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FRAMEWORK FOR REPORTING NON-RIGID IMAGE REGISTRATION

PERFORMANCE

by

Halim Choi

A thesis submitted in partial fulfillment of the
requirements for the Master of Science
degree in Electrical and Computer Engineering
in the Graduate College of
The University of Iowa

July 2011

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CERTIFICATE OF APPROVAL

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MASTER'S THESIS

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This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the
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CHAPTER 1
INTRODUCTION

1.1 Motivation and Background

Image registration is the process of geometrically aligning two or more images of same scene taken different times, different viewpoints and/or different sensors and finding the correspondence between them [16]. Image registration is used in many medical fields such as multi-modality fusion, image segmentation, deformable atlas registration, functional brain mapping, image guided surgery, and measuring growth and modeling motion.

Various attempts have been made to study image registration algorithms, but in practice obtaining perfect image registration is impossible due to lack of information, discretized approximation of the continuous transformation, limited degree of freedom of the deformation model, etc [6]. Rigid and affine algorithm is used widely. Non-rigid image registration algorithms are more general but require more complex methodology and computational effort to implement.

Evaluating non-image registration performance is a difficult task since there is no Gold Standard to evaluate image registration algorithm[3], so increasing number of research is developing evaluation database and statistics for image registration algorithms. One of the research groups for image registration evaluation is Retrospective Image Registration and Evaluation Project (http://www.insight-journal.org/rire/) led by J. Michael Fitzpatrick of Vanderbilt University for evaluating multi-modality

rigid registration accuracy [7, 20]. This project involved 11 groups applying 15 different rigid image registration algorithms to selected registration tasks. The registration algorithms were evaluated using the target registration error which is the Euclidean distance of each registration point.

Another non-rigid registration evaluation project is Retrospective Evaluation of inter-subject brain registration led by Christian Barillot of IRISA/INRIA-CNRS Rennes, France evaluate 6 registration algorithms (1 rigid algorithm and 5 non rigid algorithms) using 18 brain image volumes. The evaluation statistics used were divided to global measures and local measures. Global measures are average volume which is mean volume by averaging the 17 deformed subjects, overlap of gray and white matter, correlation of L, and consistency of the deformation field using Jacobian. Local measurement is distance between sulci and statistical study of deformed shape. People around the world participated in this projects by registering the images with their own registration algorithms and sending the resulting transformations back to the home site for analysis [9].

In 2009, Klein et al. evaluated 14 non-rigid and one rigid image registration algorithms on 80 brain MRIs. The project measures eight different error to evaluate algorithms: target, mean and union volume overlap measures, target, mean and union surface overlap measures, volume similarity and distance error. The authors noted the average runtime, degrees of freedom and year developed for each algorithm.

The recent study is empire10 (http://empire10.isi.uu.nl/) organised by Keelin Murphy et al. [12, 18, 17, 11]. This website is to validate and evaluate image regis-

tration algorithms. Every participants for this study use their own image registration algorithm using 20 scan pair of lung CT image and submit their results, then empire study team evaluate each algorithms and show in the website. In this study 4 kinds of evaluation are used: (1) Alignment of lung boundaries. Statistic of this measurement is how well lung boundary agree to scan pairs after registration using points around lung boundary. Alignment of lung boundary is calculated as the percentage of checked points for disagreed; (2) Alignment of major fissures. This statistic measures how well major fissures of lung align using checked points around lung fissures; (3) Correspondence of annotated landmark pairs. The statistic measures the Euclidean distance between defined landmark points in fixed image and in deformed image and target image [11, 13]; (4) Singularities in the deformation field. This statistic measures the determinant of the Jacobian of the deformation field. Using landmark points in lung volume, the determinant of the Jacobian of the deformation field is calculated at each points.

Besides these image registration website, there are important validation/evaluation projects. First, the VALMET software tool for assessing and improving 2D and 3D object segmentation was developed by Guido Gerig et al. (www.ia.unc.edu/public/valmet/). The VALMET software was the first publicly available software tool for measuring and visualizing the differences between multiple corresponding medical image segmentations. It includes four algorithms for comparing segmentations: overlap ratio, Haussdorf distance, surface distance, and probabilistic overlap. Another project is the ANTs software tool which consists of a suite of state-of-the-art image registration,

segmentation and template building tools for quantitative morphometric analysis developed by Brian B. Avants et al. (www.picsl.upenn.edu/ANTS/) [3].

The Non-rigid Image Registration Evaluation Project (NIREP) was started to develop a standardized set of common databases, evaluation statistics and software tool for evaluating non-rigid image registration algorithms [6]. The central NIREP website (www.nirep.org) provides a place for image registration evaluations and reasonably fair comparison of available registration algorithms for its application and also place to download NIREP evaluation database and NIREP software.

With NIREP software, users can evaluate the performance of different non-rigid registration algorithms on NIREP evaluation database, so they can make an informed decision regarding the best algorithm for their specific application. it will incorporate both qualitative and quantitative methods to evaluation registration performance. The goal of the work in this paper is to build evaluation result database for both saving the results to analyze their results, and comparing algorithms to know the best algorithm. The results and analysis will be disseminated through publications and a NIREP website.

1.2   Outline

This thesis consists the following parts. Chapter 2 describes the NIREP framework and the result data flow, the evaluation methods and the way database are created and the way results are statistically summarized, and Chapter 3 describes evaluation results with database and the visualization on the NIREP website. Chapter 4 discusses and analyzed the evaluation results obtained from this work. Chapter

5 summarizes this thesis work. Finally, chapter 6 states some problems encountered and explores future extensions.

CHAPTER 2
METHODS

2.1 NIREP

Framework for the Non rigid Image Registration Evaluation Project (NIREP) is shown in Figure 2.1. By following steps below, users can process evaluating the performance of different non-rigid registration algorithms using their evaluation database, then users can compare their own algorithm to other registration algorithms[6]. Before
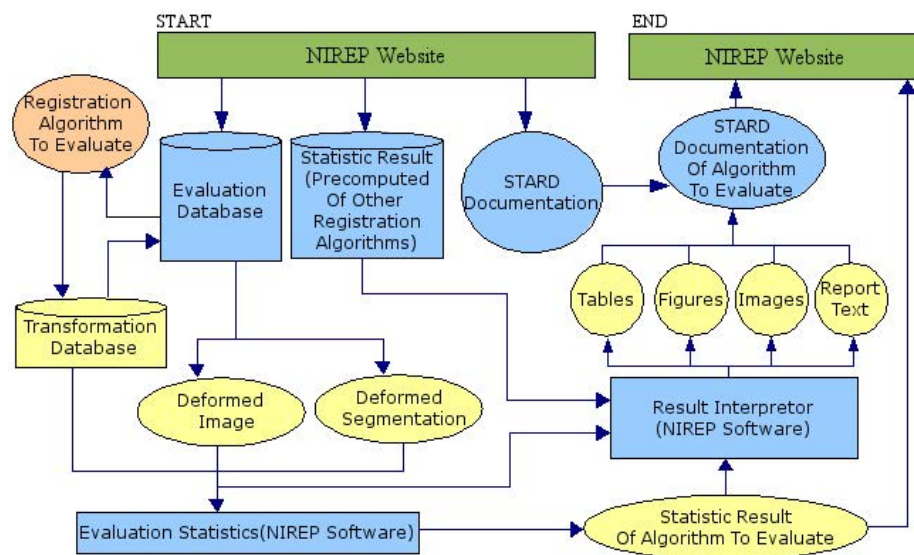
Figure 2.1: NIREP flow chart

users perform evaluation for non-rigid image registration algorithm, first users need to acquire evaluation database either their own database or NIREP evaluation database, and need to download NIREP software from the NIREP website. Optionally users can

download STARD (Standards for Reporting of Diagnostic Accuracy which is initiative to disclose all relevant information for each non-rigid registration validation test) documentation, and precomputed of other registration algorithms from the NIREP website [19].

Second, users register evaluation database using their non-rigid image registration algorithm. After performing registration, it creates transformations for all combination of images pairs. To evaluate algorithm using NIREP, user needs to create Resource Description List (RDL) for both evaluation database and transformations and NIREP Display descrition Document (ND3) file. RDL file is configuration XML file for NIREP software, and describes how the data to be read from the system. ND3 file is user readable file and describes how to display in NIREP software. Following is one example of evaluation database and transformation RDL, and ND3 file which shows overlap result table.

Database RDL: Following example is part of NA0 evaluation database RDL file. First part of RDL file contains clinical demographic characteristics of MRI and give coordinate system ID. Next part shows type of image such as Image file and object map file, so it contains file name, data type and descriptions. First image of NA0 evaluation database which is described in [19] has those information: label=na0, age=43, gender=male, race=white, ethnic category=non Hispanic, and handedness=+95, and it has both image file and object map file.

```
<?xml version="1.0" ?>
<ResourceDescriptionList namespace="na0" rdlIdentifier="na0">
```

```xml
<namespace_description id="na0" ns="na0">
    <description>First NIREP Neuroanatomy Evaluation Database</description>
</namespace_description>
<cs_description id="001">
    <name>na01</name>
    <identifier>hnnl008</identifier>
     <race>White</race>
     <gender>Male</gender>
     <age>43</age>
     <handedness>+95</handedness>
     <hand>Right</hand>
     <ethnicity>Non Hispanic</ethnicity>
</cs_description>
<label_description id="MRI">
    <modality>T1 Weighted MR</modality>
    <scanner>1.5T General Electric Signa scanner</scanner>
    <protocol>SPGR/50, TR 24, TE 7, NEX 1 matrix 256x192,
FOV 24 cm, 124 contiguous coronal slices,
interpixel distance 0.94</protocol>
</label_description>
<label_description id="OBJMAP">
    <description>Gray matter segmentations</description>
</label_description>
<!-- Start of MRI Data Descriptions -->
<data_description label="MRI">
    <coordinate_system id="001"/>
    <filename index="0">na01.img</filename>
    <datatype>IMAGE</datatype>
</data_description>
<!-- Start of Object Map Data Descriptions -->
<data_description label="OBJMAP">
    <coordinate_system id="001" />
    <filename>na01.obj</filename>
    <datatype>OBJECTMAP</datatype>
    <attributes>
        <name>brain object map</name>
        <description>Object map of subject 1</description>
    </attributes>
</data_description>
</ResourceDescriptionList>
```

Transformation RDL: When registration is performed, transformation file is

created. Transformation RDL file includes information about source coordinate system, target coordinate system, and its transformation. Following example is part of SICLE RDL file when the source image is NA0|001, target image is NA0|002 and its transformation is na01_To_na02_res10000_iter00020.coeffs.

```xml
<?xml version="1.0" ?>
  <ResourceDescriptionList namespace="na0" rdlIdentifier="sicle">
    <algorithm_description id="SICLE">
    <description>SICLE algorithm</description>
  </algorithm_description>
    <transform_description>
      <coordinate_system index = "0" ns = "na0" id="001"/>
      <coordinate_system index = "1" ns = "na0" id="002"/>
      <algorithm>SICLE</algorithm>
      <filename>na01_To_na02_res10000_iter00020.coeffs</filename>
      <datatype>TRANSFORMATION</datatype>
      <format>SICLE_COEFF</format>
      <transformation_units>IMAGE_SPACE</transformation_units>
    </transform_description>
</ResourceDescriptionList>
```

ND3 file: The example is showing overlap table in the display (overlap between image that register NA0|001 to NA0|002 with SICLE and NA0|002).

```
Begin ResourceDescriptionList
  Databases/NA0/resources.rdl
  Transformations/NA0/SICLE/sicle.rdl
End ResourceDescriptionList

Begin DisplayAttributes
columnsize(1)
rowsize(1)
End DisplayAttribute

Begin VariableList
image1 = na0|001
```

```
image2 = na0|002
algorithm = SICLE
modality = OBJMAP
End VariableList

Begin WidgetList
W1,1 = text(table,Overlap)
End WidgetList

Begin EvaluatorList
A1 = Transformation(image1,image2,algorithm)
A2 = SpatialData(image1,modality)
A3 = SpatialData(image2,modality)
A4 = TransformImage(A2,A1)
table = OverlapTable(A4,A3)
End EvaluatorLis
```

Next setp, users can evaluate registration algorithm with multiple evaluation methods using NIREP software. Users can save the evaluation results to database in NIREP. There are 3 different ways to performing evaluation with images and transformation.

First ways is performing evaluations with images and transformation. and following is the steps:

1. Open NIREP software

2. Using "Add image" and "Add Transform", add two images and transformation

3. Choose View → subvolumes → Overlap.

4. Generate Overlap images and tables.

5. For other evaluation such as ICE, Jaccobian, SSD, repeat 2-3 steps.

Second, performing evaluations with RDL

1. Open NIREP software

2. Load reference evaluation database RDL file (or create RDL file from NIREP), and Load transformaion RDL file.

3. Choose View → subvolumes → Overlap.

4. Generate Overlap images and tables.

5. For other evaluation such as ICE, Jaccobian, SSD, repeat 2-3 steps.

Last, performing with ND3 file (evaluating two image or more, and working for Batch-mode)

1. Open NIREP software

2. Load Display (ND3 file which includes evaluation database RDL file, and transformation RDL file. RDL file includes every images and every pairewise transformations. Also ND3 file has evaluaton method)

While performing evaluations all result data are automatically saved into the evaluation tables in NIREPresultdatabase which is created with SQLite in the NIREP software. Each evaluation calculates all different statistic values, so each evaluation method has its database table. From data in evaluation result table we creates new table for its statistical summary, called evaluation statistic table. Using average values in evaluation table, statical vaues are calculated for each ROI for algorithm.

Rank is one of element in this table and is calculated to compare values with different algorithms in the database for each ROI. From this table, users can see which algorithm gives better result than other algorithms.

To compare multiple algorithms with multiple evaluations, NIREP SQLite database has table, called result table. This table contains statically summarized re-

sult of each evaluation statistic table. From this result user can compare algorithms. With their evaluation data and precomputed other registration algorithms data that are downloaded from the NIREP website, users can compare their algorithm performance. Figure 2.2 illustrates evaluation result data flow. If users want to join NIREP
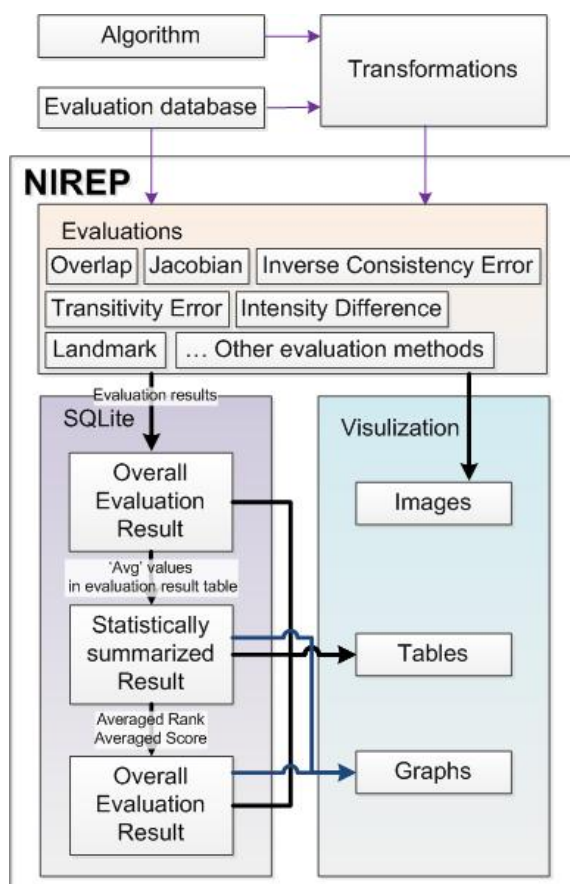
Figure 2.2: Evaluation result data flow-chart

to share their result and compete with other investigators, users needs to submit their result to NIREP website. NIREP website collects all submissions, and shows overall results of image registration evaluations and its ranking result using tables, and

graphs.

2.2   Database design

2.2.1   NIREP result database

Database gives a large space for saving data (such as numerical values) with single database file. Using database gives some benefits such as it is easy to save data, easy to look for data in database, easy to take or use values in database, and easy to marge tables with other same tables in different database.

SQLite is used to implement the NIREP evaluation result database. SQLite which uses structured query language (SQL) to query database is an open source embedded relational database, and symbiotically coexists inside the application. Advantage of using SQLite inside the application is that no network configuration or administration is required, also SQLite is small, fast and reliable [15, 14]. Everything user need is complied right into the program. Therefore, using SQLite is suitable for NIREP software.

SQLite is used to collect and manage all evaluation results calculated from the evaluation task in NIREP software. Tables in SQLite database were used to store these corresponding information. Every evaluation has single table, so each table represents one evaluation in the database. Figure 2.5 gives an example in the table format. This example illustrate what is the overlap evaluation result table looks like in the database. When user perform overlap evaluation, the results are saved into *overlap_t* (the letter *t* is short for table).

All teams to participate NIREP study must submit their results. The SQLite

database files are collected for comparing with image registration algorithms performance in the NIREP website.

SQLite database for NIREP has following advantages. SQLite database is single .db file which contains all results for the project, so it is simple to submit. Each SQLite database from participants has same tables with same columns, so it can be merged easily into single database file. When users want to use their results, users can easily approach their results and see their result tables with SQLite, and .db file can be converted to .csv file, so users also can use database with other applications.

2.2.2 Database Query Language

A database query language is a computer language used to make a requests to a database. The structured query language is the query language that used to build evaluation result database and make queries. The main SQLite queries which is used in evaluation database is **CREATE**, **INSERT**, and **SELECT** query.

Because table will be created when users perform the evaluation, table must be created without duplications. We used **CREATE TABLE IF NOT EXIST** query, and following is the SQLite query of creating overlap table:

```
CREATE TABLE IF NOT EXISTS overlap_t(name_space1 CHAR, mask1 CHAR,
        mask1_alg CHAR, mask1_scs VARCHAR(5), mask1_tcs VARCHAR(5),
        name_space2 CHAR, mask2 CHAR, mask2_alg CHAR,
        mask2_scs VARCHAR(5), mask2_tcs VARCHAR(5), ROI VARCHAR(5),
        RelativeOverlap FLOAT, DiceCoeff FLOAT, Sensitivity FLOAT,
        date DATE)
```

Once table is created, the evaluation result values are inserted to correspond-

ing column in evaluation table . However, there is a possibility that user perform with same values (same images with same transformation) several times). In this case we also dont want to have many same values in the table. The structure of SQLite queries contains 3 clauses: **INSERT INTO**, **SELECT**, and **WHERE NOT EX-ISTS**. The **INSERT INTO** clause is used to insert a new row and following is specified table name and table column names where the data will be inserted and the **SELECT** clause is used to the values to be inserted in the table. From the **WHERE NOT EXISTS()** clause is to avoid saving duplicated values, and in the **WHERE NOT EXISTS()** 3 clauses of SQLite queries are contained: **SELECT**, **FROM** and **WHERE**. The **SELECT** clause is used to select the output attributes in the table, and following the asterisk(*) is a way of selecting all columns. The **FROM** clause is used to specify the table name and in this case it will call same table used for insert data. The **WHERE** clause is used to list the predicates involving attributes of the relations that classify the values for duplications and it is all inputs, images, for the evaluation result. For example, suppose we want to perform overlap evaluation with two images, NA0—001 and NA0—002, with SICLE registration algorithm. The evaluation task in NIREP software will calculate relative overlap, dice coefficient, and sensitivity for every ROIs and for ROI=1 the result is relative overlap =0.388228, dice coefficient =0.559314, and sensitivity =0.521594. Each information is saved into corresponding column in table. The SQLite query can be expressed as:

```
INSERT INTO overlap_t (name_space1, mask1, mask1_alg,
        mask1_scs, mask1_tcs, name_space2, mask2, mask2_alg,
```

```
          mask2_scs, mask2_tcs, ROI, RelativeOverlap, DiceCoeff,
          Sensitivity, date )
SELECT 'NA0', 'OBJMAP', 'SICLE', '001', '002', 'NA0', 'OBJMAP',
          'N/A', '002', 002', '1', '0.388228', '0.559314', '0.521594',
          DATETIME('now')
WHERE NOT EXISTS (
          SELECT *
          FROM overlap_t
          WHERE name_space1='NA0' AND mask1='OBJMAP'
          AND mask1_alg=SICLE' AND mask1_scs=001'
          AND mask1_tcs='002' AND name_space2='NA0'
          AND mask2=OBJMAP AND mask2_alg='N/A'
          AND mask2_scs='002' AND mask2_tcs='002' AND ROI='1' )
```

The result of inserting example evaluation values is shown in Figure 2.3. The
evaluation result are saved for all ROIs without duplications.

Figure 2.3: Overlap between image NA0|001 registered to image NA0|002 with SICLE
algorithm and image NA0|002

To convert SQLite database file to MySQL, we used csv file. The csv file is

useful because when the database file can be convert into csv file, it can be used for another database engine, spreadsheet, or some programming software. Using SQLite, we can use **SELECT** commend so that we can have any tables we want from database. Below is the commend that create csv file from SQLite database.

```
sqlite> .mode list
sqlite> .separator ,
sqlite> .output tablename.csv
sqlite> SELECT * FROM tablename;
```

Another import commend for NIREP project is merging tables. Since many users will join this project and submit their result to us, we need to merge database to calculate Rank for algorithms. Below is the merging table command.

```
sqlite> attach ./otherdatabasefile.db as toMerge;
sqlite> INSERT INTO test select * from toMerge.test
sqlite> detach database toMerge
```

2.3   Image Registration Evaluation

2.3.1   Overlap

The alignment of of subvolumes such as object, structures, organs, and regions of interest(ROI) are one way of evaluating how well individual anatomical regions registered one another [8, 19]. The source image S refers to registered image to be compare with its registration target image T. This measures assume the segmentations are correct. Ideally all overalp should be 1.0 which means two segmentations are perfectly agreed.
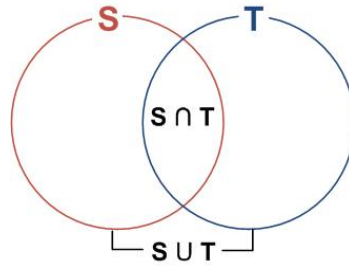
Figure 2.4: Overlap table

In Figure 2.4, S and T are two corresponding segmentations. S corresponds to a segmentation transformed from image i to j compared to the corresponding T defined in image j.

NIREP measures 3 kinds of overlap. The first overlap agreement measure is the Relative Overlap, the intersection between two regions in S and T divided by the volume of the region in union of S and T.

$$RelativeOverlap = \frac{Volume(S \cap T)}{Volume(S \cup T)} \qquad (2.1)$$

Dice coefficient, also called mean overlap, is second overlap agreement measurement. It is the intersection divided by the mean volume of the two regions.

$$DiceCoefficient = \frac{2 * Volume(S \cap T)}{Volume(S) + Volume(T)} \qquad (2.2)$$

The third overlap agreement measure is the Sensitivity which measures the proportion of actual positives which are correctly identified, and it is the intersection between two regions in S and T divided by the volume of the region in T. Sensitivity

is a measure of target overlap.

$$Sensitivity = \frac{Volume(S \cap T)}{Volume(T)} \tag{2.3}$$

Specificity, is the next overlap agreement measurement. It measures the proportion of negatives which are correctly identified. It is the complement of union of S and T divided by the volume of T complement.

$$Specificity = \frac{Volume((S \cup T)^{\complement})}{Volume(T^{\complement})} \tag{2.4}$$
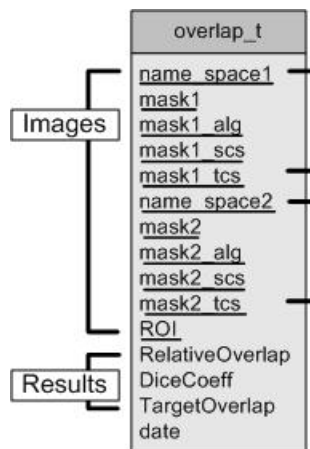
Figure 2.5: Overlap table

To save overlap evaluation, first we need to identify what images are used in the table. Two images used for evaluation can be represented in 3 different cases:

1) Applying evaluation methods between image 001 and image 002, 2) Applying evaluation methods between image 001 register to image 002 using algorithm A and image 002, 3) Applying evaluation methods between image 001 register to image 002 using algorithm A and image 003 register to image 002 using algorithm B.

Every evaluation methods in NIREP software has its corresponding database table. Figure 2.5 shows structure of overlap result table. NIREP calculate 3 different kind of overlap (relative overlap, dice coefficient, target overlap) and Specificity will be added soon in the NIREP. Each item in Table *overlap_t* represents an attribute (column name) in the table and the underline elements are used for key.

First part of table is image identifier, each column of the table represents image information.

name_space1 is corresponding Namespace in NIREP software and it identifies the type of evaluation database association of each image data. For example, if namespace consist of brain MR scan, then it could be NA0 or NA1 in NIREP evaluation database.

mask1 is image mask which used for image localization. Mostly object map (OB-JMAP) is used in NIREP

mask1_alg is the algorithm that used in image registration. If image is registered(case 2 and 3), it is the element for algorithm name such as SICLE but the algorithm name must be different when users use different parameters. For case 1 since there is no transformation it is N/A.

mask1_scs is source coordinate system which is the coordinate system for reference

image to be registered. Coordinate system is a system of using coordinates measured in some specified way to uniquely determine the position of a geometric element such as a point. Every data belonging to a namespace must be identified with at least one coordinate system.

mask1_tcs is target coordinate system.

name_space2 , **mask2**, **mask2_alg**, **mask1_scs**, **mask1_tcs** is for second image and it is identical to for first image.

ROI is Region Of Interests.

Second part is for saving evaluation data result corresponding images used for evaluation. For overlap evaluation NIREP gets Relative Overlap, Dice coefficient and Target Overlap.

2.3.2   Inverse Consistency Error

Inverse consistency evaluation method evaluates registration performance based on desired transformation properties and measures the error between forward and reverse transformation between two images [4, 5, 10].

Ideally the forward transformation equals the inverse of the reverse transformation implying a consistent definition of correspondence between two images. Comparing the forward and reverse transformations together produces the identity map when there is no inverse consistency error [8].

