIRE10 evaluation results show that MetaReg could generate combined registrations that are superior to any single one of the employed base registrations. However, the registration results of ANTS, NiftyReg, and Elastix reported previously on EMPIRE10 are slightly different from the results obtained in our experiments, although we tried to emulate these results by choosing parameter settings and registration setups as described in [5,2,6]. This difference in the base registrations explains the inferior ranking of MetaReg(ANTNifElx) compared to the originally reported ANTS results (picsl gsyn).

Scan Pair	Lung Boundaries		Fissures		Landmarks		Singularities	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
01	0.01	16.00	0.01	9.00	1.08	1.00	0.00	10.50
02	0.00	11.00	0.00	12.50	0.34	4.00	0.00	12.50
03	0.00	7.00	0.00	11.50	0.32	5.00	0.00	13.00
04	0.00	12.00	0.00	14.00	1.00	12.00	0.00	12.50
05	0.00	12.00	0.00	13.50	0.00	11.00	0.00	12.00
06	0.00	13.50	0.00	13.00	0.27	6.00	0.00	14.00
07	0.00	12.00	0.73	10.00	0.96	2.00	0.00	9.50
08	0.00	4.50	0.00	6.50	0.59	6.00	0.00	12.50
09	0.00	2.00	0.00	22.00	0.46	1.00	0.00	12.00
10	0.00	7.00	0.00	13.00	1.27	11.00	0.00	12.00
11	0.00	4.00	0.00	5.00	0.56	3.00	0.00	11.50
12	0.00	11.00	0.00	11.00	0.00	3.00	0.00	13.50
13	0.00	4.00	0.06	8.00	0.71	1.00	0.00	12.00
14	0.00	6.00	1.48	5.00	1.02	4.00	0.00	7.50
15	0.00	7.00	0.03	24.00	0.58	2.00	0.00	12.50
16	0.00	9.00	0.00	5.00	0.76	3.00	0.00	13.00
17	0.00	8.00	0.06	25.50	0.62	2.00	0.00	12.50
18	0.00	12.00	0.07	3.00	0.85	1.00	0.00	9.50
19	0.00	14.00	0.00	10.50	0.42	4.00	0.00	12.50
20	0.00	11.00	0.58	3.00	0.95	3.00	0.00	10.00
21	0.01	16.00	0.26	4.00	1.25	3.00	0.00	9.50
22	0.00	10.00	0.00	13.00	0.70	1.00	0.00	12.00
23	0.00	8.00	0.05	9.50	0.60	3.00	0.00	12.50
24	0.00	8.00	0.00	11.00	0.76	5.00	0.00	12.00
25	0.00	12.00	0.00	12.50	0.00	1.50	0.00	11.50
26	0.00	8.00	0.00	7.50	0.31	6.00	0.00	13.50
27	0.00	6.00	0.00	4.00	0.34	1.00	0.00	13.00
28	0.00	6.00	1.98	7.00	1.34	4.00	0.00	11.00
29	0.00	4.50	0.00	11.50	0.95	9.00	0.00	12.00
30	0.00	12.50	0.00	11.00	0.00	3.00	0.00	13.00
Avg	0.00	9.13	0.17	10.53	0.63	4.05	0.00	11.83
Average Ranking Overall								8.88
Final Placement								3

Table 1. MetaReg(ANTNifElx). Results for each scan pair, per category and overall. Rankings and final placement are from a total of 32 competing algorithms.

Scan Pair	Lung Boundaries		Fissures		Landmarks		Singularities	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
01	0.00	9.00	0.01	8.00	1.21	4.00	0.00	11.50
02	0.00	12.50	0.00	13.50	0.35	6.00	0.00	13.50
03	0.00	7.50	0.00	12.50	0.35	16.00	0.00	14.00
04	0.00	12.00	0.00	15.50	1.15	16.00	0.00	13.50
05	0.00	13.00	0.00	14.50	0.01	11.50	0.00	13.50
06	0.00	14.50	0.00	14.50	0.21	1.00	0.00	15.00
07	0.00	9.00	1.47	21.00	1.37	7.00	0.00	10.50
08	0.00	5.00	0.02	14.00	0.61	7.00	0.00	13.50
09	0.00	8.00	0.01	25.00	0.53	10.00	0.00	13.00
10	0.00	15.00	0.00	14.00	1.39	13.00	0.00	13.50
11	0.00	7.00	0.02	13.00	0.61	4.00	0.00	12.50
12	0.00	12.00	0.00	12.00	0.00	3.50	0.00	15.00
13	0.00	22.00	0.08	13.00	0.72	3.00	0.00	13.00
14	0.01	11.00	3.27	18.00	1.10	6.00	0.00	8.50
15	0.00	8.00	0.04	26.00	0.62	10.00	0.00	13.50
16	0.00	17.00	0.03	12.00	0.87	8.00	0.00	14.50
17	0.00	8.50	0.05	12.50	0.75	12.00	0.00	14.00
18	0.00	7.00	1.00	13.00	1.14	5.00	0.00	10.50
19	0.00	15.00	0.00	11.00	0.44	6.00	0.00	13.50
20	0.00	5.50	1.04	10.00	1.05	6.00	0.00	11.00
21	0.00	9.00	0.37	7.00	1.41	6.00	0.00	10.50
22	0.00	5.00	0.01	20.00	0.71	1.00	0.00	13.00
23	0.00	9.00	0.00	3.00	0.70	11.00	0.00	14.00
24	0.00	11.00	0.00	12.00	0.94	14.00	0.00	13.50
25	0.00	13.00	0.00	13.50	0.00	2.00	0.00	12.50
26	0.00	9.00	0.00	8.00	0.32	7.00	0.00	15.00
27	0.00	6.50	0.00	9.50	0.37	4.00	0.00	14.00
28	0.00	12.00	2.59	11.00	1.79	9.00	0.00	12.00
29	0.00	5.00	0.00	12.50	1.05	14.00	0.00	13.00
30	0.00	13.50	0.00	12.00	0.00	3.50	0.00	14.00
Avg	0.00	10.38	0.33	13.38	0.73	7.55	0.00	12.97
Average Ranking Overall								11.07
Final Placement								6