Inverse consistency error (ICE) provides accurate correspondence between two images compared to independently estimating the forward and reverse transformation. Figure 2.6 illustrates two ways of calculating inverse consistency error: (a) shows the
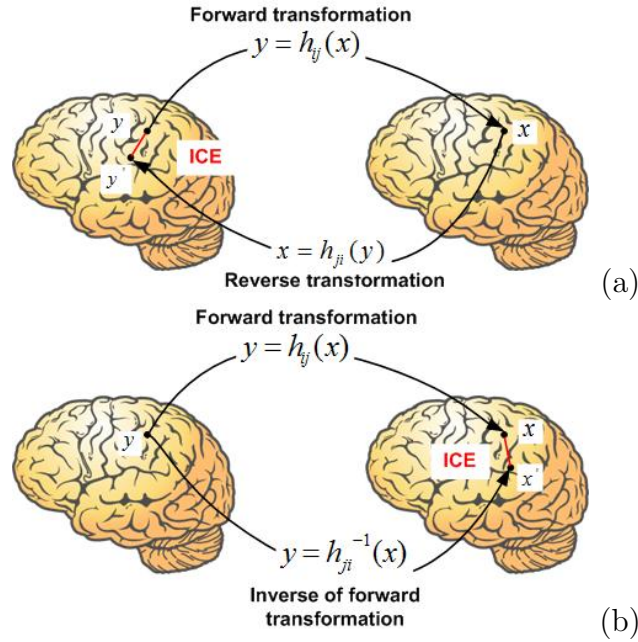
Figure 2.6: Illustration of Inverse Consistency Error (a) ICE1 (b) ICE2

inverse consistency error with respect to source image i is computed as:

$$ICE_j(x) = ||h_{ji}(h_{ij}(x)) - x|| \qquad (2.5)$$

, and (b) shows the inverse consistency error that is mapped in target coordinate system and it is calculated as:

$$ICE_j(x) = ||h_{ij}(x) - h_{ji}^{-1}(x)|| \qquad (2.6)$$

where h_{ij} it the transformation from image i to image j, and $|| \cdot ||$ is the standard Euclidean norm. ICE has 2 different way to calculate has two different tables, called $ice1\_t$, and $ice2\_t$. Transformation based evaluation such as inverse consistency error,

Figure 2.7: ICE table

transitivity error, and jaccobian calculates minimum, minimum location, maximum, maximum location, average, standard deviation, median, and sum for all voxels in each ROI. Figure 2.7 shows structure of ICE table, and it has two parts: image part is identical to *overlap_t*, and result part is for saving inverse consistency error result.

2.3.3 Transitivity Error

The transitivity property is to minimize correspondence error when two transformations are composed together [4, 5, 10].

The transitivity error(TE) evaluates the difference between a point and a point that transformed from image A to B to C and return to A. In other words difference between starting point and ending point is defined as the transitivity error.

Transitivity error provides accurate correspondence between three images and
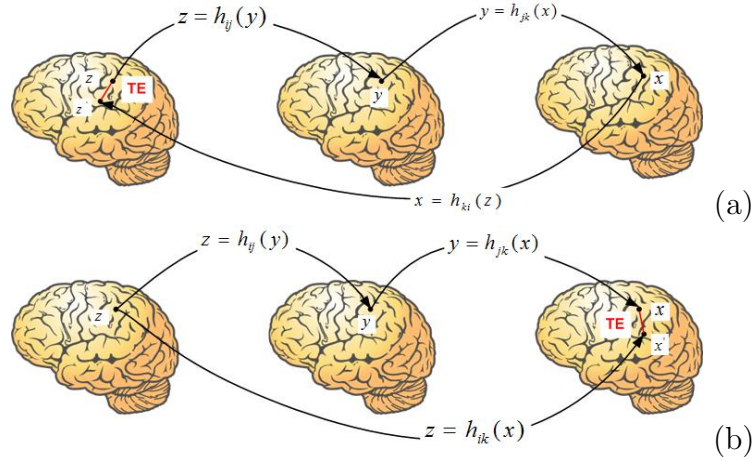
Figure 2.8: Illustration of Transitivity Error (a) TE1 (b) TE2

the identity map. Figure 2.8 (a) shows the voxel wise transitivity error with respect to source image i is computed as:

$$TE_k(x) = ||h_{ki}(h_{ij}(h_{jk}(x))) - x||. \tag{2.7}$$

, and (b) shows the transitivity error that is mapped in target coordinate system and it is defined as:

$$TE_k(x) = ||(h_{ij}(h_{jk}(x)) - h_{ik}(x)||. \tag{2.8}$$

where i is the source image, j is the second image, and k is target image shown in Figure 2.8 and $||\cdot||$ is the standard Euclidean norm. TE has 2 different way to calculate has two different tables, called $te1_t$, and $te2_t$. Figure 2.9 shows structure of TE table First part, image part, is image identifier, each column of the table represents image information.

name_space is name space for reference which is first image in Figure 2.8 (a) or (b)

Figure 2.9: TE table

and identifies the type of evaluation database association of each image data such as
NA0 and NA1.

ref_mask is image mask for reference image

ref_CS is coordinate system for reference image.

alg_ref_cs1 is the algorithm that transforms reference image to second image which
is h_{ij} in Figure 2.8 (a)

CS1 is coordinate system for second image.

alg_cs1_cs2 is the algorithm that transforms second image to third image which is
h_{jk} in Figure 2.8 (a)

CS2 is coordinate system for third image.

alg_cs2_ref is the algorithm that transforms third image to reference image which is
h_{ki} in Figure 2.8 (a)

ROI is Region Of Interests.

Second part, result part, is for saving transitivity error result which are minimum, minimum location, maximum, maximum location, average, standard deviation, median, and sum .

2.3.4   Jacobian

Jacobian evaluate how physically appropriate the registration deformation is [12]. The determinant of the Jacobian of the deformation field, J, is calculated at every voxel. This specifies for each point whether local expansion or contraction has taken place. Where J <1 local contraction is implied, J=1 implies no change and j >1 implies local expansion. All values are bigger than 0 but if the values are negative, it implies folding or tearing.

$$J3(h(x)) = \begin{vmatrix} \frac{\partial h_1(x)}{\partial x_1} & \frac{\partial h_2(x)}{\partial x_1} & \frac{\partial h_3(x)}{\partial x_1} \\ \frac{\partial h_1(x)}{\partial x_2} & \frac{\partial h_2(x)}{\partial x_2} & \frac{\partial h_3(x)}{\partial x_2} \\ \frac{\partial h_1(x)}{\partial x_3} & \frac{\partial h_2(x)}{\partial x_3} & \frac{\partial h_3(x)}{\partial x_3} \end{vmatrix}, \tag{2.9}$$

where h_1, h_2 and h_3 are three components of the transformation at location $x = [x_1, x_2, x_3]$.

The structure of $jacobian\_t$ is identical to $ice1\_t$

2.4 Statistical summary of Evaluation result

2.4.1 Structure of statistic tables for evaluation result

After save all data in evaluation result table in NIREP result database, NIREP software create population statistic table for each evaluation. Each population statistic table is table for statistically summarizing each evaluation result. Each evaluation result table has corresponding population statistic table, but tables like $overlap\_t$ which includes more than one information such as relative overlap, dice coefficient, and target overlap' have multiple population statistic tables, so $overlap\_t$ has corresponding 3 tables: $RelativeOverlap\_ps\_t$, $DiceCoeff\_ps\_t$, and $TargetOverlap\_ps\_t$. Otherwise, one evaluation result tables has one corresponding population statistic table, e.g., ice_t corresponds to ice_ps_t.

From the values in evaluation result table, population statistic is calculated and automatically saved into corresponding population statistic table. Mostly average in evaluation result table is used for calculate minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median(50th), 75th, and 95th).

As you can see in Table 2.1, population statistic table has those attributes (columns). Bold and under line elements are used as key for searching or using values.

refCS_name_space is the type of evaluation database association of reference coordinate system image data

refCS is reference coordinate system. It tells the population statistic is calculted with

Table 2.1: Overlap population statistic tables

RelativeOverlap_ps_t	DiceCoeff_ps_t
refCS_name_space	refCS_name_space
refCS	refCS
alg	alg
ROI	ROI
descriptionID	descriptionID
description	description
min	min
max	max
avg	avg
std	std
Rank	Rank
P05	P05
P25	P25
P50	P50
P75	P75
P95	P95

evaluation results that is from registered from coordinate systems to this reference

coordinate system. in batch mode, all

alg is algorithm used for evaluation

ROI is Region Of Interest

descriptionID indicates what elements are used to calculate population statistic, in

batch mode, All

description describes descriptionID in word, in batch mode, AlltoAll

For selected one image which is **name_space1** and **mask1_tcs** and **mask2_tcs**

in evaluation result table corresponds to **refCS_name_space** and **refCS**, respec-

tively. Also, **alg** in population statistic table match to **mask1_alg**, and **descriptionID**

in population statistic table corresponds to many **mask1_scs**. Using selected elements, population statistic tables are created. Therefore, we can get a values in evaluation result table. From those values, for each ROI we can calculate minimum, maximum, average, standard deviation and percentiles. For example, suppose we want relative overlap population statistic for NA0|001 with SICLE algorithm. In *RelativeOverlap_ps_t*, following values are inserted: **refCS_name_space** is NA0 and **refCS** is 001, **alg** is SICLE and **descriptionID** is 002:016 since NA0 has 001 to 016, total 16 images.

For each ROI which is 1 to 32, using those conditions in *overlap_t*, we can find RelativeOverlap values where **mask1_name_space** = NA0, **mask1_tcs** = 001, and **mask1_alg** = SICLE . When ROI is 1, 15 different values are in relative overlap column, and using those we calculate minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median(50th), 75th, and 95th) and insert into *RelativeOverlap_ps_t* database. Therefore, min is the smallest relative overlap values which means the worst relative overlap result in the ROI, max is the biggest value meaning the best result, avg is average, and std is standard deviation of 15 relative overlap result. Percentiles also calculated which is the value that denotes boundary values in frequency distributions. The 5th percentile is that value which marks off the lowest 5% of observations from the rest, the 25th, first quartile, is the value that cuts off 25% of data, 50th, second quartile or median, cuts data set in half, the 75th, third quartile, cuts off hight 25% of the data or lowest 75%, and the 95th percentile exceeds all but 5% of values.

2.4.2 Ranking population statistic

Ranking algorithms for each population statistic table is important to know one algorithm is better than other algorithms. Therefore, we need to give ranks to every algorithms for each ROI in population statistic table. If the number of algorithm is one, the rank will be 1, but if the table contains N algorithms, then the rank will be 1 to N. Avg values in population statistic table are used to calculate rank. Mostly, low avg value is better than high avg value, but only for overlap high avg values is better. Therefore, expect overlap population statistic tables ($RelativeOverlap\_ps\_t$, $DiceCoeff\_ps\_t$, and $Sensitivity\_ps\_t$) the lowest avg value will be ranked 1, next will be ranked 2, and so on. However, there are possibility to have some equal avg value, and in this case, rankings are averaged. For example, we have 6 algorithms: Demons, SICLE, SLE, AIR, Affine, and Rigid, and its avg in $RelativeOverlap\_ps\_t$ for ROI=1 is 0.50, 0.38, 038, 0.35, 0.32, and 0.26 respectively. From those values, avg of Demons is ahead of any other algorithms,meaning the highest value, then Demons gets ranking number 1. SICLE and SLE (which compare equal) both have higher value than AIR, Affine and Rigid, so both gets ranking number 2.5 (which is average of 2nd and 3rd place of rank). AIR, Affine, and Rigid get ranking number 4, 5, 6 respectively.

2.4.3 Ranking algorithms

To give ranks to all algorithms for overall evaluations, NIREP software creates another table ,$result\_t$, which summarize all evaluation result population statistic tables. From population statistic table, evaluation results are computed for every

ROIs. However to summarize overall evaluation statistics, each evaluation method need representative values which are 'Avg Score' and 'Avg Rank'. Avg Score is computed by averaging avg values for all ROIs, and Avg Rank also is computed by averaging rank values. For example, Avg Score for relative overlap are computed averaging avg values in $RelativeOverlap\_ps\_t$ shown in Figure 2.10, as a result the Avg Score is 0.381434 and Avg Rank is 2.15625 for SICLE. From Avg Rank in each

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.165232	0.478234	0.355827	0.057454	0.256404	0.319997	0.360543	0.395324	0.44805	3
2	0.205216	0.492725	0.37145	0.047611	0.285015	0.347493	0.37465	0.401964	0.441808	3
3	0.275935	0.524153	0.404709	0.047498	0.324037	0.368184	0.409135	0.441401	0.485792	2
4	0.323317	0.515857	0.417372	0.037519	0.358752	0.389418	0.420021	0.44683	0.478069	2
5	0.379597	0.599719	0.503875	0.047518	0.416916	0.47476	0.50492	0.536716	0.583898	2
6	0.425978	0.625684	0.521972	0.03916	0.450928	0.496935	0.524092	0.546911	0.584668	2
7	0.326712	0.640146	0.492565	0.06328	0.369057	0.454399	0.502276	0.537385	0.584003	2
8	0.38982	0.628065	0.530296	0.046066	0.45614	0.496367	0.53445	0.566354	0.598666	2
9	0.248033	0.426096	0.335533	0.038968	0.271235	0.311441	0.332179	0.360073	0.409414	2
10	0.20716	0.4491	0.316254	0.046401	0.242172	0.283876	0.31412	0.349829	0.393385	2
11	0.317754	0.50818	0.432796	0.035506	0.372222	0.412189	0.433323	0.457854	0.491588	2
12	0.353128	0.546255	0.422657	0.031616	0.372081	0.400314	0.419404	0.445728	0.472633	2
13	0.385907	0.602359	0.488116	0.042802	0.417426	0.454111	0.488356	0.516503	0.561082	2
14	0.409343	0.641612	0.532328	0.044357	0.451969	0.50709	0.535333	0.558646	0.606527	2
15	0.330295	0.549804	0.453501	0.047487	0.353183	0.423896	0.453371	0.488941	0.522695	2
16	0.277813	0.53247	0.439415	0.049721	0.347565	0.401845	0.447965	0.479948	0.51492	2
17	0.308483	0.437133	0.364056	0.028401	0.323045	0.340053	0.36155	0.386278	0.413115	2
18	0.273818	0.440328	0.354925	0.031976	0.299949	0.32997	0.35244	0.382207	0.403737	2
19	0.264716	0.440237	0.35168	0.035985	0.284745	0.325999	0.35292	0.377566	0.407258	2
20	0.221808	0.411051	0.323542	0.039475	0.245022	0.300838	0.329088	0.354403	0.383469	2
21	0.109838	0.45289	0.28452	0.069577	0.168668	0.242423	0.278613	0.329107	0.412223	2
22	0.171131	0.411567	0.304131	0.045309	0.229995	0.2724	0.304306	0.333563	0.381295	2
23	0.357453	0.557284	0.476958	0.037178	0.396689	0.460376	0.483148	0.503055	0.526633	2
24	0.39915	0.565187	0.472708	0.034778	0.417683	0.446292	0.471372	0.493846	0.542073	2
25	0.185485	0.419644	0.294065	0.046435	0.206147	0.262116	0.299479	0.323916	0.367953	2
26	0.141054	0.362474	0.260779	0.044404	0.179866	0.230223	0.263559	0.293291	0.327053	2
27	0.164942	0.400324	0.283942	0.050549	0.184432	0.252311	0.295692	0.316434	0.362084	3
28	0.166218	0.354808	0.279803	0.043435	0.202941	0.246604	0.291892	0.312446	0.339181	3
29	0.248915	0.4307	0.347534	0.038799	0.279174	0.319744	0.349392	0.376145	0.401846	2
30	0.178327	0.428435	0.319756	0.04675	0.246865	0.288786	0.315937	0.350479	0.410556	3
31	0.080283	0.356213	0.256928	0.047922	0.170437	0.22747	0.264544	0.289771	0.332349	2
32	0.095348	0.32143	0.2119	0.049879	0.111884	0.188569	0.215713	0.245234	0.291824	2
Avg	0.26188153125	0.486567625	0.38143415625	0.04418175	0.302895125	0.35239028125	0.38386821875	0.412435875	0.45249521875	2.15625

Figure 2.10: RelativeOverlap_ps_t in website when evaluation database is NA0 and the non-rigid registration algorithm is SICLE.

evaluations, total average rank is calculated by averaging all evaluation Avg Rank. The default calculation is averaging with same weight 1, but users can choose weight in each evaluations. From total average rank, we give total rank, then it will calculate different ranking result according to weight of average rank. The way to give a rank is in Section 2.4.2. Table 2.2 shows one example structure of $result\_t$.

Table 2.2: Result table

$result\_t$
name_space
Alg
alg_link
refCS
DescriptionID
RelativeOverlap_avg
RelativeOverlap_avg_rank
DiceCoeff_avg
DiceCoeff_avg_rank
TargetOverlap_avg
TargetOverlap_avg_rank Sn_avg
ICE_avg
ICE_avg_rank
TE_avg
TE_avg_rank
submit_date
method_type
avg_rank
total_rank

2.5   NIREP results and Visualization

2.5.1   Requirements of submission

NIREP requires to submit STARD (Standards for Reporting of Diagnostic Accuracy) documentation, and SQLite database file.

2.5.1.1   STARD documentation

NIREP follows STARD documentation to improve the accuracy and completeness of reporting of the study of diagnostic accuracy, to help investigators understand diagnostic and assess the potential for bias in the study, and to evaluate generalization of the study [1, 2].

Investigators can download STARD documentation from NIREP website. The STARD initiative includes a checklist of 25 items. This checklist gives guidelines to investigators for reporting the necessary elements of a diagnostic accuracy study and helps them better to understand diagnostic reports and to assess their quality.

2.5.1.2   NIREP result Database file

NIREP software creates SQLite database file, NIREPresult.db in NIREP build folder. This database file contains all results in evaluation result tables that user performed their registration algorithms for several evaluations.

NIREPresult.db file has not only evaluation results tables, but algorithm information table called *algorithm_info_t*. To have specific information about algorithm that participants evaluated, they need to give following information: (1) the name of algorithm, (2) affiliation of the team, (3) url (optional), (4) data name space which

is used for evaluate algorithm, (5) deformation model of algorithm, (6) degrees of freedom of algorithm, (7) algorithm parameters used for evaluation, (8) similarity measure, (9) regularization method, (10) algorithm programming code, (11) computer specifications, (12) image input to algorithm, (13) image requirements to use algorithm, (14) average running time and its standard deviation, (15) method type - either fully automatic or semi automatic. if user use same parameters on all pairs with no user interaction method type is Fully Automatic, if parameter were changed manually for different image pair, method type is Semi-Automatic and it should be reported in parameter column and (16) submit date. The example of $algorithm\_info\_t$ shown in Table 2.3.

The name of algorithm must match with algorithm name that users used for their evaluation RDL file, and if users use same algorithm but different parameters, then users must use different algorithm name.

2.5.2 NIREP Website

Researchers have worked to find the best non-rigid image registration algorithm. Many papers and journals about performance of non-rigid image registration algorithms are published, and algorithms are available to public. Comparing their behavior is important task. However, Investigator uses different data sets and different evaluation methods when they publish their algorithm performance, so proper comparison between algorithms is virtually impossible.

The NIREP website provides a place for image registration evaluations and reasonably fair comparison of available registration algorithms for its application be-

Table 2.3: Example of *algorithm_info_t*

Columns in table	Example
algorithm	SICLE
affiliation	The University of Iowa
data_name_space	NA0
deformation	3-D Fourier series (diffeomorphic)
dof	7,986 for 10 harmonics
parameters	similarity: 1.0, regularization: 0.00125, and ICC: 2500
similarity	SSD
regularization	Small-deformation linear elasticity, inverse consistency; MRess: number of basis components
code	C++
computer	Intel(R) Xeon(R) CPU 5140 @ 2.33GHz quad core 16GB RAM
input	Analyze (7.5) 8-bit
setup	Dimensions divisible by 16 Intensity correction Isotropic Individual parameter files
running time	60 min/registration
method type	fully automatic
submit date	

cause all participants apply their algorithms to same evaluation database such as NA0 and NA1 and participants apply several evaluation methods to their algorithms using NIREP software, so resulting registration will be evaluated using same criteria.

Participants download evaluation database from the NIREP website, register them, and return the results for independent evaluation. Algorithms are ranked according to their performance in each evaluation method. All results are published on the NIREP website.
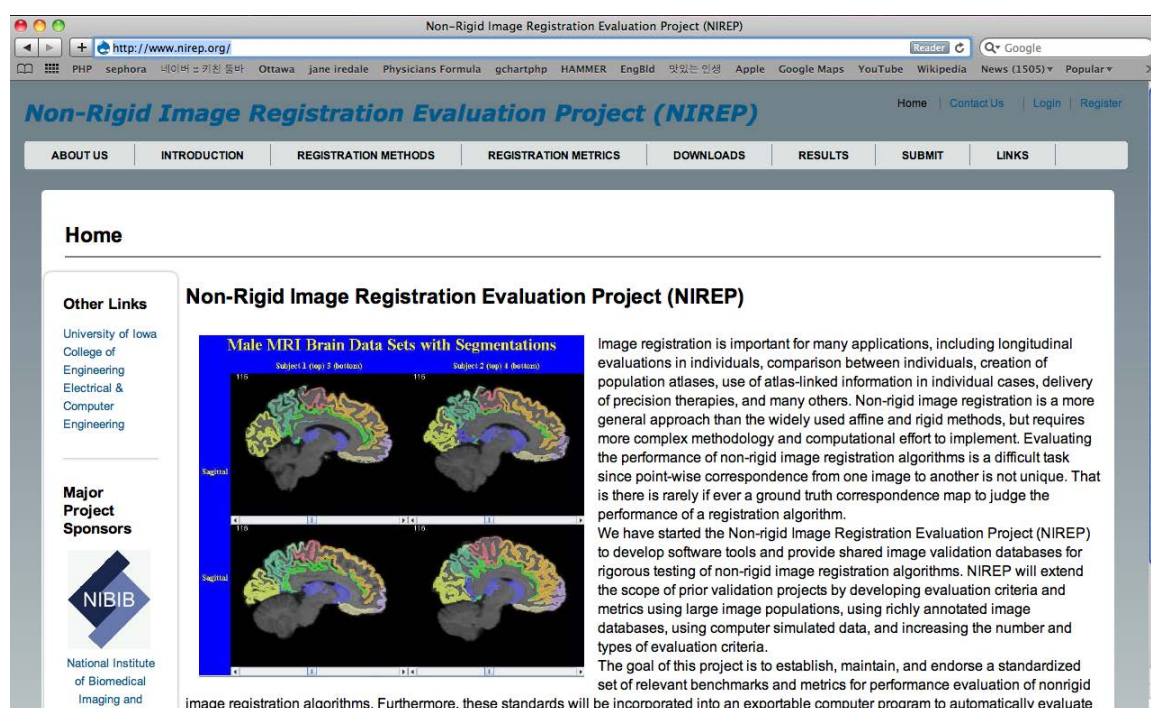
Figure 2.11: NIREP website.

When investigators want to join non-rigid image registration evaluation project (NIREP), they must follow rules below.

- NIREP software can be downloaded from NIREP website, so anyone who is interested in image registration evaluation can obtain this software.

- NIREP evaluation database are provided to participants who uses database only for NIREP purpose, so participants who download this evaluation database must submit their result to the website. In other words, NIREP evaluation database is not allowed to anonymous, and will not be used for any other purpose than NIREP.

- Result of evaluating registration performance uploaded to this website will be publicly available on this website.

- By submitting result, participant allow us to publish our evaluation.

- Participant maintain full ownership and rights to their methods.

- Participants who want to use the result of algorithms associated with the NIREP project in publications must make an appropriate citation, and notify to NIREP about their publication.

2.5.2.1   Download

For legitimate comparisons between registration algorithms, NIREP provides to investigator same evaluation data sets and same evaluation criteria through the NIREP software. Therefore, NIREP website provides a place to download NIREP software, STARD documentation, and NIREP evaluation databases. NIREP software is open source, so anonymous can obtain easily. However, NIREP evaluation data sets will be used for only NIREP purpose, so investigators need to register to website first.

2.5.2.2   Submission

Investigators who download NIREP evaluation data sets and evaluate their algorithms needs to submit their results to NIREP website in order to join this project. After log-in to NIREP website, they can see submission session. Session 2.5.1 described the items users needs to submit to NIREP. we will collect those data and show on the website.

2.5.2.3   Result Visualization

NIREP website display same result data as the SQLite database in the NIREP software, i.e., SQLite database is converted to MySQL database just for website purpose. In the main result session on the NIREP website represent result table which is described in Session 2.4.3.

The result table is sorted in ascending order based on the average rank which is computed by averaging ranks from each evaluation with default weight 1. Users also choose the weight on the evaluation and it computes average rank with different weight that users select. Then users can find the best algorithm for their purpose.

In the result table, each algorithm has their linked pages, so by clicking the algorithm name, users can go to the algorithm page. In the each algorithm page, all detail of evaluation results are shown with tables.

CHAPTER 3
RESULTS

Three non-rigid image registration algorithms were evaluated using common evaluation databases (NA0 and NA1). All 16 data sets of NA0 and 18 data sets of NA1 were used for this study. This is to show an example to evaluate performance of registration algorithms.

Four evaluation methods are applied to evaluate algorithm performances. When evaluations were performed, the results data automatically were saved into the NIREP result database using SQLite in NIREP software. After collecting all evaluation result data, all evaluations were statistically summarized for each region of interest (32 ROIs of NA0 and 57 ROIs of NA1). From statistically summarized result for each evaluation method, algorithm performances evaluated using ranking on the algorithm for each ROI and all results were saved into the NIREP result database. Fianally to evaluate algorithms based on all evaluation methods, averaged score(average) and rank in 32 ROIs for NA0 and 57 for NA1 were calculated for all statistically summarized result for every evaluations. Using averaged scores and ranks, the best algorithm among three algorithm was chosen.

3.1   Evaluation Result for NA0 database

3.1.1   Overlap Evaluation Result

The overlap performance for three non-rigid image registration algorithms with respect to NA0 database was saved in Figure 3.1. Overlap evaluation task computed relative overlap, dice coefficient, and sensitivity for each of the 32 ROI and all overlap evaluation results were saved in $overlap\_t$ with corresponding image information. From relative overlap, dice coefficient, and sensitivity values in $overlap\_t$, population statistic values of all pair-wise evaluation results for each ROI were computed and saved in $RelativeOverlap\_ps\_t$, $DiceCoeff\_ps\_t$, and $Sensitivity\_ps\_t$ respectively. In $RelativeOverlap\_ps\_t$, $DiceCoeff\_ps\_t$, and $Sensitivity\_ps\_t$, minimum, maxi-

	name_space1	mask1	mask1_alg	mask1_scs	mask1_tcs	name_space2	mask2	mask2_alg	mask2_scs	mask2_tcs	ROI	RelativeOverlap	DiceCoeff	Sensitivity	date
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	0	0.941268	0.969746	0.971626	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	1	0.388228	0.559314	0.521594	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	2	0.354399	0.523331	0.508512	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	3	0.354402	0.523334	0.567815	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	4	0.402314	0.573786	0.614773	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	5	0.555556	0.714286	0.703643	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	6	0.499223	0.665976	0.673	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	7	0.369535	0.53965	0.706001	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	8	0.479624	0.648305	0.576047	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	9	0.327764	0.493708	0.521059	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	10	0.303884	0.466121	0.42177	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	11	0.438916	0.610064	0.587513	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	12	0.453798	0.624293	0.61406	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	13	0.496064	0.663159	0.626412	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	14	0.560973	0.718748	0.695401	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	15	0.414345	0.585918	0.664357	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	16	0.405389	0.576907	0.649919	2011-06-23
na0	objectmap	SICLE	001	002	na0	objectmap	N/A	002	002	17	0.376392	0.546926	0.522608	2011-06-23

Figure 3.1: Overlap evaluation results for NA0 database are saved in $overlap\_t$. This shows overlap evaluation results between NA0|002 image with NA0|001 registered to NA0|002 with SICLE algorithm for all ROIs

mum, average, standard deviation, and percentiles (5th, 25th, median(50th), 75th, and 95th) were calculated for each ROI.

3.1.1.1 Result for Relative Overlap

Relative overlap evaluation performance for three non-rigid registration algorithms with respect to NA0 database are shown in Table 3.1 and Figure 3.2. From the overlap evaluation task, each pair-wise registration (16 NA0 data sets with 240 transformaions) computed relative overlap values, and using them for each of 32 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into *RelativeOverlap_ps_t* in NIREP result database. Using average values, avg column in population statistic table *RelativeOverlap_ps_t*, algorithms were ranked for each of 32 ROIs. As shown in Figure 3.2 Demons got 1st place for all ROIs, SICLE got 2nd palce for 27 out of 32 ROIs, and AIR5 got 3rd place.

Demons provides significantly different average values for all the 32 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.1.

3.1.1.2 Result for Dice Coefficient

Dice coefficient evaluation performance for three non-rigid registration algorithms with respect to NA0 database are shown in Table 3.2 and Figure 3.3. From the overlap evaluation task, each pair-wise registration (16 NA0 data sets with 240
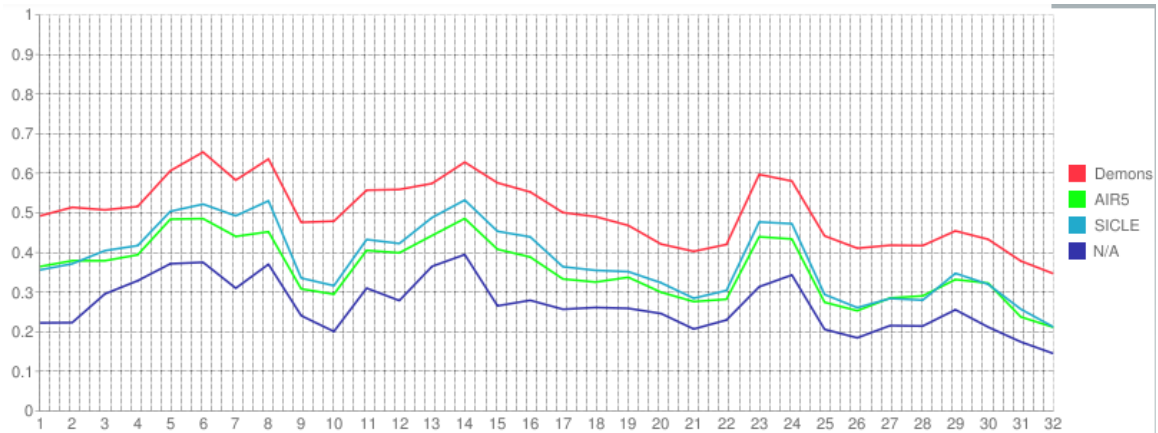
Figure 3.2: Graph of Average Relative Overlap for 32 ROIs which was computed by averaging relative overlap values for 16 NA0 datasets, computed for 240 transformations from three registration algorithms and one without transformations

Table 3.1: Table for statistically summarizing Relative Overlap results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	0.211229	0.48581	0.357664	2	3	2.84375
Demons	0.346537	0.65334	0.502887	1	1	1
SICLE	0.2119	0.532328	0.381434	2	3	2.15625

transformaions) computed dice coefficient values, and using them for each of 32 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $DiceCoeff\_ps\_t$ in NIREP result database. Using values of avg column in population statistic table, $DiceCoeff\_ps\_t$, algorithms were ranked for each of 32 ROIs. As shown in Figure 3.3 Demons got 1st place for all ROIs, SICLE got 2nd palce for 26 out of 32 ROIs, and AIR5 got 3rd.
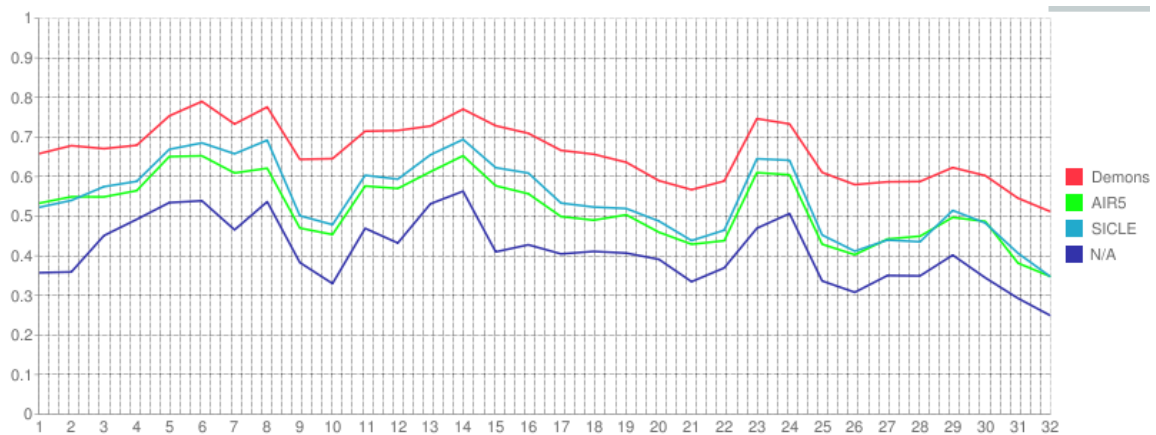
Figure 3.3: Graph of Average Dice Coefficient for 32 ROIs which was computed by averaging relative overlap values for 16 NA0 datasets, computed for 240 transformations from three registration algorithms and one without transformations

Demons provides significantly different average values for all the 32 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.2.

Table 3.2: Table for statistically summarizing Dice Coefficient results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	0.347451	0.652564	0.520799	2	3	2.84375
Demons	0.511333	0.789754	0.663179	1	1	1
SICLE	0.346836	0.693693	0.54458	2	3	2.1875

3.1.1.3 Result for Sensitivity

Sensitivity(target overlap) evaluation performance for three non-rigid registration algorithms with respect to NA0 database are shown in Table 3.3 and Figure 3.4. From the overlap evaluation task, each pair-wise registration (16 NA0 data sets with 240 transformaions) computed sensitivity(target overlap) values, and using them for each of 32 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $Sensitivity\_ps\_t$ in NIREP result database. Using values of avg column in population statistic table, $Sensitivity\_ps\_t$, algorithms were ranked for each of 32 ROIs. As shown in Figure 3.4 Demons got 1st place for all ROIs, SICLE got 2nd palce for 29 out of 32 ROIs, and AIR5 got 3rd.

Demons provides significantly different average values for all the 32 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.3.
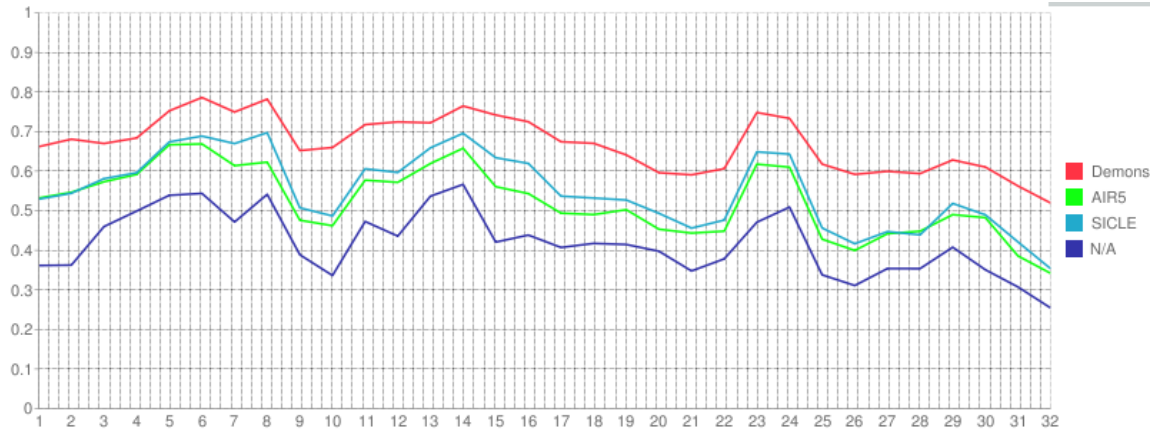
Figure 3.4: Graph of Average Sensitivity for 32 ROIs which was computed by averaging relative overlap values for 16 NA0 datasets, computed for 240 transformations from three registration algorithms and one without transformations

Table 3.3: Table for statistically summarizing Sensitivity results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	0.347451	0.652564	0.520799	2	3	2.8125
Demons	0.519316	0.785856	0.670351	1	1	1
SICLE	0.353424	0.696998	0.551091	2	3	2.09375

3.1.2 Jacobian Evaluation Result

The determinant of the Jacobian of the deformation field, j, is calculated at every point. For every 32 regions, the determinant of Jacobian evaluation computes avg, minimum, minimum location(for 3D image : min_x, min_y, min_z), maximum, maximum location, standard deviation and percentiles. However, now NIREP evaluator calculates avg, min, min_loc, max, max_loc. All of statistic values are computed and saved in to *jacobian_t* in NIREP result database, and the table is shown below in Figure 3.5.

			name_space1	mask1	mask1_alg	mask1_scs	mask1_tcs	name_space2	mask2	mask2_alg	mask2_scs	mask2_tcs	ROI	avg	min	min_x	min_y	min_z
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	0	0.968104	0.51386	135	39	122
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	1	0.89685	0.511594	134	38	124
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	2	1.13665	0.755924	104	57	185
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	3	1.13867	0.987356	128	194	164
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	4	1.11448	0.965214	123	196	162
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	5	1.07487	0.971099	160	186	104
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	6	1.06879	0.996198	68	181	135
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	7	1.09987	0.956993	157	180	101
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	8	1.06338	0.848644	91	192	93
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	9	1.16078	0.978951	171	121	157
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	10	1.07205	0.857814	48	108	165
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	11	1.10303	0.870576	194	70	121
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	12	1.10745	0.838829	50	100	167
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	13	1.02163	0.923257	162	132	108
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	14	1.03073	0.894544	85	149	109
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	15	1.06204	0.945747	136	244	101
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	16	1.07201	0.973348	93	260	115
☐	✏	✗	na0	objmap	SICLE	001	002	na0	objectmap	N/A	002	002	17	1.14966	0.945851	160	249	169

Figure 3.5: Jacobian evaluation results for NA0 data sets are saved in *jacobian_t*. This shows the jacobian values for SICLE transformation that NA0|001 registered to NA0|002 for all ROIs

Different from other evaluations, calculating Jacobian population statistic doesnt have important information. The average is equal to 1 or near 1 doesnt

imply the evaluation is good because when using the complex image contraction and expansion is not important. In Jacobian evaluation, the negative values is important because it means singularities folding or tearing in the image, so Jacobian result was used for the reference to consideration of choosing better transformation. In the overlap evaluations, Demons got better results than SICLE or AIR5 performance, but Demon has negative values in Jacobian evaluation. This implied that Demon transformation makes folding or tearing in part of image, so Demon has worst results in Jacobian evaluation than SICLE and AIR5. Figure 3.6 shows the Jacobian deformation for three non-rigid registration algorithms. The Jacobian is shown for the transformation from data set NA0 of coordinate system 008 to 014.

3.1.3   Inverse Consistency Error Evaluation Result

The inverse consistency error (ICE) evaluation performance for three non-rigid image registration algorithms with respect to NA0 database was saved in Figure 3.7. ICE evaluation task computed average, minimum, minimum location(for 3D image: min_x, min_y, min_z), maximum, maximum location, standard deviation and percentiles. for each of the 32 ROIs and all ICE evaluation results were saved in $ice1\_t$. From the ICE evaluation task, each pair-wise registration (16 NA0 data sets with 240 transformaions) computed inverse consistency error values, and using them for each of 32 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $ICE1\_ps\_t$ in NIREP result database. Using average values, avg column in population statistic table $ICE1\_ps\_t$, algorithms were ranked for each of 32 ROIs. As
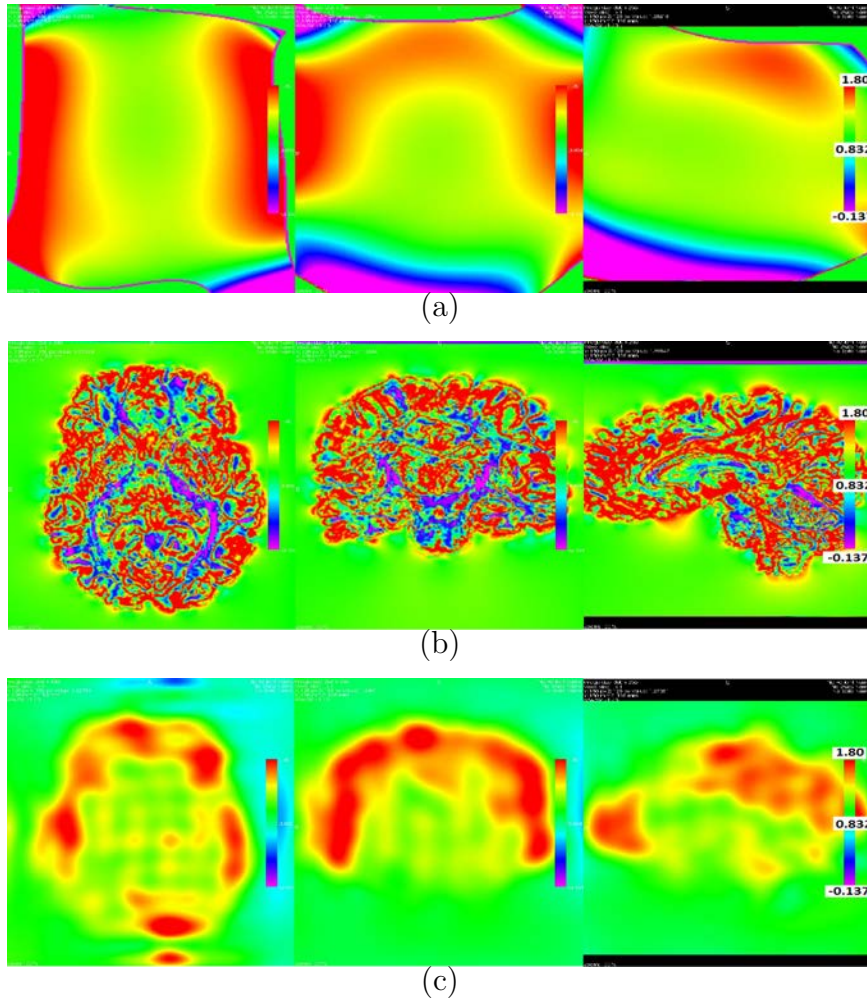
Figure 3.6: An example showing Jacobian of transformations. (a)Jacobian for AIR5 (b)Jacobain for Demons (c)Jacobian for SICLE.

		name_space1	mask1	mask1_alg	mask1_scs	mask1_tcs	name_space2	mask2	mask2_alg	mask2_scs	mask2_tcs	ROI	avg	min	min_x	min_y
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	0	0.00119888	1.16087e-11	200	29
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	1	0.00553229	6.29218e-08	166	59
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	2	0.00583791	2.01963e-07	78	49
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	3	0.00151955	2.20752e-06	133	189
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	4	0.00148359	1.11129e-06	111	223
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	5	0.00059179	2.19431e-07	168	199
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	6	0.000923985	5.79992e-07	81	134
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	7	0.00201427	8.42053e-07	164	193
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	8	0.00665877	5.48956e-06	95	177
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	9	0.00145605	1.59841e-06	200	139
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	10	0.00185023	6.09599e-07	63	125
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	11	0.00186571	8.26829e-07	161	109
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	12	0.002545	3.98112e-07	43	96
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	13	0.00218157	1.62792e-06	151	165
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	14	0.00284811	4.50006e-07	89	119
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	15	0.00215219	2.06605e-07	145	264
☐ ✏ ✗		na0	objectmap	SICLE	001	002	na0	objectmap	SICLE	002	001	16	0.00379725	9.2308e-06	100	260

Figure 3.7: ICE1 evaluation results for NA0 data sets are saved in $ice1\_t$. This shows the ICE evaluation results which is computed from NA0|001 and NA0|002 and SICLE transformation NA0|001 to NA0|002 concatenated with SICLE transformation NA0|002 to NA0|001

shown in Figure 3.8 SICLE got 1st place for all ROIs, Demon got 2nd palce 29 out of 32 ROIs, and AIR5 got 3rd place.

SICLE provides significantly different average values for all the 32 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.4

ICE Images are also computed from ICE evaluation task, besides computing statistic summaries, those images are important to visualize the error. Figure 3.9 shows the inverse consistency error (ICE) for three non-rigid registration algorithms using color scales and using Overlay Image which is superimpose ICE on the top of NA0|008 image. Those ICE images were computed from data set NA0 coordinate
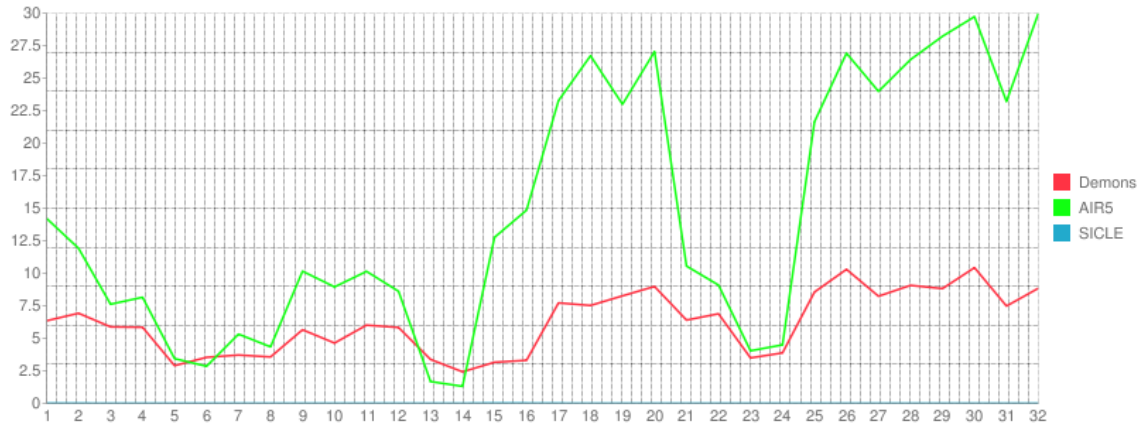
Figure 3.8: Graph of Inverse Consistency Error for 32 ROIs which was computed by averaging ICE average values for 16 NA0 datasets, computed for 240 transformations from three registration algorithms.

Table 3.4: Table for statistically summarizing ICE1 results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	1.30857	30.7369	14.5427	2	3	2.90625
Demons	2.42469	10.4308	6.18824	2	3	2.09375
SICLE	0.001379	0.017749	0.00423797	1	1	1

system 008 and coordinate system 014 and transformations 008 to 014 concatenated with the transformation from 014 to 014.
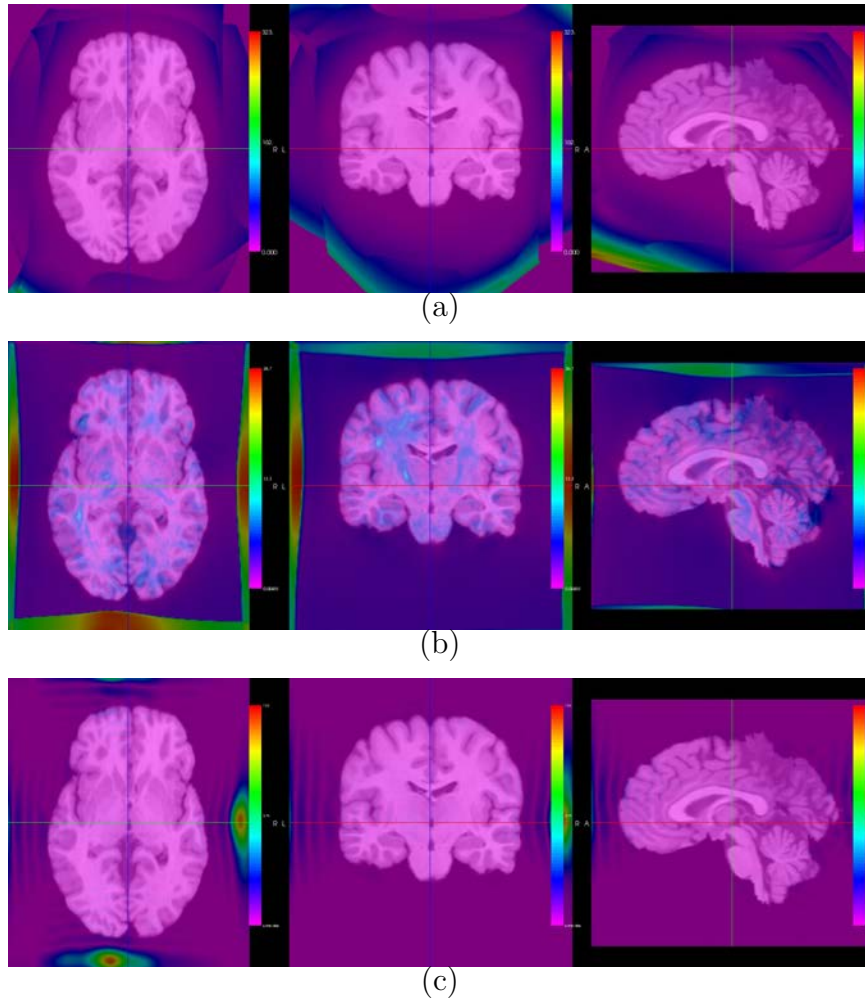
Figure 3.9: An example showing ICE1 superimposed on MRI image of NA0. The Target MRI image here is NA0|014. (a)ICE1 for AIR5 (b)ICE1 for Demons (c)ICE1 for SICLE.

3.1.4 Transitivity Error Evaluation Result

3.1.4.1 Result for Transitivity Error1

The first method of transitivity error (TE1) evaluation performance for three non-rigid image registration algorithms with respect to NA0 database was saved in Figure 3.10. TE evaluation task computed average, minimum, minimum location(for 3D image: min_x, min_y, min_z), maximum, maximum location, standard deviation and percentiles. for each of the 32 ROIs and all TE evaluation results were saved in $te1\_t$. TE1 evaluation task was performed with 5 NA0 data sets (from coordinate

			name_space	ref_mask	refCS	alg_ref_cs1	CS1	alg_cs1_cs2	CS2	alg_cs2_ref	ROI	avg	min	min_x	min_y	min_z	max	max_x	max_y	max_z	
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	0	0.693798	0.000931359	14	296	15	11.2535	100	114	222	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	1	1.44919	0.0334936	151	28	126	7.65509	118	43	122	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	2	1.93071	0.0246032	88	51	126	7.85894	117	46	122	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	3	1.19533	0.0496257	129	188	160	4.18101	134	196	178	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	4	0.95924	0.023042	109	144	178	3.39266	120	205	175	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	5	1.34324	0.218435	176	189	138	3.05394	187	169	124	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	6	1.05196	0.0202437	81	202	135	3.05591	70	194	116	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	7	1.01113	0.00890142	157	179	82	2.6446	187	199	92	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	8	1.14606	0.048092	92	187	82	3.19589	67	194	114	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	9	1.61831	0.0370137	203	166	96	3.85354	198	163	125	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	10	1.20096	0.237473	49	168	130	3.7722	35	133	172	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	11	1.43845	0.017186	204	97	139	5.52143	190	128	90	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	12	1.14108	0.0126776	48	134	121	3.58069	54	97	149	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	13	1.36751	0.0380004	151	160	95	3.60362	164	131	92	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	14	0.589726	0.00808287	95	164	114	1.85683	87	103	137	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	15	1.0023	0.0395328	129	250	99	2.39796	147	260	136	2 0
☐	✎	✗	na0	objectmap	001	SICLE	002	SICLE	003	SICLE	16	1.52415	0.0428363	112	258	110	3.72168	97	258	133	2 0

Figure 3.10: TE first method evaluation results for NA0 data sets are saved in $te1\_t$. This show TE1 was computed data set NA0|001, NA0|002, NA0|003 and SICLE transformations NA0|001 to NA0|002, NA0|002 to NA0|003, and NA0|003 to NA0|001

system 001 to coordinate system 005) and its all combination of transformations (60 transformations). From the average values in $te1\_t$ for each of 32 ROIs, all statistic

values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $TE1\_ps\_t$ in NIREP result database. Using average values, avg column in population statistic table $TE1\_ps\_t$, algorithms were ranked for each of 32 ROIs. As shown in Figure 3.11 SICLE got 1st place for all ROIs, Demon got 2nd palce 21 out of 32 ROIs, and AIR5 got 3rd place.
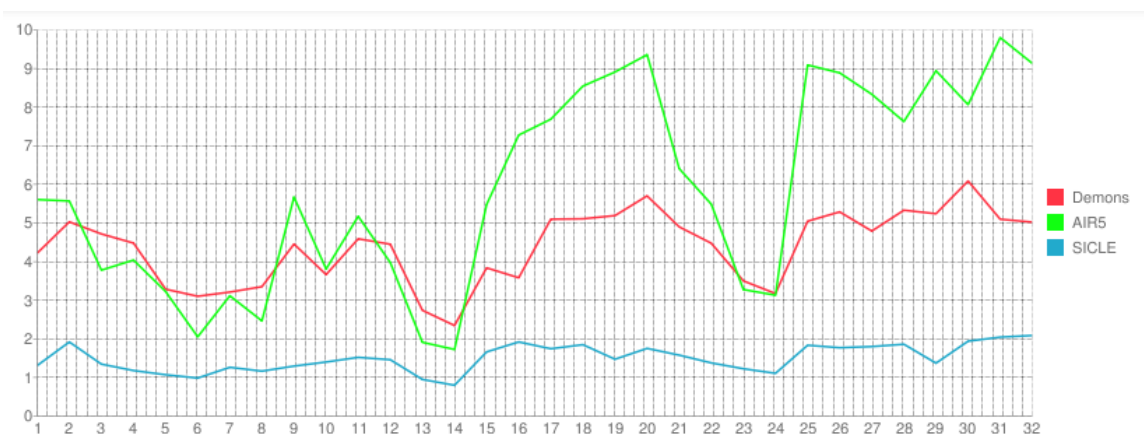
Figure 3.11: Graph of Transitivity Error using first method for 32 ROIs which was computed by averaging TE1 average values for 16 NA0 datasets, computed for 240 transformations from three registration algorithms.

SICLE provides significantly different average values for all the 32 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.5

TE1 Images are also computed from TE1 evaluation task, besides computing statistic summaries, those images are important to visualize the error. Figure 3.12

Table 3.5: Table for statistically summarizing TE1 results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	1.72527	9.79989	5.86089	2	3	2.65625
Demons	2.34562	6.08765	4.37859	2	3	2.34375
SICLE	0.799301	2.08753	1.50208	1	1	1

shows the transitivity error (TE1) for three non-rigid registration algorithms using color scales and using Overlay Image which is superimpose TE on the top of NA0|003 image. Those TE images were computed from data set NA0 coordinate system 001, 002 and 003 and transformations 001 to 002 concatenated with the transformation from 002 to 003 concatenated with the transformation from 003 to 001.