Table 2. MetaReg(NifElx). Results for each scan pair, per category and overall. Rankings and final placement are from a total of 32 competing algorithms.

Scan Pair	Lung Boundaries		Fissures		Landmarks		Singularities	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
01	0.16	27.00	0.14	16.00	1.44	9.00	0.00	12.00
02	0.00	12.50	0.00	14.00	0.37	11.00	0.00	13.00
03	0.00	8.00	0.00	13.00	0.29	1.00	0.00	14.00
04	0.00	4.00	0.00	15.00	0.84	6.00	0.00	13.50
05	0.00	13.00	0.00	15.00	0.00	6.50	0.00	13.00
06	0.00	14.50	0.00	5.50	0.29	8.00	0.00	15.00
07	0.00	5.00	0.17	4.00	1.14	3.00	0.00	10.00
08	0.01	25.00	0.00	8.00	0.61	7.00	0.00	13.50
09	0.00	2.00	0.00	7.50	0.50	3.00	0.00	12.50
10	0.00	2.50	0.00	14.50	1.99	17.00	0.00	24.00
11	0.04	21.00	0.01	9.00	0.70	10.00	0.00	12.00
12	0.00	26.00	0.00	26.00	0.00	4.00	0.00	14.50
13	0.00	4.50	0.06	6.00	0.76	6.00	0.00	12.50
14	0.00	5.00	1.00	3.00	1.80	10.00	0.00	17.00
15	0.00	8.00	0.00	7.00	0.62	11.00	0.00	13.50
16	0.00	4.50	0.00	3.00	0.91	8.00	0.00	13.50
17	0.00	8.50	0.07	28.00	0.61	3.00	0.00	13.50
18	0.00	5.00	0.04	2.00	1.10	4.00	0.00	20.00
19	0.00	15.00	0.00	11.50	0.45	9.00	0.00	13.00
20	0.00	20.00	0.31	3.00	1.02	5.00	0.00	11.50
21	0.11	23.00	0.25	4.00	1.27	4.00	0.00	11.00
22	0.00	13.00	0.00	6.50	0.75	3.00	0.00	12.50
23	0.00	9.00	0.03	8.50	0.71	12.00	0.00	13.50
24	0.00	7.00	0.00	12.00	0.74	6.00	0.00	13.00
25	0.00	13.50	0.00	14.00	0.01	7.00	0.00	12.00
26	0.00	9.00	0.00	7.50	0.34	8.00	0.00	14.50
27	0.00	7.50	0.00	4.50	0.38	5.00	0.00	14.00
28	0.03	24.00	1.57	6.00	1.56	7.00	0.00	12.00
29	0.00	5.50	0.00	13.00	1.20	18.00	0.00	13.00
30	0.00	26.00	0.00	12.50	0.00	4.00	0.00	14.00
Avg	0.01	12.28	0.12	9.98	0.75	7.18	0.00	13.70
Average Ranking Overall								10.79
Final Placement								5

Table 3. ANTS registrations. Results for each scan pair, per category and overall. Rankings and final placement are from a total of 32 competing algorithms.