3.1.4.2   Result for Transitivity Error2

The second method of transitivity error (TE2) evaluation performance for three non-rigid image registration algorithms with respect to NA0 database was saved in Figure 3.13. TE evaluation task computed average, minimum, minimum location(for 3D image: min_x, min_y, min_z), maximum, maximum location, standard deviation and percentiles. for each of the 32 ROIs and all TE evaluation results were saved in $te2\_t$.

TE2 evaluation task was performed with 5 NA0 data sets (from coordinate system 001 to coordinate system 005) and its all combination of transformations (60 transformations). From the average values in $te2\_t$ for each of 32 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th,

(a)

(b)

(c)
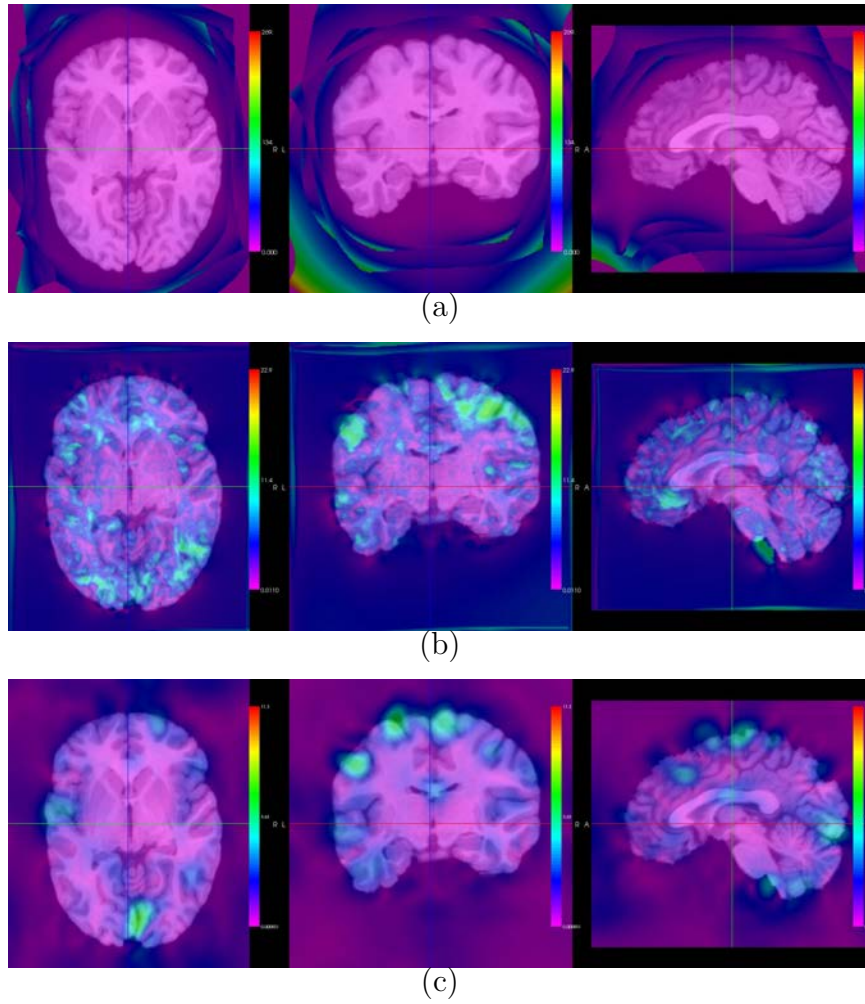
Figure 3.12: An example showing TE1 superimposed on MRI image of NA0. The Target MRI image here is NA0|003. (a)TE1 for AIR5 (b)TE1 for Demons (c)TE1 for SICLE.

name_space	ref_mask	refCS	alg_ref_cs1	CS1	alg_cs1_cs2	CS2	alg_ref_cs2	ROI	avg	min	min_x	min_y	min_z	max	max_x	max_y	max_z
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	0	0.700808	0.000652606	22	16	193	11.3459	97	118	221
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	1	1.42896	0.0252671	152	28	124	7.20422	118	43	122
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	2	2.03421	0.0326487	64	51	137	7.75962	108	56	194
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	3	1.21944	0.019439	130	153	178	4.13112	135	194	178
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	4	0.987751	0.0264829	109	145	178	3.68017	117	206	175
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	5	1.4145	0.20364	176	188	138	3.61822	187	169	124
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	6	1.13728	0.016838	82	203	134	3.23389	70	194	116
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	7	1.09627	0.0223602	161	174	87	2.99042	186	199	93
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	8	1.2372	0.0561957	92	187	82	3.39859	67	194	114
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	9	1.77376	0.0535425	188	127	132	4.9078	203	162	124
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	10	1.19816	0.228964	35	109	151	3.59237	36	137	171
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	11	1.44609	0.0280813	167	160	81	6.09176	188	126	91
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	12	1.17092	0.012212	58	136	128	3.72427	54	98	150
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	13	1.38154	0.0401255	149	159	94	4.21503	164	131	92
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	14	0.638379	0.0171127	107	120	127	2.53921	87	103	137
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	15	1.12921	0.0481324	129	250	98	2.94776	146	257	136
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	16	1.71878	0.0435307	113	259	110	4.33343	97	258	133
na0	objectmap	001	SICLE	002	SICLE	003	SICLE	17	1.87832	0.0464429	146	235	181	7.03898	155	167	214

Figure 3.13: TE second method evaluation results for NA0 data sets are saved in $te1\_t$. This show TE1 was computed data set NA0|001, NA0|002, NA0|003 and SICLE transformations NA0|001 to NA0|002, NA0|002 to NA0|003, and NA0|001 to NA0|003

median, 75th, and 95th)) were computed and saved into $TE2\_ps\_t$ in NIREP result database. Using average values, avg column in population statistic table $TE2\_ps\_t$, algorithms were ranked for each of 32 ROIs. As shown in Figure 3.14 SICLE got 1st place for all ROIs, Demon got 2nd palce 20 out of 32 ROIs, and AIR5 got 3rd place.

SICLE provides significantly different average values for all the 32 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.6

TE2 Images are also computed from TE2 evaluation task, besides computing statistic summaries, those images are important to visualize the error. Figure 3.15
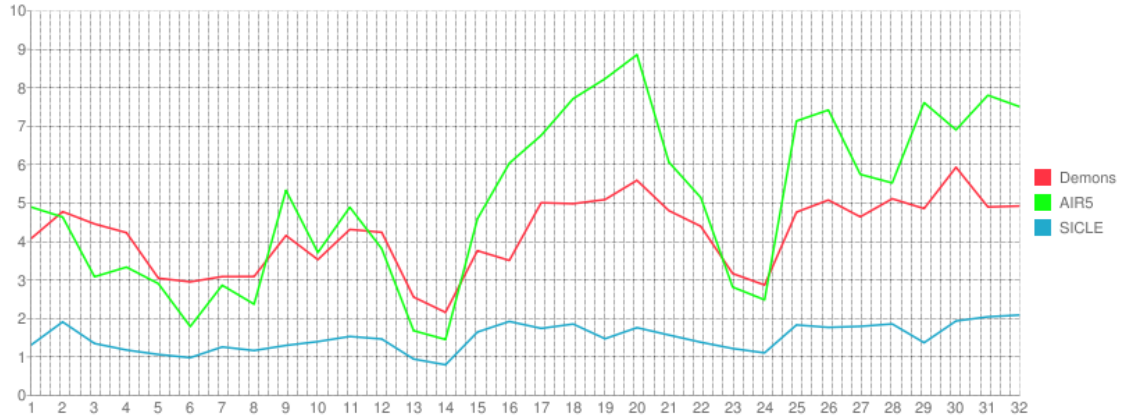
Figure 3.14: Graph of Transitivity Error using second method for 32 ROIs which was computed by averaging TE2 average values for 16 NA0 datasets, computed for 240 transformations from three registration algorithms.

Table 3.6: Table for statistically summarizing TE2 results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	1.45462	8.8586	5.03639	2	3	2.625
Demons	2.16033	5.93205	4.19089	2	3	2.375
SICLE	0.797241	2.09104	1.50223	1	1	1

shows the transitivity error (TE2) for three non-rigid registration algorithms using color scales and using Overlay Image which is superimpose TE2 on the top of NA0|003 image. Those TE2 images were computed from data set NA0 coordinate system 001, 002 and 003 and transformations 001 to 002 concatenated with the transformation from 002 to 003 concatenated with the transformation from 001 to 003.
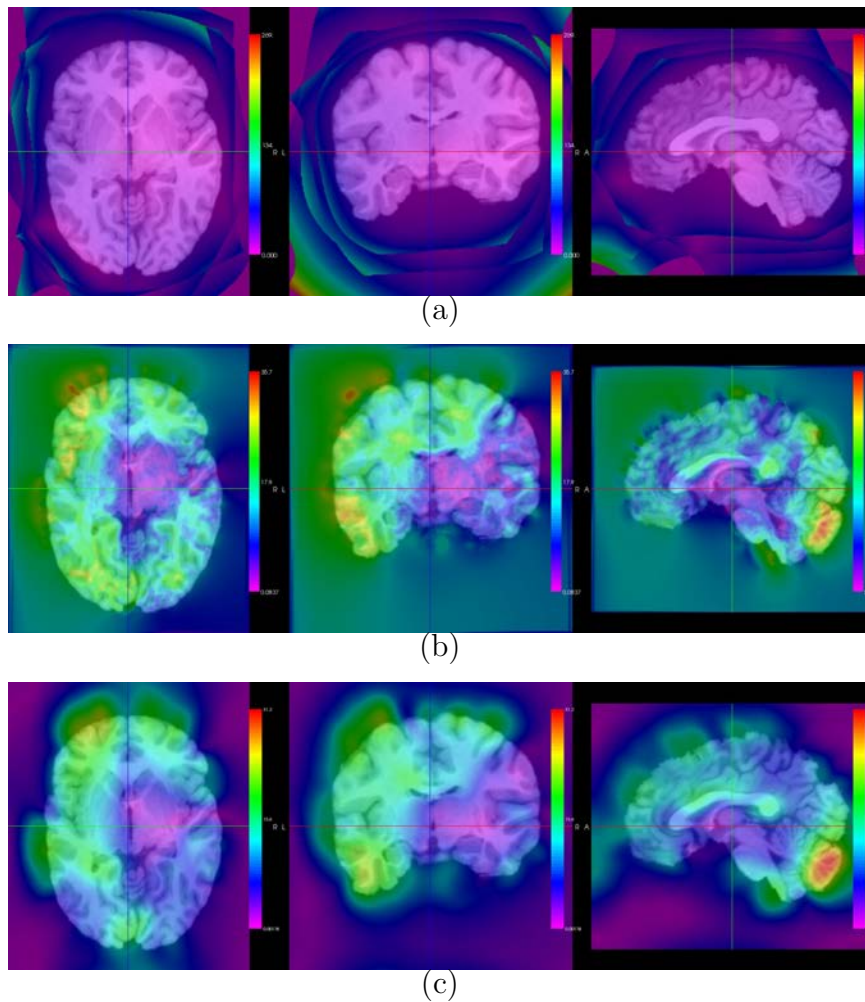
Figure 3.15: An example showing TE2 superimposed on MRI image of NA0. The Target MRI image here is NA0|003. (a)TE2 for AIR5 (b)TE2 for Demons (c)TE2 for SICLE.

3.1.5   Overall Evaluation Result

Figure 3.16 shows the overall result of NA0 evaluation database. From representative values in each evaluation, the average rank was computed with default weight of 1. By averaging all scores and ranks in $result\_t$, place which is total rank was computed. From this work, 3 different algorithm performance was evaluated on 3 different evaluation methods. SICLE got 1st place, Demons got 2nd palce, and AIR5 got 3rd place.

Algorithm	RO Score	RO Rank [1]	DC Score	DC Rank [1]	Sn Score	Sn Rank [1]	ICE1 Score	ICE1 Rank [1]	TE1 Score	TE1 Rank [1]	TE2 Score	TE2 Rank [1]	Average Rank (Submit)	Rank
SICLE	0.381434	2.15625	0.54458	2.1875	0.551091	2.09375	0.00423797	1	1.50208	1	1.50223	1	1.57291666667	1
Demons	0.502887	1	0.663179	1	0.670351	1	6.18824	2.09375	4.37859	2.34375	4.19089	2.375	1.63541666667	2
AIR5	0.357664	2.84375	0.520799	2.8125	0.523642	2.90625	14.5427	2.90625	5.86089	2.65625	5.03639	2.625	2.79166666667	3

Figure 3.16: Overall Evaluation Result table for NA0 database in NIREP website

3.2   Evaluation Result for NA1 database

3.2.1   Overlap Evaluation Result

The overlap performance for three non-rigid image registration algorithms with respect to NA1 database was saved in Figure 3.17. Overlap evaluation task computed relative overlap, dice coefficient, and sensitivity for each of the 57 ROI and all overlap evaluation results were saved in $overlap\_t$ with corresponding image information. From relative overlap, dice coefficient, and sensitivity values in $overlap\_t$, population statistic values of all pair-wise evaluation results for each ROI were computed and saved in $RelativeOverlap\_ps\_t$, $DiceCoeff\_ps\_t$, and $Sensitivity\_ps\_t$ respectively.

			name_space1	mask1	mask1_alg	mask1_scs	mask1_tcs	name_space2	mask2	mask2_alg	mask2_scs	mask2_tcs	ROI	RelativeOverlap	DiceCoeff	Sensitivity	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	0	0.961682	0.980467	0.980378	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	1	0.207133	0.343181	0.271453	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	2	0.181691	0.30751	0.313707	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	3	0.0836205	0.154335	0.138456	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	4	0.266159	0.420419	0.444904	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	5	0.228859	0.372474	0.500257	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	6	0.249522	0.399388	0.487887	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	7	0.274023	0.43017	0.501055	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	8	0.142755	0.249844	0.233973	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	9	0.137599	0.241911	0.306465	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	10	0.307764	0.470672	0.434929	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	11	0.27851	0.43568	0.46013	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	12	0.432737	0.604071	0.594738	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	13	0.437089	0.608298	0.606757	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	14	0.304779	0.467173	0.422968	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	15	0.330379	0.496669	0.454966	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	16	0.321332	0.486376	0.504756	
☐	✐	✗	na1	objectmap	SICLE	001	002	na1	objectmap	N/A	002	002	17	0.3002	0.461775	0.430098	

Figure 3.17: Overlap evaluation results for NA1 database are saved in *overlap_t*. This shows overlap evaluation results between NA1|002 image with NA1|001 registered to NA1|002 with SICLE algorithm for all ROIs

In $RelativeOverlap\_ps\_t$, $DiceCoeff\_ps\_t$, and $Sensitivity\_ps\_t$, minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median(50th), 75th, and 95th) were calculated for each ROI.

3.2.1.1 Result for Relative Overlap

Relative overlap evaluation performance for three non-rigid registration algorithms with respect to NA1 database are shown in Table 3.7 and Figure 3.18. From the overlap evaluation task, each pair-wise registration (18 NA1 data sets with 306 transformaions) computed relative overlap values, and using them for each of 57 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into

RelativeOverlap_ps_t in NIREP result database. Using average values, avg column in population statistic table *RelativeOverlap_ps_t*, algorithms were ranked for each of 57 ROIs. As shown in Figure 3.18 SICLE got 1st place for 28 out of 57 ROIs, AIR5 got 2nd palce, and Demons got 3rd place. SICLE and AIR5 got similar val-
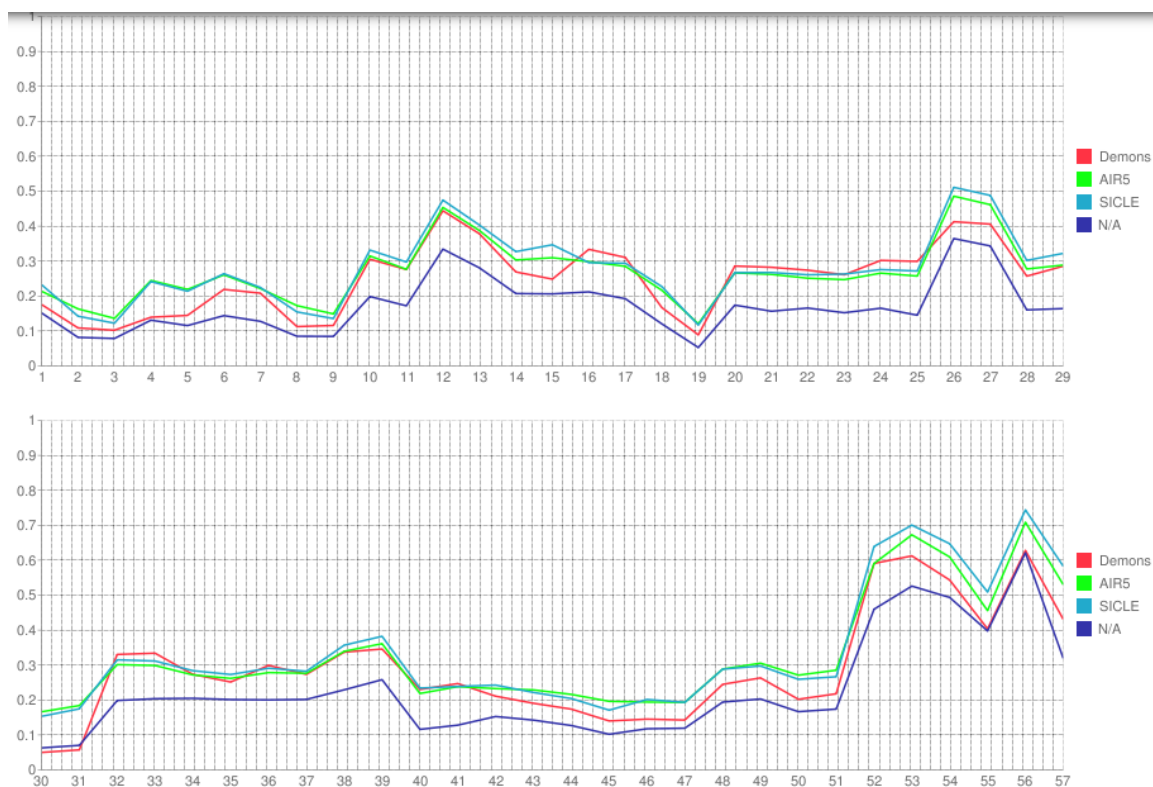
Figure 3.18: Graph of Average Relative Overlap for 57 ROIs which was computed by averaging relative overlap values for 18 NA1 datasets, computed for 306 transformations from three registration algorithms and one without transformations.

ues but Demons provides significantly different, i.e., Demons had smallar RO of 57 regins than all other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were

Table 3.7: Table for statistically summarizing Relative Overlap results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	0.120695	0.708584	0.297918	1	3	1.94737
Demons	0.04995	0.627963	0.269823	1	3	2.54386
SICLE	0.116892	0.743895	0.30764	1	3	1.50877

calculated, and the result is shown in Table 3.7.

3.2.1.2   Result for Dice Coefficient

Dice coefficient evaluation performance for three non-rigid registration algorithms with respect to NA1 database are shown in Table 3.8 and Figure 3.19. From the overlap evaluation task, each pair-wise registration (18 NA1 data sets with 306 transformaions) computed dice coefficient values, and using them for each of 57 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $DiceCoeff\_ps\_t$ in NIREP result database. Using values of avg column in population statistic table, $DiceCoeff\_ps\_t$, algorithms were ranked for each of 57 ROIs. As shown in Figure 3.19 SICLE got 1st place for 29 out of 57 ROIs, AIR5 got 2nd palce, and Demons got 3rd place.

SICLE and AIR5 got similar values but Demons provides significantly different, i.e., Demons had smallar DC of 57 regins than all other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.8.
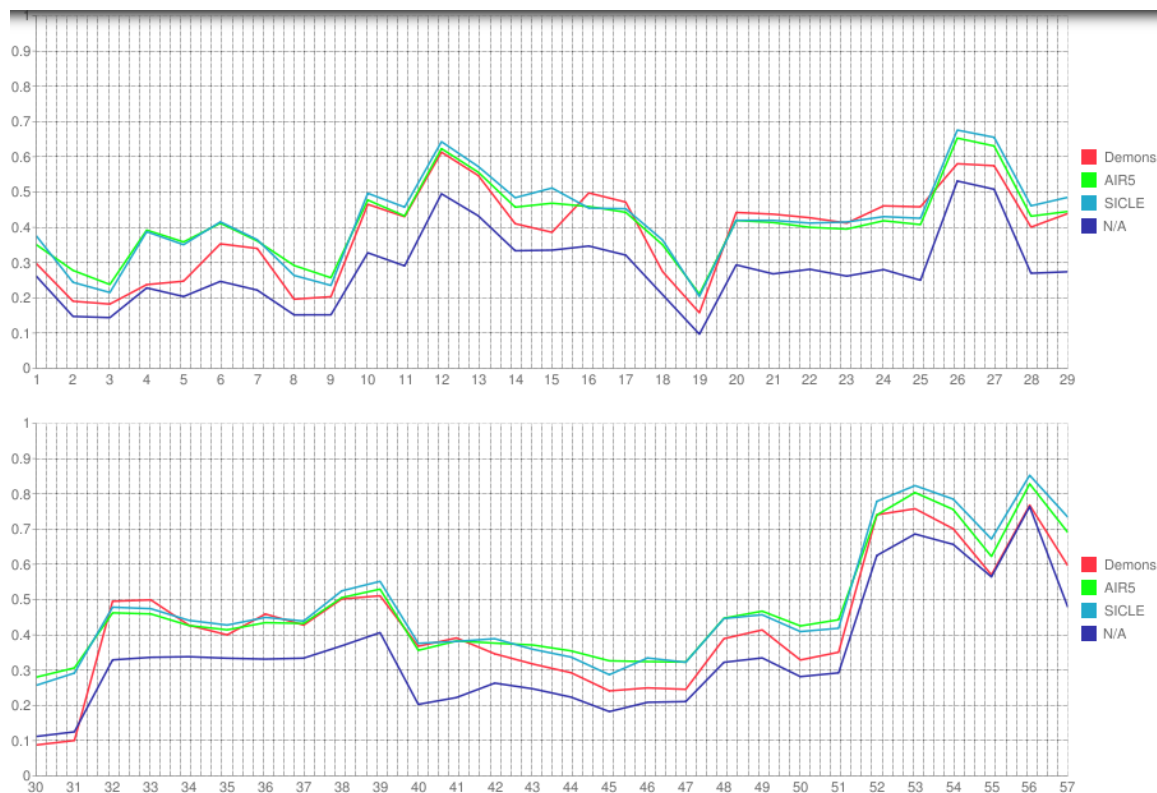
Figure 3.19: Graph of Average Dice Coefficient for 57 ROIs which was computed by averaging relative overlap values for 18 NA1 datasets, computed for 306 transformations from three registration algorithms and one without transformations

Table 3.8: Table for statistically summarizing Dice Coefficient results using NA1 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	0.210571	0.82836	0.444193	2	3	1.92982
Demons	0.087695	0.85259	0.405413	1	3	2.54386
SICLE	0.087695	0.85259	0.452436	1	3	1.50877

3.2.1.3 Result for Sensitivity

Sensitivity(target overlap) evaluation performance for three non-rigid registration algorithms with respect to NA1 database are shown in Table 3.9 and Figure 3.2.1.3. From the overlap evaluation task, each pair-wise registration (18 NA1 data sets with 306 transformaions) computed sensitivity(target overlap) values, and using them for each of 57 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $Sensitivity\_ps\_t$ in NIREP result database. Using values of avg column in population statistic table, $Sensitivity\_ps\_t$, algorithms were ranked for each of 57 ROIs. As shown in Figure 3.2.1.3 SICLE got 1st place for 34 out of 57 ROIs, AIR5 got 2nd palce, and Demons got 3rd place.

SICLE and AIR5 got similar values but Demons provides significantly different, i.e., Demons had smallar DC of 57 regins than all other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.9.
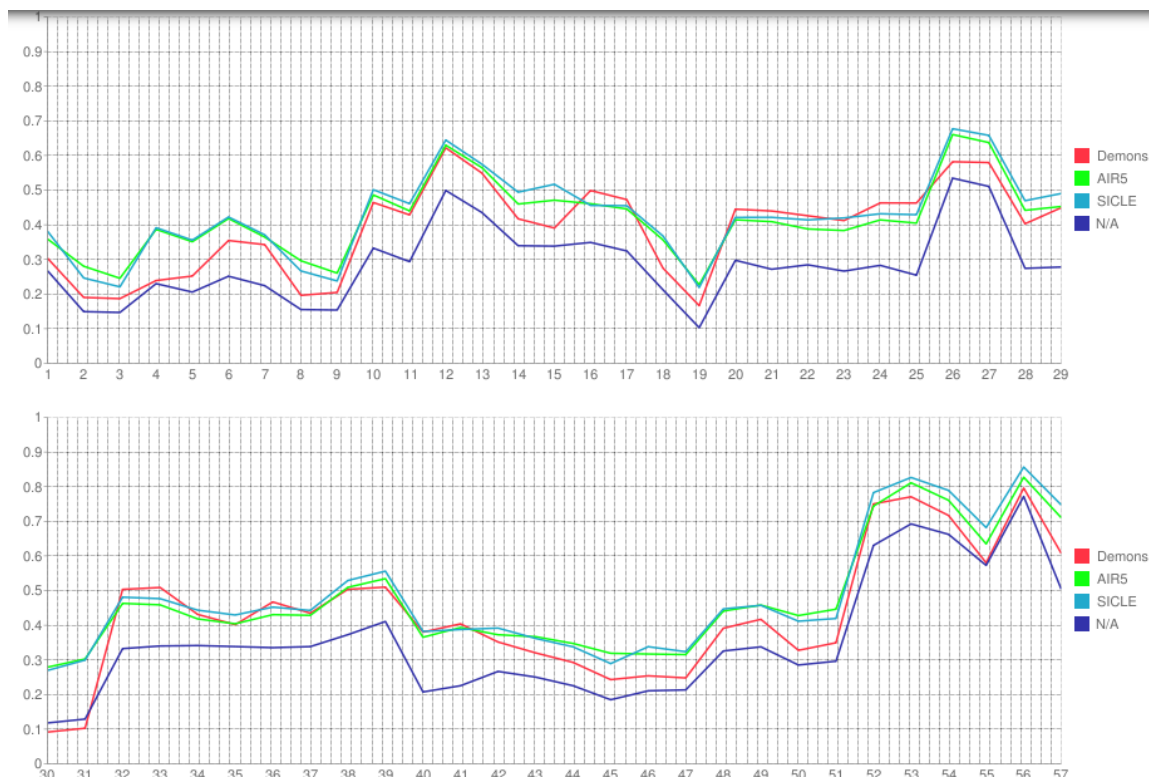
Figure 3.20: Graph of Average Sensitivity for 57 ROIs which was computed by averaging relative overlap values for 18 NA1 datasets, computed for 306 transformations from three registration algorithms and one without transformations.

Table 3.9: Table for statistically summarizing Sensitivity results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	0.226822	0.827113	0.445501	1	3	2.01754
Demons	0.091681	0.795753	0.4100015	1	3	2.52632
SICLE	0.218849	0.856501	0.456579	1	3	1.45614

3.2.2   Jacobian Evaluation Result

The determinant of the Jacobian of the deformation field, j, is calculated at every point. For every 57 regions, the determinant of Jacobian evaluation computes avg, minimum, minimum location(for 3D image : min_x, min_y, min_z), maximum, and maximum location. All of statistic values are computed and saved in to $jacobian\_t$ in NIREP result database, and the table is shown below in Figure 3.21.

In Jacobian evaluation, the negative values is important because it means singularities folding or tearing in the image, so Jacobian result was used for the reference to consideration of choosing better transformation. Figure 3.22 shows the Jacobian deformation for three non-rigid registration algorithms. The Jacobian is shown for the transformation from data set NA1|008 to NA1|014.

3.2.3   Inverse Consistency Error Evaluation Result

The inverse consistency error (ICE) evaluation performance for three non-rigid image registration algorithms with respect to NA1 database was saved in Figure 3.23. ICE evaluation task computed average, minimum, minimum location(for 3D image:

		name_space1	mask1	mask1_alg	mask1_scs	mask1_tcs	name_space2	mask2	mask2_alg	mask2_scs	mask2_tcs	ROI	avg	min	min_x	min_y	min_z
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	0	1.00011	0.627635	164	173	127
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	1	0.907409	0.723597	128	164	124
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	2	1.10131	0.951766	141	78	134
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	3	1.03376	0.851246	110	43	121
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	4	1.13969	0.930287	168	63	112
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	5	0.890776	0.656449	107	48	105
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	6	1.04722	0.782099	149	95	120
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	7	1.01125	0.660888	108	48	106
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	8	1.17824	0.917494	142	79	128
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	9	1.02298	0.679132	110	47	107
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	10	0.905473	0.720206	129	166	123
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	11	0.931916	0.724931	125	166	124
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	12	0.92107	0.750581	156	161	126
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	13	0.99689	0.78172	100	101	139
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	14	0.993957	0.880569	150	149	111
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	15	1.26024	1.06416	103	159	109
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	16	0.946164	0.805192	176	124	118
☐ ✎ ✗	na1	objmap	SICLE	001	002	na1	objectmap	N/A	002	002	17	0.992874	0.808384	93	98	144

Figure 3.21: Jacobian evaluation results for NA1 data sets are saved in $jacobian\_t$. This shows the jacobian values for SICLE transformation that NA1|001 registered to NA1|002 for all ROIs

min_x, min_y, min_z), maximum, maximum location, standard deviation and per-centiles. for each of the 32 ROIs and all ICE evaluation results were saved in $ice1\_t$.

From the ICE1 evaluation task, each pair-wise registration (18 NA1 data sets with 306 transformaions) computed inverse consistency error values, and using them for each of 57 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $ICE1\_ps\_t$ in NIREP result database. Using average values, avg column in population statistic table $ICE1\_ps\_t$, algorithms were ranked for each of 57 ROIs. As shown in Figure 3.24 SICLE got 1st place for all ROIs, AIR5 got 2nd palce 35 out of 57 ROIs, and Demons got 3rd place.
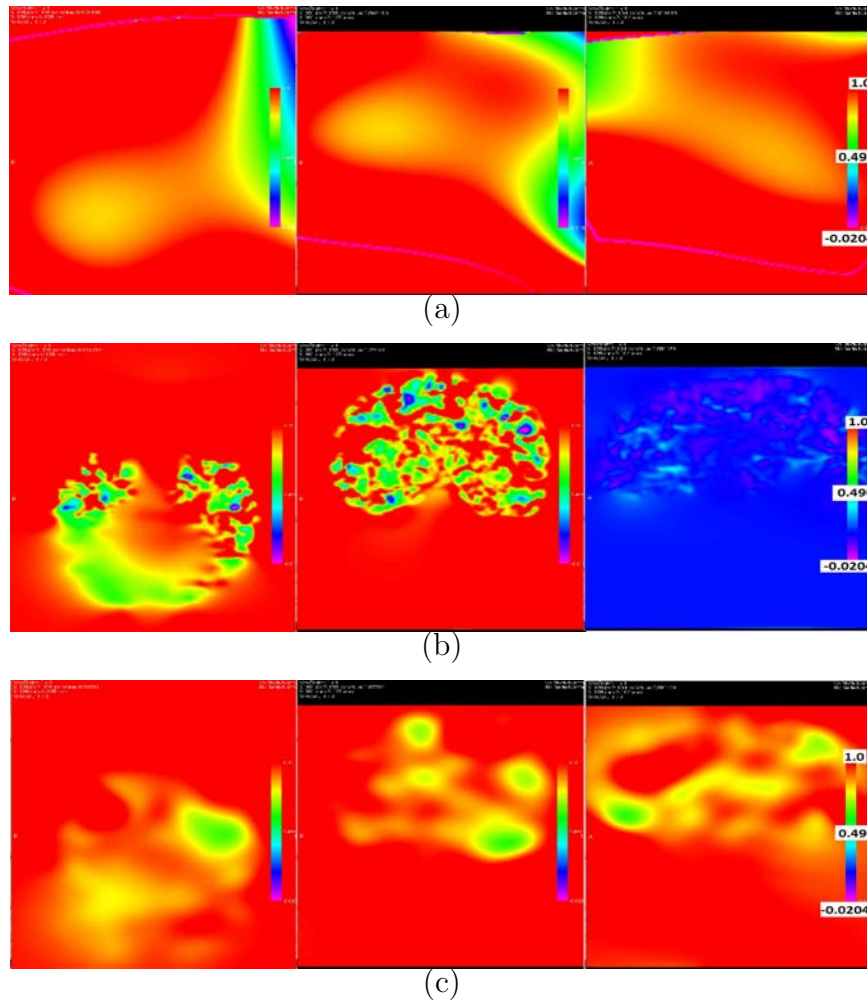
Figure 3.22: An example showing Jacobian of transformations. (a)Jacobian for AIR5 (b)Jacobain for Demons (c)Jacobian for SICLE.

name_space1	mask1	mask1_alg	mask1_scs	mask1_tcs	name_space2	mask2	mask2_alg	mask2_scs	mask2_tcs	ROI	avg	min	min_x	min_y
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	0	0.000411169	1.97877e-13	14	232
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	1	0.00195228	1.71247e-06	127	108
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	2	0.00220769	3.7798e-06	123	66
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	3	0.00340381	1.14042e-05	113	54
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	4	0.0039837	1.53482e-06	133	32
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	5	0.00659301	1.10403e-06	81	50
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	6	0.00306661	4.98615e-06	135	69
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	7	0.00384201	1.04676e-06	113	69
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	8	0.00427307	7.05582e-06	130	66
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	9	0.00609511	5.19828e-06	111	73
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	10	0.0016078	1.48829e-06	133	113
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	11	0.00164993	1.79124e-06	123	162
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	12	0.00184023	7.36589e-07	149	150
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	13	0.00117911	2.15502e-06	97	156
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	14	0.00652417	7.62609e-06	159	164
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	15	0.00430455	1.11348e-05	100	158
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	16	0.00211877	9.82003e-07	167	131
na1	objectmap	SICLE	001	002	na1	objectmap	SICLE	002	001	17	0.00186498	2.61752e-	69	127

Figure 3.23: ICE1 evaluation results for NA1 data sets are saved in $ice1\_t$. This shows the ICE evaluation results which is computed from NA1|001 and NA0|002 and SICLE transformation NA1|001 to NA1|002 concatenated with SICLE transformation NA1|002 to NA1|001
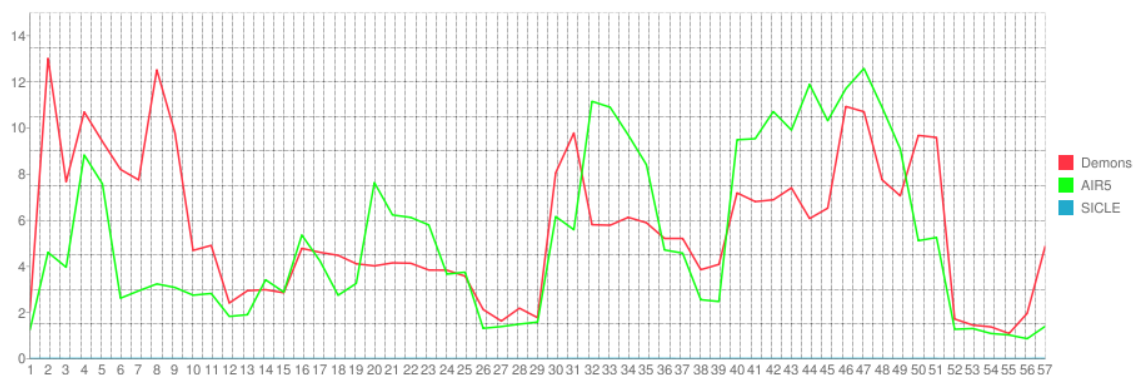
Figure 3.24: Graph of Inverse Consistency Error for 57 ROIs which was computed by averaging ICE average values for 18 NA0 datasets, computed for 306 transformations from three registration algorithms.

Table 3.10: Table for statistically summarizing ICE1 results using NA1 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	0.869333	12.5807	5.23083	2	3	2.2807
Demons	1.09509	13.0198	5.61892	2	3	2.61404
SICLE	0.000804	0.005722	0.00289747	1	1	1

SICLE provides significantly different average values for all the 57 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.10

ICE Images are also computed from ICE evaluation task, besides computing statistic summaries, those images are important to visualize the error. Figure 3.25 shows the inverse consistency error (ICE) for three non-rigid registration algorithms using color scales and using Overlay Image which is superimpose ICE on the top of NA1|008 image. Those ICE images were computed from data set NA1 coordinate system 008 and coordinate system 014 and transformations 008 to 014 concatenated with the transformation from 014 to 008.

3.2.4   Transitivity Error Evaluation Result

3.2.4.1   Result for Transitivity Error1

The first method of transitivity error (TE1) evaluation performance for three non-rigid image registration algorithms with respect to NA1 database was saved in Figure 3.26. TE evaluation task computed average, minimum, minimum location(for
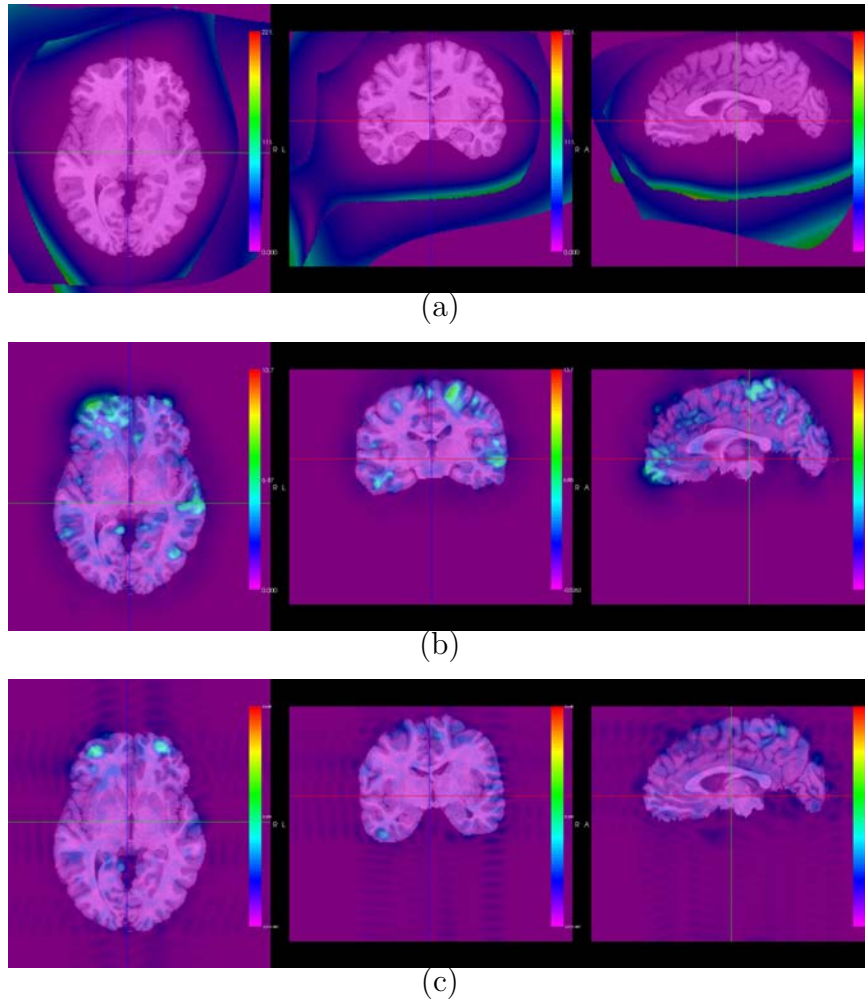
Figure 3.25: An example showing ICE1 superimposed on MRI image of NA1. The Target MRI image here is NA1|014. (a)ICE1 for AIR5 (b)ICE1 for Demons (c)ICE1 for SICLE.

3D image: min_x, min_y, min_z), maximum, maximum location, standard deviation
and percentiles. for each of the 32 ROIs and all TE evaluation results were saved
in $te1\_t$. TE1 evaluation task was performed with 5 NA1 data sets (from coordinate

			name_space	ref_mask	refCS	alg_ref_cs1	CS1	alg_cs1_cs2	CS2	alg_cs2_ref	ROI	avg	min	min_x	min_y	min_z	max	max_x	max_y	max_z
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	0	0.268854	0.000138102	241	220	21	6.36533	152	96	185
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	1	0.506605	0.00418454	155	133	144	1.53177	128	94	140
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	2	1.65585	0.0884076	125	151	137	4.27125	136	62	141
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	3	1.32378	0.548093	115	66	137	2.56329	126	50	110
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	4	1.38434	0.0340902	168	53	104	3.16735	166	64	126
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	5	1.77547	0.109625	88	65	114	6.31196	108	59	91
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	6	1.60698	0.267689	129	59	98	2.89091	132	50	108
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	7	1.87841	0.0740163	128	66	104	6.08513	110	60	94
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	8	1.58912	0.251741	139	60	128	2.74866	132	52	110
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	9	1.72531	0.37071	129	60	99	5.04685	117	61	96
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	10	0.806343	0.018286	141	136	122	2.26547	137	84	121
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	11	0.84817	0.0301743	124	129	157	2.28586	103	91	119
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	12	0.431727	0.0163489	153	137	147	1.09448	166	132	141
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	13	0.651631	0.0243288	101	144	125	2.34714	89	151	142
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	14	0.957142	0.0429449	156	158	104	2.69199	164	162	118
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	15	1.04747	0.165284	102	146	108	1.61357	101	163	111
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	16	1.00651	0.183501	162	115	129	2.70083	165	163	118

Figure 3.26: TE first method evaluation results for NA1 data sets are saved in $te1\_t$.
This show TE1 was computed data set NA1|001, NA1|002, NA1|003 and SICLE
transformations NA1|001 to NA1|002, NA1|002 to NA1|003, and NA1|003 to NA1|001

system 001 to coordinate system 005) and its all combination of transformations (60
transformations). From the average values in $te1\_t$ for each of 57 ROIs, all statistic
values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th,
median, 75th, and 95th)) were computed and saved into $TE1\_ps\_t$ in NIREP result
database. Using average values, avg column in population statistic table $TE1\_ps\_t$,
algorithms were ranked for each of 57 ROIs. As shown in Figure 3.27 SICLE got 1st
place for all ROIs, Demon got 2nd palce 39 out of 57 ROIs, and AIR5 got 3rd place.

Figure 3.27: Graph of Transitivity Error using first method for 57 ROIs which was computed by averaging TE1 average values for 18 NA0 datasets, computed for 306 transformations from three registration algorithms.

Table 3.11: Table for statistically summarizing TE1 results using NA0 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	1.35221	6.03082	3.64579	2	3	2.68421
Demons	1.14596	4.62109	3.11445	2	3	2.31579
SICLE	0.341811	2.60179	1.28655	1	1	1

SICLE provides significantly different average values for all the 57 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.11

TE1 Images are also computed from TE1 evaluation task, besides computing statistic summaries, those images are important to visualize the error. Figure 3.28 shows the transitivity error (TE1) for three non-rigid registration algorithms using color scales and using Overlay Image which is superimpose TE on the top of NA1|003 image. Those TE images were computed from data set NA1 coordinate system 001,

002 and 003 and transformations 001 to 002 concatenated with the transformation

from 002 to 003 concatenated with the transformation from 003 to 001.
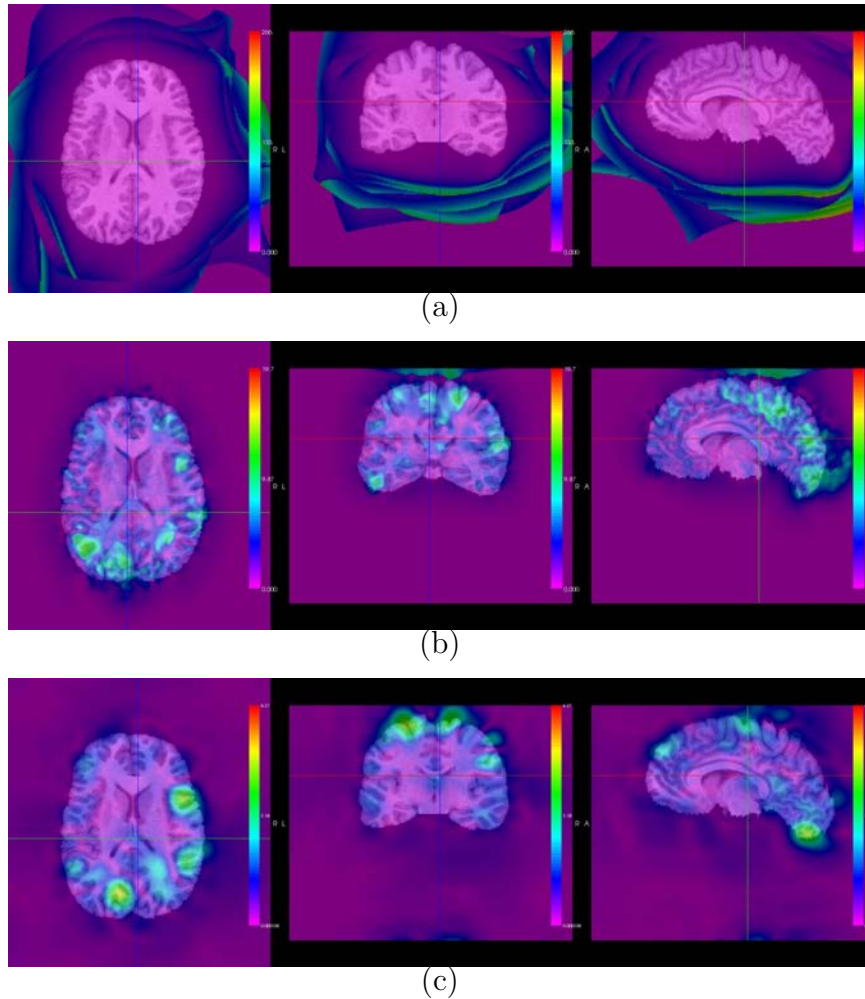
Figure 3.28: An example showing TE1 superimposed on MRI image of NA1. The Target MRI image here is NA1|003. (a)TE1 for AIR5 (b)TE1 for Demons (c)TE1 for SICLE.

3.2.4.2 Result for Transitivity Error2

The second method of transitivity error (TE2) evaluation performance for three non-rigid image registration algorithms with respect to NA1 database was saved in Figure 3.29. TE evaluation task computed average, minimum, minimum location(for 3D image: min_x, min_y, min_z), maximum, maximum location, standard deviation and percentiles. for each of the 57 ROIs and all TE evaluation results were saved in $te2\_t$.

			name_space	ref_mask	refCS	alg_ref_cs1	CS1	alg_cs1_cs2	CS2	alg_ref_cs2	ROI	avg	min	min_x	min_y	min_z	max	max_x	max_y	max_z
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	0	0.272621	0.000109678	241	220	21	6.80354	149	91	187
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	1	0.516623	0.0151132	142	141	123	1.77823	117	96	122
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	2	1.72638	0.0932219	125	151	135	4.61601	136	62	141
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	3	1.31828	0.597154	116	66	137	2.48412	126	48	109
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	4	1.48217	0.0295181	169	54	105	3.50654	166	64	125
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	5	1.60579	0.0887235	88	65	114	5.20245	107	56	89
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	6	1.8294	0.273075	129	59	98	2.93622	133	50	108
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	7	1.83282	0.0592474	128	66	104	4.83466	113	60	92
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	8	1.68435	0.233851	139	60	128	2.86948	136	51	105
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	9	1.61269	0.284354	128	58	98	3.96099	117	61	96
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	10	0.815703	0.0186919	128	172	127	2.6015	137	84	121
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	11	0.878531	0.029386	124	129	157	2.57357	103	88	123
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	12	0.418942	0.019194	153	158	144	0.953619	166	132	141
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	13	0.651184	0.012082	101	144	125	2.28773	89	151	142
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	14	0.924958	0.0619498	157	157	104	2.59569	164	164	117
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	15	1.09579	0.16367	102	146	108	1.59769	100	164	110
☐	✎	✗	na1	objectmap	001	SICLE	002	SICLE	003	SICLE	16	0.993196	0.171768	183	132	117	2.59528	165	165	117

Figure 3.29: TE second method evaluation results for NA1 data sets are saved in $te1\_t$. This show TE1 was computed data set NA1|001, NA1|002, NA1|003 and SICLE transformations NA1|001 to NA1|002, NA1|002 to NA1|003, and NA1|001 to NA1|003

TE2 evaluation task was performed with 5 NA1 data sets (from coordinate system 001 to coordinate system 005) and its all combination of transformations (60

transformations). From the average values in $te2\_t$ for each of 57 ROIs, all statistic values(minimum, maximum, average, standard deviation, and percentiles (5th, 25th, median, 75th, and 95th)) were computed and saved into $TE2\_ps\_t$ in NIREP result database. Using average values, avg column in population statistic table $TE2\_ps\_t$, algorithms were ranked for each of 57 ROIs. As shown in Figure 3.30 SICLE got 1st place for all ROIs, Demon got 2nd palce 37 out of 57 ROIs, and AIR5 got 3rd place.

Figure 3.30: Graph of Transitivity Error using second method for 57 ROIs which was computed by averaging TE1 average values for 18 NA0 datasets, computed for 306 transformations from three registration algorithms.

SICLE provides significantly different average values for all the 57 regions than all the other registration algorithms. To compute representative values for algorithm, average score which is averaging all ROIs average value, average rank were calculated, and the result is shown in Table 3.12

TE2 Images are also computed from TE2 evaluation task, besides computing statistic summaries, those images are important to visualize the error. Figure 3.31

Table 3.12: Table for statistically summarizing TE2 results using NA1 data sets

Algorithm	Score min	Score max	Score avg	Rank min	Rank max	Rank avg
AIR5	1.10046	5.82382	3.3445	2	3	2.64912
Demons	0.719832	4.32759	2.81197	2	3	2.35088
SICLE	0.340949	2.6044	1.28455	1	1	1

shows the transitivity error (TE2) for three non-rigid registration algorithms using color scales and using Overlay Image which is superimpose TE2 on the top of NA1|003 image. Those TE2 images were computed from data set NA1 coordinate system 001, 002 and 003 and transformations 001 to 002 concatenated with the transformation from 002 to 003 concatenated with the transformation from 001 to 003.

3.2.5 Overall Evaluation Result

Figure 3.32 shows the overall result of NA1 evaluation database. From representative values in each evaluation, the average rank was computed with default weight of 1. By averaging all scores and ranks in $result\_t$, place which is total rank was computed. From this work, 3 different algorithm performance was evaluated on 3 different evaluation methods. SICLE got 1st place, AIR got 2nd palce, and Demon got 3rd place.

(a)

(b)

(c)
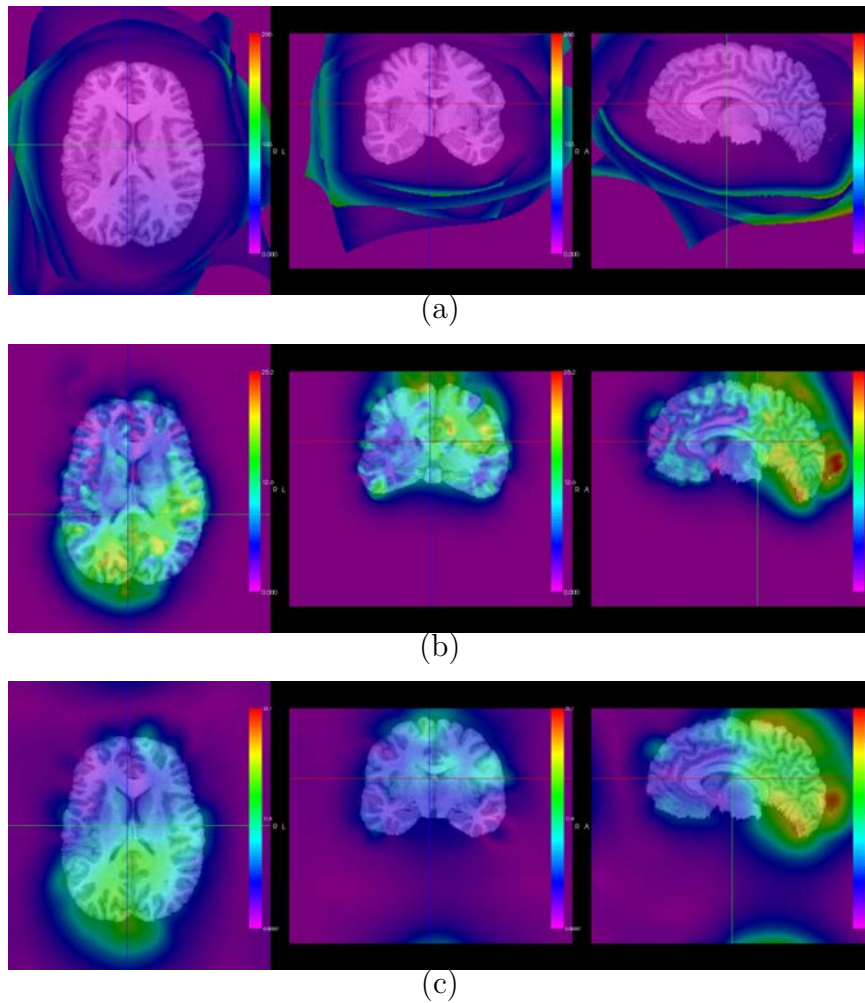
Figure 3.31: An example showing TE2 superimposed on MRI image of NA1. The Target MRI image here is NA1|003. (a)TE2 for AIR5 (b)TE2 for Demons (c)TE2 for SICLE.