Scan Pair	Lung Boundaries		Fissures		Landmarks		Singularities	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
01	0.00	4.00	0.01	10.00	1.33	6.00	0.00	12.00
02	0.00	12.50	0.00	14.00	0.43	16.00	0.00	13.00
03	0.00	8.00	0.00	13.00	0.43	19.00	0.00	14.00
04	0.00	14.00	0.00	15.00	1.85	21.00	0.00	13.50
05	0.00	13.00	0.00	15.00	0.09	19.00	0.00	13.00
06	0.00	14.50	0.01	27.00	0.28	7.00	0.00	15.00
07	0.00	2.50	1.88	23.00	1.41	8.00	0.00	10.00
08	0.00	5.50	0.02	14.00	0.77	14.00	0.00	13.50
09	0.00	2.00	0.05	27.00	0.56	17.00	0.00	12.50
10	0.00	15.00	0.00	14.50	2.20	18.00	0.00	12.00
11	0.00	8.00	0.02	14.00	0.97	15.00	0.00	12.00
12	0.00	22.00	0.00	12.00	0.06	15.00	0.00	14.50
13	0.00	10.00	0.08	16.00	0.65	1.00	0.00	12.50
14	0.54	30.00	4.00	20.00	1.44	6.00	0.00	8.00
15	0.00	8.00	0.03	27.00	0.65	19.00	0.00	13.50
16	0.00	14.00	0.01	8.50	1.01	13.00	0.00	13.50
17	0.00	8.50	0.05	12.50	0.60	1.00	0.00	13.50
18	0.00	2.00	0.51	11.00	1.24	6.00	0.00	10.00
19	0.00	15.00	0.00	24.50	0.48	16.00	0.00	13.00
20	0.00	6.00	1.06	10.00	1.07	8.00	0.00	11.50
21	0.00	4.00	0.85	15.00	1.59	7.00	0.00	11.00
22	0.00	1.50	0.03	22.00	0.81	9.00	0.00	12.50
23	0.00	9.00	0.10	16.50	0.64	6.00	0.00	13.50
24	0.00	17.00	0.00	12.00	1.06	17.00	0.00	13.00
25	0.00	13.50	0.00	14.00	0.15	18.00	0.00	12.00
26	0.00	9.00	0.00	7.50	0.45	16.00	0.00	14.50
27	0.00	7.50	0.00	21.00	0.39	9.00	0.00	14.00
28	0.00	6.00	2.70	11.00	3.17	21.00	0.00	12.00
29	0.00	5.50	0.00	13.00	1.16	17.00	0.00	13.00
30	0.00	13.00	0.00	12.50	0.09	13.00	0.00	14.00
Avg	0.02	10.02	0.38	15.75	0.90	12.60	0.00	12.67
Average Ranking Overall								12.76
Final Placement								11

Table 4. NiftyReg registrations. Results for each scan pair, per category and overall. Rankings and final placement are from a total of 32 competing algorithms.

Scan Pair	Lung Boundaries		Fissures		Landmarks		Singularities	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
01	0.00	9.00	0.02	11.00	1.87	12.00	0.00	12.00
02	0.00	12.50	0.00	14.00	0.31	1.00	0.00	27.00
03	0.00	17.00	0.00	13.00	0.34	12.00	0.00	14.00
04	0.00	17.00	0.00	15.00	0.75	3.00	0.00	13.50
05	0.00	13.00	0.00	15.00	0.00	6.50	0.00	13.00
06	0.00	14.50	0.00	5.50	0.32	12.00	0.00	15.00
07	0.00	9.00	1.01	18.00	2.20	17.00	0.02	26.00
08	0.00	5.50	0.27	20.00	0.65	8.00	0.00	13.50
09	0.00	17.00	0.00	7.50	0.56	16.00	0.00	26.00
10	0.00	18.00	0.00	14.50	1.00	6.00	0.00	26.00
11	0.00	5.00	0.11	19.00	0.70	11.00	0.01	27.00
12	0.00	11.00	0.00	12.00	0.00	4.00	0.00	14.50
13	0.00	22.00	0.08	15.00	0.94	16.00	0.23	31.00
14	0.00	11.00	4.57	22.00	1.55	7.00	0.01	23.00
15	0.00	17.00	0.00	7.00	0.62	9.00	0.00	13.50
16	0.00	24.00	0.02	13.00	0.86	7.00	0.01	27.00
17	0.00	24.00	0.06	19.50	0.73	12.00	0.00	13.50
18	0.00	8.00	1.81	17.00	1.89	12.00	0.00	10.00
19	0.00	15.00	0.00	11.50	0.41	3.00	0.00	28.00
20	0.00	6.00	1.98	16.00	1.85	16.00	0.00	11.50
21	0.00	10.00	0.32	7.00	1.40	6.00	0.00	11.00
22	0.00	7.00	0.00	6.50	0.78	8.00	0.00	25.00
23	0.00	24.00	0.00	3.00	0.63	5.00	0.00	13.50
24	0.00	10.00	0.00	12.00	0.61	2.00	0.00	13.00
25	0.00	13.50	0.00	14.00	0.00	2.00	0.01	29.00
26	0.00	9.00	0.00	14.50	0.22	1.00	0.00	14.50
27	0.00	7.50	0.00	13.00	0.39	7.00	0.00	14.00
28	0.00	13.00	3.67	17.00	2.18	13.00	0.00	12.00
29	0.00	18.00	0.00	13.00	0.76	3.00	0.00	13.00
30	0.00	13.00	0.00	12.50	0.00	4.00	0.00	14.00
Avg	0.00	13.35	0.46	13.27	0.82	8.05	0.01	18.13
Average Ranking Overall								13.20
Final Placement								13

Table 5. Elastix registrations. Results for each scan pair, per category and overall. Rankings and final placement are from a total of 32 competing algorithms.

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