Algorithm	RO Score	RO Rank	DC Score	DC Rank	Sn Score	Sn Rank	ICE1 Score	ICE1 Rank	TE1 Score	TE1 Rank	TE2 Score	TE2 Rank	Average Rank	Rank
		1		1		1		1		1		1	Submit	
SICLE	0.30764	1.50877	0.452436	1.52632	0.456579	1.45614	0.00289747	1	1.28655	1	1.28455	1	1.24854	1
AIR5	0.297918	1.94737	0.444193	1.92982	0.445501	2.01754	5.23083	2.38596	3.64579	2.68421	3.3445	2.64912	2.269	2
Demons	0.269823	2.54386	0.405413	2.54386	0.410015	2.52632	5.61892	2.61404	3.11445	2.31579	2.81197	2.35088	2.48246	3

Figure 3.32: Overall Evaluation Result table for NA1 database in NIREP website

CHAPTER 4
DISCUSSION

4.1   Discussion of evaluating registration performances

For overlap evaluations which includes relative overlap, dice coefficient and sensitivity, we know that bigger overlap values implies the better performance of the registration algorithm. For NA0 database as shown in Figure 3.2,Table 3.1, Figure 3.3,Table 3.2, Figure 3.4, and Table 3.3, the overall best overlap statistic result is given by Demons algorithm. Also SICLE gives slightly better than AIR5 performance. For the comparison to other algorithms, overlap evaluation was computed without transformation, and for all ROIs it has smallest values. For NA1 database as shown in Figure 3.18,Table 3.7, Figure 3.19,Table 3.8, Figure 3.2.1.3, and Table 3.9, the overall best overlap statistic result is given by SICLE algorithm but three algorithms doesnt gives not significantly different results. In most ROIs overlap evaluation results are low values (nearly 0.2 to 0.6) because of complexity of brain cortex and partly to the small ROIs that were used and especially ROIs just include graymatter.

For Jacobian evaluation, we didnt use it as computing the population statistic because Jacobian was used for the reference of the transformation. Having a Jacobian results values near 1 or equal to 1 doesnt imply the transformation is good, but having negative values in Jacobian evaluation results means the transformation has folding or tearing. SICLE and AIR doesnt have negative values but Demons contains negative values.

For Inverse Consistency Error (ICE) evaluations, Figure 3.8, Table 3.4, Figure 3.9, Figure 3.24, Table 3.10, Figure 3.25 shows that the SICLE algorithm has significantly less ICE than any other algorithms for both NA0 and NA1 databases.

For Transitivity Error (TE) evaluations(both TE1 and TE2), Figure 3.11, Table 3.5, Figure 3.12, Figure 3.14, Table 3.6, Figure 3.15, Figure 3.27, Table 3.11, Figure 3.28, Figure 3.30, Table 3.12, and Figure 3.31 shows that the SICLE algorithm has significantly less TE than any other algorithms for both NA0 and NA1 databases.

From above all evaluation statistics overall results are computed and it is shown in Figure 3.16 for NA1 data sets and Figure 3.32 for NA1 data sets. For the default all evaluation has same weight 1, and the result for NA0 are SICLE got first palce, Demons got second, and AIR5 got third place, and for NA1 are SICLE got first palce, AIR5 got second, and Demons got third place. The fact that one registration algorithm produced the best result for one criterion and nearly the worse for another, illustrates the need to use multiple evaluation criteria. SICLE has the best performance on ICE and TE statistic evaluation and this shows us the inverse consistency constraint reduced the TE as well. Moreover, Demon has a good performance on overlap statistic evaluations. Therefore, by changing weight on the each evaluation ranks, total rank is changed, so user can choose the weight to get the best algorithms for their purpose or applications.

4.2   Discussion of using result database

NIREP website shows all evaluation results from every participants who join this project and submit their results. All result data shown on the website are saved in

MySQL database which is used for NIREP website. However, all evaluation results are computed from NIREP software. Therefore, database engine was needed for NIREP software, and we chose SQLite because it is open source, server-less, and light.

Using database engine has several advantages. It provides convenient way to save result data from NIREP evaluation tasks, to create several different tables, and to use data in database. For example, evaluation tasks such as overlap, Jacobian, ICE(inverse consistency error) and TE(transitivity error) evaluation computes different results shown in Chapter 3, so we created one or more table for each evaluation. Each evaluation task has its table, i.e., each task is connected with its table in database, so by performing evaluation task, all results data are automatically saved into its evaluation table in SQLite database. In the future when evaluation methods will be added more to NIREP software, only adding evaluation tasks to NIREP and connecting to SQLite. Moreover, using evaluation data in database, we statistically summarized for all evaluation results and the population statistic values were saved into evaluation population statistic tables. Using population statistic values in the database, table and graph can be generated. All evaluation population statistic tables are shown in the website, and using mean in the table, line graphs are created, and using percentiles, the candlestick graphs are computed.

CHAPTER 5
CONCLUSION

The NIREP have been started to develop software tools and provide shared image evaluation databases for rigorous testing of non-rigid image registration algorithms, and evaluation methods have developed in NIREP software to evaluate all different non-rigid image registration performances. The NIREP website is developed to share evaluation results to public.

In this thesis work, the framework for reporting non-rigid image registration performance was provided from the beginning of using NIREP software to submit the result to the NIREP website. In the non-rigid image registration evaluation project to compare many different non-rigid registration algorithm, common data sets which is NA0 and NA1 and common evaluation methods (relative overlap, dice coefficient, sensitivity, jacobian, inverse consistency error, and two way of transitivity error) were used. To show the evaluation results, 3 non-rigid registration algorithms(AIR5, Demons, SICLE) were used. Every evaluation calculated the its evaluation results, so to save all evaluation results data, SQLite is connected to NIREP software, i.e., all evaluation results were computed through the NIREP software and the results are saved into NIREP result database in SQLite. Each evaluation has different table structure in NIREP result database, so each evaluation has own database table. After all evaluation results were saved into the NIREP result database, each evaluation was statistically summarized for every ROIs using evaluation results (minimum, maxi-

mum, average, standard deviation and percentiles was computed). All statistically summarized values was saved into evaluation population statistic tables. For each ROI and in same evaluation database (NA0 or NA1), algorithms were ranked. By averaging those ranks and average values in population statistic table, representative values of each evaluation task for each algorithms was computed. Overall evaluation of 3 non-rigid image registration was computed by averaging all averaged ranks. Tables, graphs, and images were produced to help interpret registration performances and compare registration result. Tables and graphs were produced from database and shown on the NIREP website to share the evaluation results. Result session on the website shows overall result table for different evaluation database. The overall result table has all evaluation results values and ranks, and it also computes overall rank with weight user choose. All algorithms name has link connected to its page on the website and this pages contains all different evaluation population statistic tables and its graphs to show more details.

This work presents that people can download our databases to evaluate their own registration algorithms through these common databases and common evaluation methods by NIREP and submit their results to the website to share with other investigators.

CHAPTER 6
PROBLEMS AND FUTURE WORK

In NIREP software, evaluation task computes image and its corresponding evaluation results table, and the values shown in the table are saved into the result database. The evaluation results on the table is from the NIREP software table widget not from the result database. Also All statistically summarized values are only computed and saved into the result database. Therefore we need to connect widget to the SQLite query commend to create tables and graphs that user wants to see. When table or graph is created from values that is in the result database, NIREP evaluation doesnt need to perform same evaluation with same data sets that already did.

Also, after more evaluation methods are added, NIREP will be open to public, then investigators can join this project to evaluate their algorithms. Following evaluation procedure presented in this thesis, they need to submit their result to compare with others.

APPENDIX A
FIGURES FOR NA0 EVALUATION RESULT

Table A.1: Relative Overlap results for 'AIR5' in *RelativeOverlap_ps_t* using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.26693	0.479256	0.364301	0.043338	0.289659	0.333415	0.362503	0.396743	0.435552	2
2	0.271558	0.458794	0.379274	0.035081	0.318497	0.355629	0.379339	0.403149	0.434502	2
3	0.281032	0.474592	0.379261	0.030271	0.31301	0.351862	0.381128	0.409893	0.437626	3
4	0.316935	0.483477	0.394046	0.035859	0.33579	0.366891	0.393578	0.421832	0.452176	3
5	0.326503	0.584467	0.463982	0.052771	0.394823	0.44923	0.469211	0.525843	0.563906	3
6	0.334961	0.607256	0.48641	0.043696	0.415359	0.457451	0.489002	0.513622	0.554367	3
7	0.285201	0.576278	0.440592	0.061827	0.317046	0.401739	0.444052	0.484233	0.535164	3
8	0.325446	0.563985	0.452359	0.053595	0.361251	0.413178	0.459325	0.491953	0.534868	3
9	0.22007	0.405395	0.308127	0.035778	0.251293	0.283223	0.30538	0.329893	0.377179	3
10	0.200465	0.407553	0.294694	0.040696	0.230946	0.267601	0.293774	0.319421	0.36787	3
11	0.330783	0.468617	0.405308	0.029505	0.349027	0.385722	0.405461	0.428735	0.451499	3
12	0.330551	0.479369	0.399085	0.028601	0.355895	0.379343	0.394239	0.41637	0.455517	3
13	0.322976	0.577703	0.442828	0.049597	0.346323	0.408781	0.442833	0.477277	0.520063	3
14	0.327733	0.604678	0.48581	0.047126	0.400126	0.457148	0.486086	0.517554	0.563859	3
15	0.169212	0.510999	0.408078	0.061083	0.278346	0.380622	0.414801	0.450629	0.488453	3
16	0.187276	0.526811	0.368589	0.063097	0.28217	0.344821	0.396189	0.429165	0.484852	3
17	0.263815	0.415116	0.333174	0.030445	0.284916	0.311329	0.331576	0.354351	0.381759	3
18	0.247073	0.407991	0.325316	0.032465	0.271664	0.301696	0.325917	0.346253	0.37656	3
19	0.223269	0.420784	0.337432	0.035484	0.275245	0.315553	0.338499	0.365423	0.389754	3
20	0.173603	0.382504	0.299694	0.04263	0.219137	0.267725	0.308263	0.330017	0.36162	3
21	0.122805	0.43959	0.276089	0.060816	0.166656	0.236072	0.276282	0.319083	0.369949	3
22	0.176691	0.405351	0.282067	0.045689	0.210915	0.249159	0.278736	0.316619	0.363818	3
23	0.320693	0.542252	0.439658	0.035083	0.37013	0.419476	0.442834	0.464061	0.468344	3
24	0.357396	0.547922	0.434045	0.035281	0.378834	0.408887	0.432279	0.457722	0.497704	3
25	0.166779	0.37649	0.274328	0.036507	0.209626	0.25175	0.273552	0.297368	0.333471	3
26	0.158737	0.347057	0.252991	0.034461	0.192596	0.232685	0.251078	0.274459	0.311822	3
27	0.17524	0.372843	0.285159	0.039561	0.209425	0.261124	0.285089	0.314871	0.34879	2
28	0.21865	0.360682	0.290525	0.027237	0.245642	0.268243	0.291026	0.310647	0.333889	2
29	0.227939	0.409894	0.331783	0.039671	0.26214	0.304428	0.334854	0.361147	0.394407	3
30	0.223877	0.419056	0.32269	0.037227	0.260347	0.296285	0.322902	0.351372	0.386579	2
31	0.091308	0.333293	0.237348	0.044753	0.151984	0.21091	0.240489	0.267804	0.304657	3
32	0.113381	0.278657	0.211229	0.034207	0.151351	0.190113	0.209744	0.236824	0.264639	3
Avg	0.24240275	0.45840975	0.3576641875	0.041669875	0.28433965625	0.33012746875	0.35881290625	0.38706853125	0.42397856375	2.84375

Figure A.1: Relative Overlap Candlestick graph for AIR5 using data from P05, P25, P50, P75, P95 in *RelativeOverlap_ps_t* using NA0 data sets

Table A.2: Relative Overlap results for 'Demon' in *RelativeOverlap_ps_t* using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.340029	0.643911	0.492038	0.056053	0.385634	0.458561	0.492752	0.531421	0.57713	1
2	0.389724	0.608716	0.514037	0.041036	0.44647	0.464179	0.512925	0.543371	0.582097	1
3	0.341027	0.688115	0.507531	0.06911	0.403955	0.456172	0.498429	0.565916	0.618635	1
4	0.376218	0.643028	0.516027	0.054355	0.423811	0.475771	0.515423	0.559413	0.603978	1
5	0.461903	0.707802	0.608265	0.056342	0.508018	0.55866	0.618766	0.652615	0.682574	1
6	0.548302	0.747066	0.65334	0.035883	0.585253	0.633274	0.684674	0.675806	0.707811	1
7	0.364659	0.784236	0.562628	0.062908	0.409657	0.541584	0.562645	0.649918	0.699917	1
8	0.457466	0.773317	0.635976	0.062716	0.524627	0.592335	0.64424	0.661862	0.743863	1
9	0.366487	0.647995	0.476119	0.050574	0.400998	0.441675	0.471126	0.50304	0.572683	1
10	0.325796	0.655861	0.479078	0.064477	0.377103	0.437182	0.472534	0.524036	0.589181	1
11	0.442744	0.676934	0.557278	0.046146	0.475757	0.530813	0.556984	0.586938	0.637356	1
12	0.46914	0.674992	0.559044	0.040284	0.497422	0.527085	0.556311	0.586974	0.622378	1
13	0.38437	0.712402	0.574158	0.058888	0.470864	0.533975	0.579631	0.611198	0.670738	1
14	0.462574	0.736473	0.627943	0.050673	0.54465	0.593953	0.629225	0.667563	0.705612	1
15	0.36696	0.701596	0.575846	0.067665	0.436732	0.541693	0.586416	0.622446	0.660159	1
16	0.339907	0.694716	0.552788	0.070516	0.41837	0.512115	0.580807	0.606073	0.649201	1
17	0.397419	0.697521	0.500811	0.045061	0.425012	0.464631	0.502563	0.534833	0.573711	1
18	0.314606	0.611133	0.490532	0.052576	0.40839	0.452347	0.486465	0.533288	0.573567	1
19	0.343352	0.597516	0.46826	0.05315	0.377651	0.426608	0.47034	0.511861	0.547178	1
20	0.248261	0.557858	0.421189	0.065034	0.286222	0.379466	0.432743	0.465881	0.519928	1
21	0.160368	0.635835	0.402885	0.100839	0.22443	0.333475	0.402604	0.4782	0.568292	1
22	0.2339	0.601939	0.420247	0.065386	0.327311	0.389525	0.41388	0.487683	0.544387	1
23	0.435983	0.708863	0.596992	0.053327	0.493166	0.562687	0.601091	0.636031	0.674735	1
24	0.45448	0.711042	0.580283	0.052032	0.503857	0.539478	0.578597	0.615852	0.67552	1
25	0.261018	0.59782	0.441849	0.060097	0.339937	0.396609	0.44186	0.482346	0.538437	1
26	0.147387	0.575867	0.410774	0.060157	0.324863	0.373259	0.406849	0.449322	0.504618	1
27	0.245242	0.56199	0.418242	0.066696	0.288112	0.374131	0.427891	0.464981	0.512256	1
28	0.284219	0.570248	0.417435	0.044283	0.345804	0.385049	0.417481	0.447071	0.494224	1
29	0.31501	0.58638	0.454481	0.057249	0.352466	0.417048	0.457545	0.495328	0.540686	1
30	0.266982	0.608835	0.433287	0.057642	0.342553	0.393628	0.433151	0.466387	0.525583	1
31	0.181831	0.519038	0.378485	0.069066	0.26896	0.331383	0.382161	0.428933	0.491669	1
32	0.16909	0.536791	0.346537	0.063795	0.236454	0.306221	0.346227	0.386717	0.443925	1
Avg	0.341771375	0.6463955	0.50286653125	0.06853175	0.40176590625	0.463358125	0.5042605625	0.54487675	0.59537676125	1

Figure A.2: Relative Overlap Candlestick graph for Demon using data from P05, P25, P50, P75, P95 in *RelativeOverlap_ps_t* using NA0 data sets

Table A.3: Relative Overlap results for 'SICLE' in $RelativeOverlap\_ps\_t$ using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.165232	0.478234	0.355827	0.057454	0.256404	0.319997	0.360543	0.395324	0.44805	3
2	0.205216	0.492725	0.37145	0.047611	0.285015	0.347493	0.37465	0.401964	0.441808	3
3	0.275935	0.524153	0.404709	0.047498	0.324037	0.368184	0.409135	0.441401	0.485792	2
4	0.323317	0.515857	0.417372	0.037519	0.358752	0.389418	0.420021	0.44683	0.478069	2
5	0.379597	0.599719	0.503875	0.047518	0.416916	0.47476	0.50492	0.536716	0.583898	2
6	0.425978	0.625684	0.521972	0.03916	0.450928	0.496935	0.524092	0.546911	0.584668	2
7	0.326712	0.640146	0.492565	0.06328	0.369057	0.454399	0.502276	0.537385	0.584003	2
8	0.38982	0.628065	0.530296	0.046066	0.45614	0.496367	0.53445	0.566354	0.598666	2
9	0.248033	0.426096	0.335533	0.038968	0.271235	0.311441	0.332179	0.360073	0.409414	2
10	0.20716	0.4491	0.316254	0.046401	0.242172	0.283876	0.31412	0.349829	0.393385	2
11	0.317754	0.50818	0.432796	0.035506	0.372222	0.412189	0.433323	0.457854	0.491588	2
12	0.353128	0.546255	0.422657	0.031616	0.372081	0.400314	0.419404	0.445728	0.472633	2
13	0.385907	0.602359	0.488116	0.042802	0.417426	0.454111	0.488356	0.516503	0.561082	2
14	0.409343	0.641612	0.532328	0.044357	0.451969	0.50709	0.535333	0.558646	0.606527	2
15	0.330295	0.549804	0.453501	0.047487	0.353183	0.423896	0.453371	0.488941	0.522695	2
16	0.277813	0.53247	0.439415	0.049721	0.347565	0.401845	0.447965	0.479948	0.51492	2
17	0.308483	0.437133	0.364056	0.028401	0.323045	0.340053	0.36155	0.386278	0.413115	2
18	0.273818	0.440328	0.354925	0.031976	0.299949	0.32997	0.35244	0.382207	0.403737	2
19	0.264716	0.440237	0.35168	0.035985	0.284745	0.325999	0.35292	0.377566	0.407258	2
20	0.221808	0.411051	0.323542	0.039475	0.245022	0.300838	0.329088	0.354403	0.383469	2
21	0.109838	0.45289	0.28452	0.069577	0.168668	0.242423	0.278613	0.329107	0.412223	2
22	0.171131	0.411567	0.304131	0.045309	0.229995	0.2724	0.304306	0.333563	0.381295	2
23	0.357453	0.557284	0.476958	0.037178	0.396689	0.460376	0.483148	0.503055	0.526633	2
24	0.39115	0.565187	0.472708	0.034778	0.417683	0.446292	0.471372	0.493646	0.542073	2
25	0.185485	0.419644	0.294065	0.046435	0.206147	0.262116	0.299479	0.323916	0.367953	2
26	0.141054	0.382474	0.260779	0.044404	0.179866	0.230223	0.263559	0.293291	0.327053	2
27	0.164942	0.400324	0.283942	0.050549	0.184432	0.252311	0.295692	0.316434	0.362084	3
28	0.166216	0.354808	0.279803	0.043435	0.202941	0.246604	0.291892	0.312446	0.339181	3
29	0.248915	0.4307	0.347534	0.038799	0.279174	0.319744	0.349392	0.376145	0.401846	2
30	0.178327	0.428435	0.319756	0.04675	0.246865	0.288786	0.315937	0.350479	0.410556	3
31	0.080283	0.356213	0.256928	0.047922	0.170437	0.22747	0.264544	0.289771	0.332349	2
32	0.095348	0.32143	0.2119	0.049879	0.111884	0.168569	0.215713	0.245234	0.291824	2
Avg	0.26188153125	0.486567625	0.38143415625	0.04418175	0.302895125	0.35239028125	0.38386821875	0.412435875	0.45249521875	2.15625

Figure A.3: Relative Overlap Candlestick graph for SICLE using data from P05, P25, P50, P75, P95 in $RelativeOverlap\_ps\_t$ using NA0 data sets

Table A.4: Dice Coefficient results for 'AIR5' in $DiceCoeff\_ps\_t$ using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.44093	0.543987	0.496809	0.029017	0.44093	0.471349	0.502533	0.515312	0.543987	3
2	0.430523	0.539973	0.494016	0.026753	0.430523	0.478056	0.493922	0.51487	0.539973	3
3	0.478077	0.581461	0.521827	0.025771	0.478077	0.497388	0.527224	0.535994	0.581461	3
4	0.481322	0.563914	0.530391	0.021717	0.481322	0.508748	0.535393	0.549423	0.563914	3
5	0.552156	0.710054	0.650131	0.043189	0.552156	0.62016	0.655759	0.686548	0.710054	3
6	0.586456	0.679425	0.635342	0.023429	0.586456	0.618395	0.639168	0.64877	0.679425	3
7	0.503027	0.639279	0.579763	0.041969	0.503027	0.557833	0.580052	0.612363	0.639279	3
8	0.50263	0.665705	0.577336	0.04551	0.50263	0.531932	0.576077	0.619748	0.665705	3
9	0.384668	0.518193	0.45558	0.031803	0.384668	0.438209	0.462117	0.4759	0.518193	3
10	0.395922	0.498428	0.442119	0.028537	0.395922	0.41785	0.431371	0.472697	0.498428	3
11	0.497323	0.594666	0.556774	0.023851	0.497323	0.550055	0.560969	0.571873	0.594666	3
12	0.496864	0.585268	0.543835	0.027947	0.496864	0.520918	0.543182	0.577386	0.585268	3
13	0.510868	0.647691	0.601347	0.037836	0.510868	0.572686	0.602331	0.63371	0.647691	3
14	0.493873	0.679801	0.623523	0.04541	0.493873	0.604091	0.631605	0.653135	0.679801	3
15	0.490566	0.65959	0.584068	0.046441	0.490566	0.548393	0.584118	0.624362	0.65959	3
16	0.486491	0.604568	0.551223	0.036146	0.486491	0.517301	0.561725	0.589558	0.604568	3
17	0.43817	0.503443	0.469607	0.020953	0.43817	0.450113	0.467808	0.488806	0.503443	3
18	0.418572	0.492071	0.452051	0.020426	0.418572	0.439732	0.442437	0.472322	0.492071	3
19	0.365037	0.481965	0.434321	0.033059	0.365037	0.422721	0.441088	0.453622	0.481965	3
20	0.334853	0.490538	0.439701	0.044817	0.334853	0.419329	0.450669	0.486575	0.490538	3
21	0.233114	0.404245	0.314084	0.047805	0.233114	0.278525	0.31156	0.344555	0.404245	3
22	0.358889	0.510096	0.426587	0.045749	0.358889	0.387551	0.420654	0.46874	0.510096	3
23	0.496394	0.611898	0.551118	0.02782	0.496394	0.530925	0.543142	0.574152	0.611898	3
24	0.52059	0.590858	0.563757	0.017569	0.52059	0.548611	0.566058	0.579104	0.590858	3
25	0.333268	0.483655	0.397553	0.039932	0.333268	0.363421	0.396974	0.423638	0.483655	3
26	0.295136	0.43096	0.369521	0.035637	0.295136	0.359614	0.375711	0.390897	0.43096	3
27	0.335637	0.471392	0.412796	0.03497	0.335637	0.367194	0.406621	0.442468	0.471392	3
28	0.415176	0.493114	0.438566	0.020742	0.415176	0.42007	0.433131	0.453992	0.493114	3
29	0.453638	0.57834	0.510748	0.03361	0.453638	0.480496	0.519132	0.534854	0.57834	3
30	0.400963	0.518352	0.456429	0.02688	0.400963	0.44617	0.45504	0.46071	0.518352	3
31	0.268192	0.419234	0.366617	0.040773	0.268192	0.356887	0.380492	0.391952	0.419234	3
32	0.225645	0.394361	0.310232	0.04408	0.225645	0.275419	0.305050	0.334654	0.394361	3
Avg	0.4260240625	0.54957265625	0.492492875	0.033410875	0.4260240625	0.4603856875	0.49391	0.5182059375	0.54957265625	3

Figure A.4: Dice Coefficient Candlestick graph for AIR5 using data from P05, P25, P50, P75, P95 in $DiceCoeff\_ps\_t$ using NA0 data sets

Table A.5: Dice Coefficient results for 'Demon' in $DiceCoeff\_ps\_t$ using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.513705	0.685435	0.623009	0.042604	0.513705	0.58765	0.630053	0.652196	0.685435	1
2	0.594083	0.682201	0.644423	0.027213	0.594083	0.626416	0.647654	0.669209	0.682201	1
3	0.542447	0.697708	0.619738	0.039969	0.542447	0.592216	0.60903	0.636006	0.697708	1
4	0.590614	0.689608	0.647576	0.024643	0.590614	0.632085	0.650879	0.661582	0.689608	1
5	0.645783	0.784025	0.706512	0.037868	0.645783	0.688072	0.696864	0.729448	0.784025	1
6	0.726	0.803622	0.780761	0.020822	0.726	0.770861	0.790146	0.794758	0.803622	1
7	0.640435	0.805366	0.724483	0.042669	0.640435	0.700101	0.723721	0.751768	0.805366	1
8	0.65273	0.833632	0.738054	0.046573	0.65273	0.711182	0.733981	0.756844	0.833632	1
9	0.565656	0.658484	0.60014	0.02694	0.565656	0.575322	0.597171	0.62684	0.658484	1
10	0.491623	0.676609	0.614126	0.044735	0.491623	0.598045	0.609737	0.649147	0.676609	1
11	0.652747	0.752496	0.693013	0.023692	0.652747	0.674155	0.691068	0.70521	0.752496	1
12	0.653281	0.760007	0.704893	0.027966	0.653281	0.688979	0.701093	0.717457	0.760007	1
13	0.619779	0.780886	0.707604	0.046435	0.619779	0.666749	0.704071	0.748209	0.780886	1
14	0.680758	0.82088	0.764936	0.039563	0.680758	0.733671	0.768983	0.796928	0.82088	1
15	0.611134	0.768935	0.715244	0.04417	0.611134	0.697944	0.727743	0.751904	0.768935	1
16	0.606439	0.783779	0.720294	0.044634	0.606439	0.70104	0.733857	0.753753	0.783779	1
17	0.56879	0.702015	0.625329	0.035125	0.56879	0.594815	0.634426	0.649182	0.702015	1
18	0.538664	0.733928	0.631591	0.036714	0.538664	0.621234	0.63426	0.640079	0.733928	1
19	0.511187	0.598616	0.554252	0.024556	0.511187	0.530138	0.554966	0.573545	0.598616	1
20	0.454558	0.670733	0.580547	0.049567	0.454558	0.563073	0.575539	0.617338	0.670733	1
21	0.276409	0.518638	0.40478	0.073986	0.276409	0.330117	0.435739	0.463765	0.518638	1
22	0.45892	0.673372	0.591449	0.049606	0.45892	0.559207	0.596107	0.634034	0.673372	1
23	0.647377	0.74521	0.696096	0.032411	0.647377	0.660516	0.705443	0.719056	0.74521	1
24	0.660192	0.746113	0.699701	0.021894	0.660192	0.686384	0.700792	0.710288	0.746113	1
25	0.461422	0.66021	0.543742	0.049215	0.461422	0.503104	0.541811	0.587692	0.66021	1
26	0.49493	0.609342	0.542027	0.031528	0.49493	0.513864	0.533725	0.572653	0.609342	1
27	0.406685	0.67044	0.559147	0.060747	0.406685	0.522999	0.569139	0.589563	0.67044	1
28	0.488784	0.646088	0.580963	0.046335	0.488784	0.543178	0.595038	0.62199	0.646088	1
29	0.509463	0.70785	0.618493	0.054763	0.509463	0.602897	0.612475	0.685093	0.70785	1
30	0.474987	0.633604	0.560208	0.042341	0.474987	0.5287	0.561924	0.598362	0.633604	1
31	0.43177	0.621871	0.517808	0.055318	0.43177	0.457278	0.517482	0.55728	0.621871	1
32	0.345923	0.509887	0.446876	0.042789	0.345923	0.410674	0.458005	0.484296	0.509887	1
Avg	0.54741484375	0.7009871875	0.62993178125	0.04030534375	0.54741484375	0.602270875	0.6325975625	0.65892115625	0.7009871875	

Figure A.5: Dice Coefficient Candlestick graph for Demon using data from P05, P25, P50, P75, P95 in $DiceCoeff\_ps\_t$ using NA0 data sets

Table A.6: Dice Coefficient results for 'SICLE' in $DiceCoeff\_ps\_t$ using NA0 data sets

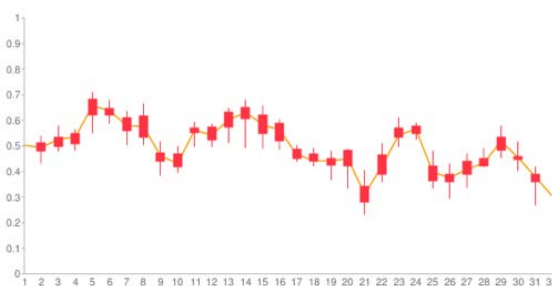| ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.404655	0.570377	0.509122	0.050803	0.404655	0.481112	0.529781	0.548508	0.570377	2
2	0.474163	0.560838	0.52684	0.02789	0.474163	0.511223	0.527399	0.55425	0.560838	2
3	0.482696	0.597659	0.53913	0.03099	0.482696	0.523334	0.538126	0.556444	0.597659	2
4	0.523636	0.594545	0.558713	0.021148	0.523636	0.540035	0.561043	0.573786	0.594545	2
5	0.585141	0.714286	0.657782	0.03702	0.585141	0.628853	0.660031	0.697161	0.714286	2
6	0.616068	0.689039	0.663255	0.020909	0.616068	0.661073	0.666457	0.677833	0.689039	2
7	0.53965	0.681249	0.634203	0.036418	0.53965	0.615568	0.635071	0.659563	0.681249	2
8	0.570036	0.732061	0.655552	0.043845	0.570036	0.630115	0.648305	0.685379	0.732061	2
9	0.427081	0.553096	0.490301	0.039192	0.427081	0.456207	0.493289	0.516086	0.553096	2
10	0.372662	0.520278	0.455136	0.039881	0.372662	0.426656	0.466121	0.486466	0.520278	2
11	0.555341	0.64142	0.603073	0.020126	0.555341	0.587568	0.607073	0.614672	0.64142	2
12	0.526179	0.624311	0.570435	0.027984	0.526179	0.548784	0.566901	0.588551	0.624311	2
13	0.593576	0.688632	0.641819	0.028371	0.593576	0.61989	0.645513	0.664707	0.688632	2
14	0.617259	0.722512	0.669852	0.031083	0.617259	0.676059	0.696484	0.71556	0.722512	2
15	0.500213	0.650398	0.590428	0.039904	0.500213	0.572344	0.592375	0.613392	0.650398	2
16	0.529674	0.66325	0.611196	0.034706	0.529674	0.595027	0.618126	0.633117	0.66325	2
17	0.478863	0.546826	0.503921	0.018414	0.478863	0.487301	0.503029	0.515862	0.546826	2
18	0.429917	0.554148	0.491876	0.025867	0.429917	0.480503	0.493118	0.503482	0.554148	2
19	0.418617	0.510296	0.471153	0.030142	0.418617	0.443143	0.476352	0.504114	0.510296	2
20	0.393602	0.525195	0.47698	0.034609	0.393602	0.464184	0.48011	0.503646	0.525195	2
21	0.197935	0.452387	0.333076	0.068296	0.197935	0.284079	0.305599	0.400944	0.452387	2
22	0.379872	0.54956	0.48277	0.044596	0.379872	0.469172	0.486304	0.510801	0.54956	2
23	0.53896	0.654204	0.585039	0.029393	0.53896	0.562682	0.579009	0.600873	0.654204	2
24	0.562838	0.63691	0.602689	0.017905	0.562838	0.59139	0.599394	0.61517	0.63691	2
25	0.314766	0.519658	0.420999	0.048114	0.314766	0.404593	0.419729	0.448869	0.519658	2
26	0.301903	0.458382	0.392774	0.038697	0.301903	0.368765	0.398503	0.415756	0.458382	2
27	0.294611	0.496296	0.422843	0.054995	0.294611	0.383585	0.431429	0.485696	0.496296	2
28	0.340801	0.505381	0.443016	0.052119	0.340801	0.399758	0.460991	0.479821	0.505381	2
29	0.480251	0.593356	0.535418	0.033907	0.480251	0.495287	0.544018	0.564255	0.593356	2
30	0.42246	0.513983	0.45958	0.025421	0.42246	0.436729	0.45427	0.480762	0.513983	2
31	0.291373	0.469817	0.410175	0.048126	0.291373	0.391588	0.412357	0.453285	0.469817	2
32	0.212408	0.346167	0.31533	0.032575	0.212408	0.30374	0.32518	0.337707	0.346167	2
Avg	0.44922521875	0.57926690625	0.523296125	0.0354233125	0.44922521875	0.50128740625	0.52567090625	0.549657125	0.57926690625	2

Figure A.6: Dice Coeffcient Candlestick graph for SICLE using data from P05, P25, P50, P75, P95 in $DiceCoeff\_ps\_t$ using NA0 data sets

Table A.7: Sensitivity results for 'AIR5' in $Sensitivity\_ps\_t$ using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.409543	0.503139	0.456211	0.023949	0.409543	0.441772	0.454363	0.471418	0.503139	3
2	0.425986	0.49474	0.469426	0.019782	0.425986	0.451638	0.467225	0.488528	0.49474	3
3	0.461738	0.606339	0.530245	0.033326	0.461738	0.50594	0.536856	0.543832	0.606339	2
4	0.407941	0.815981	0.496146	0.045129	0.407941	0.460256	0.488479	0.518161	0.815981	3
5	0.633151	0.785059	0.689245	0.039428	0.633151	0.664882	0.68298	0.710179	0.785059	1
6	0.643068	0.772751	0.690567	0.035288	0.643068	0.669309	0.683654	0.716477	0.772751	2
7	0.466362	0.653568	0.571452	0.058024	0.466362	0.516136	0.597237	0.621248	0.653568	3
8	0.397937	0.624177	0.501025	0.063229	0.397937	0.448535	0.507004	0.538528	0.624177	3
9	0.36914	0.508678	0.438769	0.04412	0.36914	0.405986	0.422518	0.491276	0.508678	3
10	0.325163	0.532581	0.399425	0.051805	0.325163	0.351639	0.393466	0.423608	0.532581	3
11	0.437535	0.556399	0.520905	0.027469	0.437535	0.5119	0.52214	0.542468	0.556399	3
12	0.4744	0.578941	0.536179	0.030202	0.4744	0.50866	0.540323	0.560223	0.578941	3
13	0.461312	0.629378	0.560238	0.044608	0.461312	0.526405	0.575011	0.586379	0.629378	3
14	0.45013	0.677216	0.591562	0.056588	0.45013	0.548709	0.593289	0.637664	0.677216	3
15	0.511299	0.663752	0.592012	0.043345	0.511299	0.566301	0.596808	0.608343	0.663752	3
16	0.363538	0.640384	0.518082	0.071281	0.363538	0.48305	0.510891	0.580428	0.640384	3
17	0.357292	0.466403	0.422917	0.03443	0.357292	0.388141	0.438362	0.45043	0.466403	3
18	0.308418	0.473319	0.382484	0.043331	0.308418	0.354291	0.38358	0.414783	0.473319	3
19	0.280225	0.413115	0.352952	0.036694	0.280225	0.321466	0.353857	0.384212	0.413115	3
20	0.314807	0.478724	0.395437	0.049378	0.314807	0.351521	0.402019	0.429774	0.478724	3
21	0.167481	0.382948	0.279965	0.058843	0.167481	0.226435	0.295279	0.324184	0.382948	3
22	0.319995	0.523274	0.449693	0.061705	0.319995	0.411635	0.448809	0.493525	0.523274	3
23	0.482958	0.582686	0.531925	0.028513	0.482958	0.513665	0.522189	0.564333	0.582686	3
24	0.518133	0.616127	0.562579	0.029245	0.518133	0.541542	0.560924	0.590898	0.616127	3
25	0.364562	0.455273	0.399009	0.028415	0.364562	0.371266	0.395477	0.426388	0.455273	3
26	0.242258	0.399672	0.317531	0.037144	0.242258	0.288633	0.316111	0.337719	0.399672	3
27	0.260102	0.435406	0.373434	0.04556	0.260102	0.348916	0.383745	0.413088	0.435406	3
28	0.369319	0.474225	0.436836	0.027027	0.369319	0.41364	0.446569	0.454937	0.474225	3
29	0.398117	0.519523	0.466063	0.035659	0.398117	0.43755	0.472626	0.501444	0.519523	3
30	0.35483	0.456012	0.393193	0.029994	0.35483	0.36567	0.385454	0.413697	0.456012	3
31	0.207577	0.43226	0.345797	0.052137	0.207577	0.32912	0.350771	0.379586	0.43226	3
32	0.248777	0.398539	0.308947	0.044095	0.248777	0.26299	0.308455	0.338865	0.398539	3
Avg	0.3885348125	0.54221215625	0.46813221875	0.04124165625	0.3885348125	0.43712159375	0.46979506875	0.49833196875	0.54221215625	2.875

Figure A.7: Sensitivity Candlestick graph for AIR5 using data from P05, P25, P50, P75, P95 in $Sensitivity\_ps\_t$ using NA0 data sets

Table A.8: Sensitivity results for 'Demon' in $Sensitivity\_ps\_t$ using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.494542	0.639277	0.573004	0.045348	0.494542	0.527248	0.581071	0.612317	0.639277	1
2	0.52994	0.688203	0.605686	0.042021	0.52994	0.578308	0.611709	0.627778	0.688203	1
3	0.553909	0.703641	0.613596	0.038703	0.553909	0.585905	0.599299	0.641368	0.703641	1
4	0.507534	0.696119	0.593873	0.051469	0.507534	0.552396	0.587854	0.6123	0.696119	1
5	0.581851	0.780594	0.670442	0.056794	0.581851	0.618087	0.660725	0.736697	0.780594	2
6	0.677619	0.822536	0.76552	0.039416	0.677619	0.744154	0.77276	0.797186	0.822536	1
7	0.570072	0.842883	0.736729	0.089962	0.570072	0.636252	0.770900	0.820079	0.842883	1
8	0.541182	0.811501	0.654301	0.073817	0.541182	0.604547	0.655347	0.66787	0.811501	1
9	0.476074	0.662728	0.549906	0.053012	0.476074	0.498088	0.543864	0.600053	0.662728	1
10	0.38349	0.677351	0.563854	0.068319	0.38349	0.523454	0.565861	0.616509	0.677351	1
11	0.572323	0.70719	0.651473	0.036541	0.572323	0.630731	0.646825	0.688868	0.70719	1
12	0.673284	0.768262	0.722947	0.029886	0.673284	0.686746	0.728833	0.747874	0.768262	1
13	0.580747	0.748801	0.670216	0.050978	0.580747	0.626372	0.675664	0.71394	0.748801	1
14	0.662761	0.834877	0.76122	0.053437	0.662761	0.701417	0.776814	0.804577	0.834877	1
15	0.640488	0.792392	0.740405	0.046758	0.640488	0.711879	0.755058	0.76157	0.792392	1
16	0.590914	0.790152	0.724508	0.06191	0.590914	0.675161	0.729445	0.787818	0.790152	1
17	0.487446	0.680959	0.591513	0.050281	0.487446	0.560126	0.576805	0.639062	0.680959	1
18	0.469734	0.698951	0.583852	0.050018	0.469734	0.539403	0.571586	0.635153	0.698951	1
19	0.387673	0.517473	0.450880	0.036426	0.387673	0.408634	0.462180	0.481144	0.517473	1
20	0.502244	0.663205	0.548107	0.046577	0.502244	0.520238	0.525554	0.553834	0.663205	1
21	0.197133	0.575907	0.346193	0.101821	0.197133	0.256192	0.336622	0.427781	0.575907	1
22	0.525951	0.75457	0.616897	0.070512	0.525951	0.560372	0.58907	0.670195	0.75457	1
23	0.553304	0.733227	0.658169	0.04177	0.553304	0.630384	0.658037	0.677942	0.733227	1
24	0.6119	0.729009	0.672363	0.036078	0.6119	0.630082	0.674921	0.70244	0.729009	1
25	0.418818	0.662874	0.531379	0.058804	0.418818	0.4838	0.540422	0.570912	0.662874	1
26	0.398768	0.554087	0.473461	0.047231	0.398768	0.447603	0.459718	0.522867	0.554087	1
27	0.401822	0.67723	0.520650	0.073497	0.401822	0.462036	0.507045	0.549952	0.67723	1
28	0.51533	0.668155	0.580672	0.046653	0.51533	0.541956	0.588760	0.614323	0.668155	1
29	0.419617	0.671312	0.57888	0.063624	0.419617	0.540467	0.580054	0.639031	0.671312	1
30	0.403296	0.568287	0.437438	0.049078	0.403296	0.437649	0.504731	0.538684	0.568287	1
31	0.324245	0.801599	0.476004	0.073198	0.324245	0.432052	0.482422	0.518185	0.801599	1
32	0.346482	0.520894	0.459731	0.044641	0.346482	0.431369	0.465082	0.497202	0.520894	1
Avg	0.50020290625	0.6956658125	0.589468	0.0547524375	0.50020290625	0.5557571875	0.59979265625	0.64051034375	0.6956658125	1.03125

Figure A.8: Candlestick graph for Demon using data from P05, P25, P50, P75, P95 in $Sensitivity\_ps\_t$ using NA0 data sets

Table A.9: Sensitivity results for 'SICLE' in $Sensitivity\_ps\_t$ using NA0 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.401845	0.530023	0.482994	0.034833	0.401845	0.47375	0.491089	0.508143	0.530023	2
2	0.423253	0.545281	0.503681	0.035172	0.423253	0.481932	0.512187	0.536809	0.545281	2
3	0.476179	0.568111	0.525758	0.024114	0.476179	0.508613	0.529322	0.53907	0.568111	3
4	0.421884	0.614773	0.51081	0.048612	0.421884	0.479231	0.508048	0.544513	0.614773	2
5	0.601136	0.721139	0.655325	0.036757	0.601136	0.626263	0.651526	0.693371	0.721139	3
6	0.610157	0.748582	0.677267	0.030877	0.610157	0.659038	0.6729	0.693727	0.748582	3
7	0.570072	0.724858	0.658861	0.043205	0.570072	0.614378	0.669691	0.68491	0.724858	2
8	0.473403	0.71135	0.580807	0.057893	0.473403	0.546898	0.576047	0.600608	0.71135	2
9	0.358328	0.574134	0.472352	0.052181	0.358328	0.440296	0.490331	0.514918	0.574134	2
10	0.302162	0.53965	0.406629	0.051779	0.302162	0.36579	0.409028	0.431395	0.53965	2
11	0.515648	0.636456	0.583289	0.031847	0.515648	0.563061	0.580545	0.613873	0.636456	2
12	0.523414	0.618451	0.56837	0.027433	0.523414	0.54648	0.564654	0.591745	0.618451	2
13	0.525664	0.677269	0.609417	0.036714	0.525664	0.603948	0.611592	0.626412	0.677269	2
14	0.589114	0.74961	0.676821	0.040407	0.589114	0.659254	0.688105	0.701187	0.74961	2
15	0.597428	0.701433	0.651587	0.032166	0.597428	0.618386	0.664357	0.675628	0.701433	2
16	0.496059	0.678953	0.617755	0.049554	0.496059	0.586728	0.630629	0.658896	0.678953	2
17	0.441106	0.535757	0.48667	0.029508	0.441106	0.463813	0.483548	0.51493	0.535757	2
18	0.350519	0.541437	0.453033	0.050467	0.350519	0.424555	0.446384	0.500247	0.541437	2
19	0.310712	0.467619	0.38737	0.044904	0.310712	0.351175	0.386765	0.425956	0.467619	2
20	0.390056	0.555863	0.442275	0.040968	0.390056	0.412685	0.437844	0.456079	0.555863	2
21	0.135767	0.405997	0.282823	0.067316	0.135767	0.234678	0.309417	0.332196	0.405997	2
22	0.389226	0.588868	0.489861	0.055137	0.389226	0.435569	0.494155	0.522967	0.588868	2
23	0.474056	0.579026	0.54486	0.029432	0.474056	0.519633	0.547354	0.575035	0.579026	2
24	0.522444	0.62894	0.578193	0.028867	0.522444	0.55367	0.584418	0.603429	0.62804	2
25	0.338721	0.476977	0.421109	0.037162	0.338721	0.401073	0.43258	0.448435	0.476977	2
26	0.252009	0.403531	0.345928	0.038047	0.252009	0.32656	0.337897	0.378873	0.403531	2
27	0.280755	0.509908	0.38866	0.055641	0.280755	0.358262	0.405427	0.42154	0.509908	2
28	0.34736	0.510832	0.446041	0.051176	0.34736	0.417969	0.453916	0.492614	0.510832	2
29	0.407936	0.57982	0.509034	0.045418	0.407936	0.47427	0.516062	0.543041	0.57982	2
30	0.342744	0.442473	0.39859	0.034192	0.342744	0.362863	0.393548	0.435497	0.442473	2
31	0.227291	0.486552	0.394473	0.071251	0.227291	0.355537	0.417596	0.44748	0.486552	2
32	0.196467	0.367433	0.319104	0.046956	0.196467	0.284515	0.330851	0.356962	0.367433	2
Avg	0.41540359375	0.5756658125	0.50214834375	0.0425008125	0.41540359375	0.47311978125	0.50712946875	0.533503125	0.5756658125	2.09375
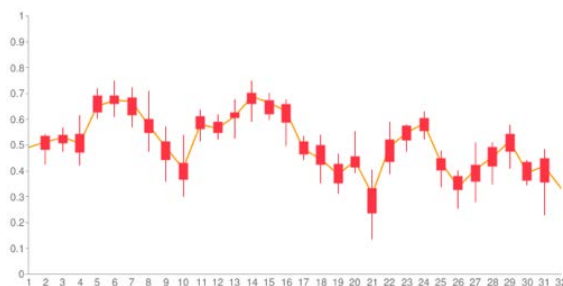
Figure A.9: Sensitivity Candlestick graph for SICLE using data from P05, P25, P50, P75, P95 in $Sensitivity\_ps\_t$ using NA0 data sets

APPENDIX B
FIGURES FOR NA1 EVALUATION RESULT

Table B.1: Relative Overlap results for 'AIR5' in *RelativeOverlap_ps_t* using NA1 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.146831	0.283384	0.213656	0.032892	0.146831	0.19014	0.213775	0.239152	0.283384	2
2	0.11641	0.30303	0.196094	0.046661	0.11641	0.145762	0.196966	0.226736	0.30303	1
3	0.038485	0.220423	0.113853	0.043234	0.038485	0.080117	0.122535	0.138971	0.220423	1
4	0.228158	0.280566	0.256895	0.014369	0.228158	0.246274	0.257039	0.270146	0.280566	1
5	0.178019	0.30154	0.222798	0.0292	0.178019	0.200217	0.220847	0.240804	0.30154	2
6	0.129265	0.296667	0.257114	0.036815	0.129265	0.24709	0.262707	0.282505	0.296667	2
7	0.18195	0.290546	0.245973	0.02647	0.18195	0.228473	0.254775	0.266878	0.290546	3
8	0.119939	0.28729	0.202542	0.045329	0.119939	0.166435	0.202794	0.240860	0.28729	1
9	0.107718	0.261183	0.184619	0.042147	0.107718	0.155279	0.185564	0.220371	0.261183	1
10	0.254582	0.35899	0.301606	0.033055	0.254582	0.275332	0.295091	0.331634	0.35899	3
11	0.249108	0.341299	0.289126	0.027363	0.249108	0.266916	0.283053	0.314633	0.341299	2
12	0.362377	0.519144	0.429826	0.033416	0.362377	0.409131	0.426567	0.446274	0.519144	2
13	0.293685	0.498643	0.395957	0.050019	0.293685	0.368923	0.394521	0.42175	0.498643	2
14	0.126188	0.425495	0.288363	0.068482	0.126188	0.261461	0.285666	0.33499	0.425495	2
15	0.029267	0.446587	0.28904	0.097004	0.029267	0.237936	0.31227	0.350892	0.446587	2
16	0.252465	0.33617	0.298644	0.023008	0.252465	0.28337	0.289722	0.32304	0.33617	3
17	0.24623	0.320049	0.283725	0.019703	0.24623	0.268963	0.28468	0.29719	0.320049	3
18	0.080299	0.266996	0.164946	0.06345	0.080299	0.106963	0.172797	0.208496	0.266996	3
19	0.051577	0.334845	0.131174	0.081223	0.051577	0.07044	0.097334	0.171324	0.334845	2
20	0.233937	0.327356	0.269074	0.024444	0.233937	0.25389	0.26603	0.273353	0.327356	3
21	0.202751	0.304119	0.253382	0.033853	0.202751	0.219251	0.250106	0.285649	0.304119	3
22	0.174285	0.326741	0.256372	0.034722	0.174285	0.244827	0.258481	0.275287	0.326741	3
23	0.193923	0.306931	0.245129	0.033125	0.193923	0.216635	0.240819	0.27573	0.306931	3
24	0.228096	0.325869	0.271951	0.025129	0.228096	0.254241	0.268537	0.289609	0.325869	3
25	0.230496	0.306695	0.264484	0.023118	0.230496	0.242842	0.265273	0.28372	0.306695	3
26	0.439714	0.533672	0.481264	0.023999	0.439714	0.464866	0.474378	0.491629	0.533672	2
27	0.406245	0.528705	0.472236	0.034163	0.406245	0.45191	0.466694	0.498599	0.528705	2
28	0.195669	0.37787	0.26322	0.05101	0.195669	0.225958	0.25143	0.286385	0.37787	3
29	0.214546	0.370183	0.291229	0.04607	0.214546	0.250037	0.296328	0.329875	0.370183	3
30	0.037313	0.229167	0.111862	0.06205	0.037313	0.052858	0.096	0.167758	0.229167	1
31	0.102795	0.324478	0.181572	0.050461	0.102795	0.15079	0.182301	0.203573	0.324478	1
32	0.261903	0.327163	0.28604	0.017292	0.261903	0.272461	0.282796	0.297233	0.327163	3
33	0.241578	0.324802	0.284076	0.021466	0.241578	0.265935	0.283185	0.302646	0.324802	3
34	0.228056	0.303099	0.271997	0.020624	0.228056	0.256791	0.271028	0.290377	0.303099	2
35	0.220333	0.277527	0.251447	0.016161	0.220333	0.239166	0.253594	0.263971	0.277527	2
36	0.208779	0.343129	0.271353	0.031404	0.208779	0.250264	0.267527	0.290726	0.343129	3
37	0.201731	0.310886	0.268805	0.027268	0.201731	0.248122	0.267096	0.29453	0.310886	2
38	0.282727	0.413196	0.321777	0.031833	0.282727	0.291157	0.317284	0.344093	0.413196	3
39	0.276952	0.36139	0.323671	0.021627	0.276952	0.310717	0.321756	0.339673	0.36139	2
40	0.128151	0.285043	0.196044	0.036422	0.128151	0.175078	0.191621	0.213605	0.285043	2

Figure B.1: Relative Overlap Candlestick graph for AIR5 using data from P05, P25, P50, P75, P95 in *RelativeOverlap_ps_t* using NA1 data sets

Table B.2: Relative Overlap results for 'Demon' in *RelativeOverlap_ps_t* using NA1 data sets

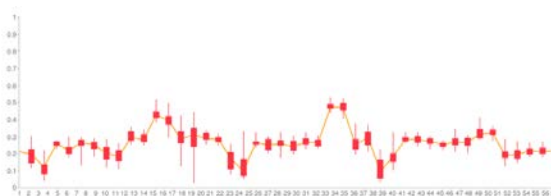| ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.126378	0.246005	0.180007	0.040079	0.126378	0.132917	0.171988	0.219191	0.246005	3
2	0.006209	0.254993	0.118113	0.074291	0.006209	0.045912	0.122809	0.181999	0.254993	3
3	0.034874	0.21897	0.111893	0.052513	0.034874	0.067952	0.097786	0.159577	0.21897	2
4	0.006975	0.261887	0.114402	0.073757	0.006975	0.037544	0.118126	0.180331	0.261887	3
5	0.075093	0.321606	0.183502	0.060671	0.075093	0.137411	0.202476	0.227723	0.321606	3
6	0.072063	0.341294	0.201162	0.080521	0.072063	0.129712	0.189612	0.271763	0.341294	3
7	0.165868	0.341681	0.248026	0.053353	0.165868	0.193808	0.245151	0.291133	0.341681	2
8	0	0.276104	0.119232	0.081937	0	0.041162	0.11932	0.208749	0.276104	3
9	0.039044	0.292416	0.14591	0.058118	0.039044	0.115155	0.159536	0.184339	0.292416	3
10	0.226685	0.439587	0.317113	0.060325	0.226685	0.258935	0.32052	0.360622	0.439587	2
11	0.174679	0.394873	0.289067	0.052724	0.174679	0.262639	0.297294	0.323755	0.394873	3
12	0.325666	0.509584	0.421371	0.053024	0.325666	0.373723	0.423682	0.465932	0.509584	3
13	0.267558	0.456688	0.330547	0.059126	0.267558	0.290952	0.308751	0.354131	0.456688	3
14	0.078337	0.405539	0.247402	0.10623	0.078337	0.14577	0.261414	0.333174	0.405539	3
15	0.100274	0.426846	0.270116	0.089654	0.100274	0.196876	0.282322	0.339747	0.426846	3
16	0.284358	0.42666	0.371872	0.03664	0.284358	0.34607	0.373008	0.401353	0.42666	1
17	0.214008	0.412622	0.337681	0.05747	0.214008	0.316628	0.347767	0.365763	0.412622	1
18	0.074255	0.332744	0.196762	0.099943	0.074255	0.130143	0.220767	0.250727	0.332744	2
19	0	0.37796	0.114064	0.091725	0	0.052139	0.089223	0.167776	0.37796	3
20	0.212406	0.372973	0.301385	0.043097	0.212406	0.273428	0.302632	0.332716	0.372973	1
21	0.163457	0.394962	0.304373	0.061602	0.163457	0.254652	0.311843	0.355801	0.394962	1
22	0.176452	0.391551	0.28321	0.05007	0.176452	0.247642	0.270015	0.317986	0.391551	1
23	0.161471	0.362896	0.27578	0.042978	0.161471	0.253477	0.269924	0.297702	0.362896	1
24	0.181666	0.400813	0.326686	0.058192	0.181666	0.285764	0.343637	0.379328	0.400813	1
25	0.257932	0.384132	0.325365	0.036294	0.257932	0.301942	0.317325	0.360326	0.384132	1
26	0.320384	0.506931	0.4142	0.046973	0.320384	0.382174	0.414304	0.446619	0.506931	3
27	0.353439	0.499071	0.425282	0.045199	0.353439	0.389794	0.415374	0.466083	0.499071	3
28	0.157561	0.376812	0.280488	0.05849	0.157561	0.264316	0.30406	0.327292	0.376812	2
29	0.239066	0.420347	0.323486	0.052891	0.239066	0.268883	0.321441	0.367469	0.420347	3
30	0	0.04703	0.010926	0.017424	0	0	0	0.029754	0.04703	3
31	0	0.196721	0.047627	0.053912	0	0	0.040434	0.079953	0.196721	3
32	0.270974	0.391624	0.316651	0.034649	0.270974	0.285067	0.30966	0.338998	0.391624	1
33	0.237654	0.378726	0.303665	0.041114	0.237654	0.274332	0.31941	0.345306	0.378726	2
34	0.181447	0.318504	0.262922	0.037741	0.181447	0.245118	0.253917	0.299751	0.318504	3
35	0.153329	0.288026	0.223585	0.045595	0.153329	0.176262	0.23034	0.272933	0.288026	3
36	0.260698	0.367589	0.307117	0.027188	0.260698	0.283065	0.30513	0.327492	0.367589	1
37	0.190688	0.338012	0.265176	0.040748	0.190688	0.231989	0.268816	0.303209	0.338012	3
38	0.262976	0.433414	0.336758	0.045403	0.262976	0.305793	0.336426	0.37952	0.433414	3
39	0.18713	0.393666	0.300257	0.055725	0.18713	0.26471	0.308994	0.346532	0.393666	3
40	0.060714	0.326296	0.161432	0.084521	0.060714	0.085235	0.137215	0.227685	0.326296	3

Figure B.2: Relative Overlap Candlestick graph for Demon using data from P05, P25, P50, P75, P95 in *RelativeOverlap_ps_t* using NA1 data sets

Table B.3: Relative Overlap results for 'SICLE' in *RelativeOverlap_ps_t* using NA1

data sets

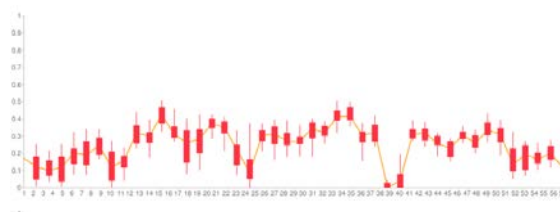| ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.165296	0.297404	0.228101	0.032549	0.165296	0.207767	0.219404	0.249515	0.297404	1
2	0.047312	0.302943	0.177289	0.068504	0.047312	0.13533	0.181691	0.233633	0.302943	2
3	0.020682	0.167509	0.101752	0.042661	0.020682	0.063495	0.105999	0.14198	0.167509	3
4	0.197994	0.296013	0.244104	0.030727	0.197994	0.214875	0.24779	0.269481	0.296013	2
5	0.174649	0.328077	0.240074	0.03149	0.174649	0.224842	0.236241	0.266611	0.328077	1
6	0.136351	0.365183	0.266211	0.045855	0.136351	0.249118	0.266166	0.295532	0.365183	1
7	0.197913	0.308064	0.259035	0.03372	0.197913	0.227933	0.271155	0.285592	0.308064	1
8	0.079072	0.255298	0.178733	0.056126	0.079072	0.135485	0.182706	0.235221	0.255298	2
9	0.09474	0.27335	0.17364	0.048807	0.09474	0.139205	0.162507	0.201602	0.27335	2
10	0.286598	0.370204	0.325934	0.027036	0.286598	0.295453	0.325683	0.353495	0.370204	1
11	0.263623	0.359537	0.312113	0.029313	0.263623	0.282985	0.312824	0.338357	0.359537	1
12	0.40392	0.49688	0.442297	0.025173	0.40392	0.420993	0.436136	0.463579	0.49688	1
13	0.317646	0.476286	0.408132	0.036371	0.317646	0.387199	0.404109	0.427283	0.476286	1
14	0.156385	0.458929	0.361182	0.067533	0.156385	0.336042	0.375962	0.409295	0.458929	1
15	0.151731	0.44946	0.329497	0.061111	0.151731	0.286951	0.330379	0.41099	0.44946	1
16	0.255692	0.342492	0.310479	0.022849	0.255692	0.291065	0.318923	0.32563	0.342492	3
17	0.255797	0.363714	0.308479	0.030145	0.255797	0.281397	0.306408	0.327974	0.363714	2
18	0.152991	0.377732	0.236208	0.056908	0.152991	0.197451	0.227811	0.265866	0.377732	1
19	0.036227	0.3223	0.137482	0.071868	0.036227	0.08627	0.135684	0.187182	0.3223	1
20	0.244966	0.328269	0.27208	0.026106	0.244966	0.248508	0.266966	0.29614	0.328269	2
21	0.212305	0.349808	0.277792	0.042236	0.212305	0.247747	0.280922	0.305645	0.349808	2
22	0.187497	0.317403	0.266987	0.03567	0.187497	0.246768	0.274317	0.296139	0.317403	2
23	0.196686	0.338772	0.270871	0.036003	0.196686	0.252284	0.26478	0.295667	0.338772	3
24	0.199055	0.387541	0.298041	0.040847	0.199055	0.277065	0.298959	0.321835	0.387541	2
25	0.193269	0.33322	0.274618	0.035859	0.193269	0.244047	0.285665	0.297401	0.33322	2
26	0.480913	0.554712	0.510868	0.018914	0.480913	0.494898	0.506663	0.520929	0.554712	1
27	0.462977	0.544358	0.497338	0.02445	0.462977	0.472147	0.493428	0.517182	0.544358	1
28	0.202192	0.398021	0.305245	0.052327	0.202192	0.263519	0.302679	0.34454	0.398021	1
29	0.241906	0.41293	0.337648	0.045141	0.241906	0.31025	0.324523	0.369417	0.41293	1
30	0	0.241505	0.07853	0.070369	0	0.012355	0.072498	0.120338	0.241505	2
31	0.009248	0.253396	0.172042	0.063069	0.009248	0.131622	0.183063	0.227281	0.253396	2
32	0.275041	0.347161	0.304675	0.021436	0.275041	0.281397	0.306262	0.322697	0.347161	2
33	0.271076	0.369659	0.312872	0.024305	0.271076	0.297987	0.316837	0.324612	0.369659	1
34	0.232825	0.336629	0.284803	0.025164	0.232825	0.269686	0.282147	0.302818	0.336629	1
35	0.225086	0.288	0.264726	0.018764	0.225086	0.248953	0.271085	0.283518	0.288	1
36	0.228005	0.337574	0.284762	0.026191	0.228005	0.260782	0.276367	0.309303	0.337574	2
37	0.249032	0.323832	0.284852	0.025567	0.249032	0.261459	0.274919	0.311159	0.323832	1
38	0.281656	0.427901	0.339272	0.035798	0.281656	0.30931	0.338856	0.365195	0.427901	1
39	0.300301	0.381757	0.34042	0.02568	0.300301	0.31363	0.348295	0.3641	0.381757	1
40	0.144531	0.301433	0.224029	0.048026	0.144531	0.184484	0.224457	0.262326	0.301433	1
41	0.177761	0.334821	0.235977	0.037366	0.177761	0.207616	0.244194	0.26906	0.334821	1
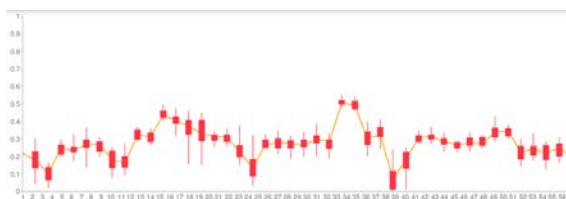
Figure B.3: Relative Overlap Candlestick graph for SICLE using data from P05, P25, P50, P75, P95 in *RelativeOverlap_ps_t* using NA1 data sets

Table B.4: Dice Coefficient results for 'AIR5' in $DiceCoeff\_ps\_t$ using NA1 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.256064	0.44162	0.360874	0.044715	0.256064	0.319491	0.352247	0.385953	0.44162	2
2	0.208544	0.465116	0.325359	0.064943	0.208544	0.254436	0.329108	0.369957	0.465116	1
3	0.074117	0.361224	0.201748	0.06921	0.074117	0.148344	0.218318	0.24397	0.361224	1
4	0.371545	0.438177	0.408668	0.018232	0.371545	0.395216	0.408969	0.425377	0.438177	1
5	0.302234	0.463359	0.363488	0.038518	0.302234	0.333553	0.361794	0.38814	0.463359	2
6	0.228936	0.457584	0.407988	0.090131	0.228936	0.396266	0.416102	0.440526	0.457584	2
7	0.30788	0.460267	0.394093	0.034658	0.30788	0.371962	0.406089	0.421316	0.460267	3
8	0.214188	0.446348	0.334461	0.063044	0.214188	0.285361	0.337204	0.368226	0.446348	1
9	0.194486	0.414188	0.309541	0.060542	0.194486	0.268808	0.313039	0.361077	0.414188	1
10	0.405843	0.528319	0.462452	0.038787	0.405843	0.431768	0.456707	0.498088	0.528319	3
11	0.398858	0.508908	0.447873	0.032538	0.398858	0.421363	0.441218	0.47863	0.508908	2
12	0.553217	0.683469	0.60048	0.03213	0.553217	0.580683	0.596033	0.619045	0.683469	2
13	0.454028	0.665459	0.565451	0.051417	0.454028	0.538953	0.565615	0.593177	0.665459	2
14	0.224098	0.596979	0.443113	0.085486	0.224098	0.414406	0.444387	0.501808	0.596979	2
15	0.056869	0.617435	0.4389	0.127891	0.056869	0.384406	0.475923	0.519489	0.617435	2
16	0.403149	0.503185	0.459686	0.027272	0.403149	0.441803	0.449278	0.488321	0.503185	3
17	0.396159	0.484905	0.445451	0.024043	0.396159	0.423784	0.443193	0.458203	0.484905	3
18	0.148661	0.407639	0.279524	0.079784	0.148661	0.193053	0.294675	0.345037	0.407639	3
19	0.098095	0.501699	0.223517	0.117423	0.098095	0.131526	0.177401	0.29253	0.501699	3
20	0.379171	0.493247	0.423476	0.0297	0.379171	0.404963	0.420259	0.429341	0.493247	3
21	0.337145	0.466397	0.403126	0.043161	0.337145	0.36961	0.400135	0.444241	0.466397	3
22	0.296836	0.492547	0.405878	0.04492	0.296836	0.393312	0.410782	0.435405	0.492547	3
23	0.32485	0.469697	0.392615	0.042354	0.32485	0.35612	0.388162	0.433487	0.469697	3
24	0.371463	0.491555	0.426999	0.031029	0.371463	0.40541	0.423381	0.449142	0.491555	3
25	0.374639	0.48942	0.4178	0.026833	0.374639	0.390779	0.419314	0.442026	0.48942	3
26	0.610839	0.69611	0.649451	0.02166	0.610839	0.634684	0.643496	0.659184	0.69611	2
27	0.577772	0.691703	0.640764	0.031819	0.577772	0.622454	0.638246	0.665383	0.691703	2
28	0.327296	0.548484	0.41425	0.061847	0.327296	0.368568	0.401628	0.444923	0.548484	3
29	0.353295	0.540341	0.44912	0.055202	0.353295	0.400045	0.457191	0.490073	0.540341	3
30	0.071942	0.372881	0.195728	0.098415	0.071942	0.1004	0.175182	0.287309	0.372881	1
31	0.186427	0.489971	0.30436	0.069964	0.186427	0.26206	0.306383	0.338261	0.489971	1
32	0.415093	0.493026	0.44456	0.02071	0.415093	0.426241	0.440908	0.458249	0.493026	3
33	0.389146	0.49034	0.442023	0.026123	0.389146	0.420136	0.441379	0.46466	0.49034	3
34	0.371412	0.466197	0.427253	0.025662	0.371412	0.408644	0.426471	0.450066	0.466197	2
35	0.361103	0.434476	0.401583	0.020712	0.361103	0.386011	0.404568	0.417673	0.434476	2
36	0.349438	0.510939	0.425921	0.038694	0.345438	0.400324	0.422124	0.450462	0.510939	3
37	0.336734	0.474315	0.422978	0.034336	0.336734	0.397569	0.421586	0.455029	0.474315	3
38	0.440822	0.58477	0.48603	0.035535	0.440822	0.451001	0.481725	0.512006	0.58477	3
39	0.433771	0.530913	0.488646	0.024775	0.433771	0.474116	0.486661	0.507097	0.530913	2

Figure B.4: Dice Coefficient Candlestick graph for AIR5 using data from P05, P25, P50, P75, P95 in $DiceCoeff\_ps\_t$ using NA1 data sets

Table B.5: Dice Coefficient results for 'Demon' in $DiceCoeff\_ps\_t$ using NA1 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.224397	0.397443	0.303143	0.057495	0.224397	0.234643	0.293498	0.359547	0.397443	3
2	0.016283	0.406366	0.203384	0.118974	0.016283	0.087781	0.216436	0.30793	0.406366	3
3	0.067398	0.35927	0.197338	0.083234	0.067398	0.127267	0.178152	0.275106	0.35927	2
4	0.011878	0.402412	0.197406	0.119706	0.011878	0.072368	0.211292	0.305559	0.402412	3
5	0.139696	0.486689	0.305737	0.086687	0.139696	0.241379	0.336765	0.370966	0.486689	3
6	0.135481	0.508903	0.327524	0.111302	0.135481	0.22806	0.31878	0.427361	0.508903	3
7	0.28454	0.509333	0.39453	0.068878	0.28454	0.32467	0.393769	0.460971	0.509333	2
8	0	0.432729	0.203563	0.129574	0	0.079068	0.213201	0.34537	0.432729	3
9	0.075154	0.377172	0.250359	0.067999	0.075154	0.206373	0.275172	0.311291	0.377172	3
10	0.369589	0.610713	0.478343	0.069597	0.369589	0.411142	0.485446	0.530079	0.610713	2
11	0.297407	0.56628	0.445849	0.06466	0.297407	0.415989	0.45833	0.488919	0.56628	3
12	0.491324	0.675132	0.590936	0.052662	0.491324	0.544091	0.595192	0.635671	0.675132	3
13	0.422163	0.628905	0.494021	0.063666	0.422163	0.450791	0.471826	0.523037	0.628905	3
14	0.145292	0.575031	0.384698	0.145668	0.145292	0.254389	0.414476	0.499742	0.575031	3
15	0.18227	0.598307	0.417217	0.115399	0.18227	0.331624	0.440329	0.507181	0.598307	3
16	0.442802	0.598114	0.541138	0.038506	0.442802	0.514122	0.543344	0.572606	0.598114	1
17	0.352964	0.584193	0.502005	0.066681	0.352964	0.480914	0.516086	0.556716	0.584193	1
18	0.138245	0.499337	0.323118	0.098277	0.138245	0.230312	0.361686	0.400844	0.499337	2
19	0	0.548579	0.193727	0.134741	0	0.099087	0.163829	0.287295	0.548579	3
20	0.350388	0.543307	0.46148	0.051246	0.350388	0.429418	0.464529	0.499169	0.543307	1
21	0.280985	0.566289	0.463152	0.074919	0.280985	0.405778	0.475427	0.52477	0.566289	1
22	0.302859	0.562755	0.439039	0.080817	0.302859	0.397232	0.425216	0.482532	0.562755	1
23	0.307196	0.532537	0.430563	0.052864	0.307196	0.404397	0.425102	0.458804	0.532537	1
24	0.307316	0.572257	0.489359	0.068733	0.307316	0.444481	0.511503	0.500016	0.572257	1
25	0.410089	0.555051	0.489844	0.041568	0.410089	0.462833	0.481771	0.529765	0.555051	1
26	0.485289	0.672799	0.584206	0.047219	0.485289	0.568208	0.585977	0.619373	0.672799	3
27	0.522283	0.665841	0.595360	0.044603	0.522283	0.560889	0.586946	0.635818	0.665841	3
28	0.272229	0.547368	0.445679	0.073246	0.272229	0.418092	0.466329	0.493158	0.547368	2
29	0.387039	0.591894	0.486424	0.060461	0.387039	0.423768	0.486501	0.537443	0.591894	2
30	0	0.089834	0.021039	0.03348	0	0	0	0.057646	0.089834	3
31	0	0.328767	0.086117	0.093594	0	0	0.077726	0.148029	0.328767	3
32	0.426403	0.56283	0.476801	0.039443	0.426403	0.444734	0.472886	0.506344	0.56283	1
33	0.38404	0.549396	0.471244	0.048429	0.38404	0.420491	0.484171	0.513013	0.549396	2
34	0.307161	0.483222	0.414841	0.047892	0.307161	0.393724	0.404998	0.461213	0.483222	3
35	0.26589	0.447237	0.361839	0.061266	0.26589	0.299664	0.374433	0.428819	0.447237	3
36	0.412191	0.5268	0.469256	0.031679	0.412191	0.441229	0.467586	0.493378	0.5268	1
37	0.332762	0.505245	0.417559	0.050741	0.332762	0.376608	0.411204	0.465242	0.505245	3
38	0.416438	0.604729	0.502049	0.051654	0.416438	0.46836	0.503473	0.550164	0.604729	2
39	0.315264	0.564936	0.458078	0.066031	0.315264	0.41861	0.472109	0.514626	0.564936	3
40	0.096533	0.492041	0.269145	0.121787	0.096533	0.170364	0.241317	0.370867	0.492041	3

Figure B.5: Dice Coefficient Candlestick graph for Demon using data from P05, P25, P50, P75, P95 in $DiceCoeff\_ps\_t$ using NA1 data sets

Table B.6: Dice Coefficient results for 'SICLE' in $DiceCoeff\_ps\_t$ using NA1 data sets

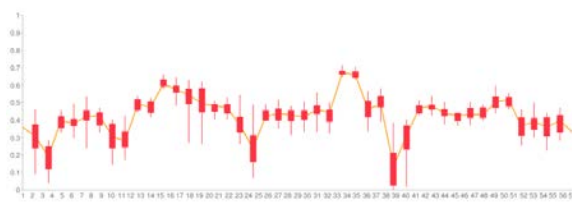| ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.283697	0.45846	0.370335	0.042863	0.283697	0.344052	0.359855	0.399507	0.45846	1
2	0.09035	0.465013	0.295275	0.101746	0.09035	0.238302	0.30751	0.378545	0.465013	2
3	0.040525	0.286951	0.181968	0.070876	0.040525	0.119406	0.19168	0.248655	0.286951	2
4	0.330543	0.466806	0.391436	0.039721	0.330543	0.353711	0.397166	0.424542	0.466806	2
5	0.297364	0.495083	0.386169	0.040353	0.297364	0.36713	0.382192	0.408412	0.495083	1
6	0.23998	0.534995	0.420837	0.069279	0.23998	0.39687	0.422919	0.456206	0.534995	1
7	0.330429	0.471023	0.410708	0.043035	0.330429	0.371247	0.426628	0.444216	0.471023	1
8	0.146555	0.406741	0.299343	0.082404	0.146555	0.238567	0.309063	0.380809	0.406741	1
9	0.173083	0.42934	0.293515	0.069452	0.173083	0.244385	0.27958	0.335547	0.42934	2
10	0.445513	0.540363	0.491003	0.030751	0.445513	0.456136	0.491344	0.522332	0.540363	1
11	0.41725	0.528911	0.475032	0.032883	0.41725	0.441123	0.476567	0.505626	0.528911	1
12	0.575417	0.663668	0.612903	0.024094	0.575417	0.592494	0.607376	0.633478	0.663668	1
13	0.482142	0.645249	0.578619	0.038934	0.482142	0.558201	0.575605	0.59867	0.645249	1
14	0.270473	0.639131	0.526769	0.079295	0.270473	0.491749	0.546472	0.580649	0.639131	1
15	0.263483	0.620176	0.489886	0.095097	0.263483	0.445922	0.496669	0.582467	0.620176	1
16	0.407252	0.510234	0.473371	0.026937	0.407252	0.450882	0.483611	0.491275	0.510234	2
17	0.407386	0.533416	0.470699	0.035139	0.407386	0.439201	0.471425	0.493468	0.533416	2
18	0.269381	0.548338	0.37903	0.070773	0.269381	0.329778	0.371084	0.420043	0.548338	1
19	0.069922	0.487484	0.234932	0.107987	0.069922	0.15871	0.236946	0.31511	0.487484	1
20	0.39353	0.49428	0.427119	0.0318	0.39353	0.398088	0.421426	0.456908	0.49428	2
21	0.350251	0.518308	0.433097	0.051557	0.350251	0.397104	0.436625	0.468179	0.518308	2
22	0.315785	0.481862	0.420173	0.045439	0.315785	0.395851	0.430532	0.455745	0.481862	2
23	0.332695	0.506094	0.425086	0.043255	0.332695	0.402917	0.418697	0.456231	0.506094	2
24	0.33292	0.556601	0.45767	0.049211	0.33292	0.433852	0.460305	0.486937	0.556601	2
25	0.323961	0.498746	0.429636	0.04498	0.323961	0.392299	0.444627	0.456454	0.498746	2
26	0.649481	0.713589	0.676052	0.016421	0.649481	0.662115	0.672563	0.68501	0.713589	1
27	0.632925	0.704964	0.663941	0.021754	0.632925	0.64144	0.660799	0.681757	0.704964	1
28	0.336372	0.569457	0.465254	0.061598	0.336372	0.417112	0.464938	0.512584	0.569407	1
29	0.389572	0.584201	0.503112	0.051208	0.389572	0.473574	0.490023	0.539524	0.584201	1
30	0	0.389052	0.138074	0.115989	0	0.024399	0.135195	0.214802	0.389052	2
31	0.016326	0.404264	0.286372	0.096966	0.016326	0.232569	0.309473	0.370327	0.404264	2
32	0.431423	0.515397	0.466638	0.025133	0.431423	0.439152	0.466914	0.485603	0.515397	2
33	0.42653	0.630996	0.476106	0.028021	0.42653	0.450149	0.481200	0.490101	0.630996	1
34	0.37771	0.502678	0.442741	0.030613	0.37771	0.424793	0.440117	0.46486	0.502678	1
35	0.367462	0.447206	0.418279	0.023623	0.367462	0.396084	0.426542	0.441778	0.447206	1
36	0.371342	0.504756	0.442541	0.034203	0.371342	0.413671	0.433053	0.472444	0.504756	2
37	0.398761	0.489234	0.442787	0.030848	0.398761	0.414528	0.431272	0.47462	0.489234	1
38	0.439518	0.599343	0.505699	0.039402	0.439518	0.472477	0.506187	0.535004	0.599343	1
39	0.461894	0.552568	0.507382	0.028617	0.461894	0.477499	0.516645	0.53383	0.552568	1
40	0.252659	0.463233	0.364377	0.06011	0.252659	0.311468	0.366623	0.415326	0.463233	1
41	0.301863	0.501671	0.380394	0.048102	0.301863	0.343843	0.392534	0.411507	0.501671	1
42	0.22327	0.443564	0.358033	0.062497	0.22327	0.306198	0.36046	0.418243	0.443564	1
43	0.282705	0.472628	0.387539	0.056376	0.282705	0.330034	0.399583	0.431907	0.472628	1

Figure B.6: Dice Coeffcient Candlestick graph for SICLE using data from P05, P25, P50, P75, P95 in $DiceCoeff\_ps\_t$ using NA1 data sets

Table B.7: Sensitivity results for 'AIR5' in *Sensitivity_ps_t* using NA1 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.235496	0.436184	0.326035	0.05775	0.235496	0.279408	0.307199	0.37972	0.436184	2
2	0.195341	0.432839	0.32771	0.065698	0.195341	0.276174	0.335819	0.384533	0.432839	1
3	0.056216	0.314994	0.169717	0.067206	0.056216	0.114139	0.173184	0.203061	0.314994	2
4	0.350653	0.44896	0.386296	0.029902	0.350653	0.365653	0.372559	0.421642	0.44896	1
5	0.318102	0.540981	0.399746	0.033898	0.318102	0.352431	0.394016	0.426493	0.540981	2
6	0.341809	0.501435	0.389413	0.05797	0.341809	0.352789	0.392736	0.431204	0.501435	2
7	0.206899	0.488698	0.375096	0.042329	0.206899	0.35561	0.372373	0.400461	0.488698	3
8	0.24146	0.481639	0.353152	0.076291	0.24146	0.279534	0.332524	0.432689	0.481639	1
9	0.193246	0.445016	0.331492	0.067942	0.193246	0.275811	0.334628	0.381504	0.445016	1
10	0.34691	0.501073	0.413945	0.042804	0.34691	0.380596	0.40996	0.453404	0.501073	3
11	0.429444	0.527326	0.462413	0.024446	0.429444	0.44607	0.466281	0.473096	0.527326	3
12	0.55674	0.657807	0.605667	0.031662	0.55674	0.577836	0.605026	0.636318	0.657807	3
13	0.444127	0.691826	0.553363	0.064002	0.444127	0.516428	0.5311	0.573678	0.691826	2
14	0.181216	0.578793	0.38511	0.06876	0.181216	0.352457	0.363288	0.442444	0.578793	2
15	0.048322	0.566884	0.414269	0.125614	0.048322	0.360433	0.463806	0.524785	0.566884	2
16	0.420096	0.542616	0.47076	0.036447	0.420096	0.441171	0.468268	0.511766	0.542616	3
17	0.406176	0.521464	0.465519	0.033783	0.406176	0.441514	0.458177	0.495842	0.521464	3
18	0.137242	0.367306	0.253787	0.077476	0.137242	0.171326	0.275503	0.336455	0.367306	3
19	0.066254	0.431353	0.179989	0.112136	0.066254	0.096388	0.140304	0.22931	0.431353	2
20	0.346628	0.482279	0.408367	0.034804	0.346628	0.387916	0.406492	0.426428	0.482279	3
21	0.268356	0.454746	0.372168	0.046777	0.268356	0.333953	0.369236	0.415965	0.454746	3
22	0.299086	0.474864	0.403805	0.038023	0.299086	0.377857	0.410872	0.427388	0.474864	3
23	0.306872	0.47756	0.370066	0.047052	0.306872	0.334625	0.366141	0.411819	0.47756	3
24	0.333612	0.483326	0.414473	0.037197	0.333612	0.391432	0.407494	0.445694	0.483326	3
25	0.327508	0.525529	0.426444	0.049913	0.327508	0.395472	0.435446	0.461111	0.525529	3
26	0.562179	0.702995	0.633696	0.035668	0.562179	0.614099	0.639416	0.656987	0.702995	2
27	0.543215	0.673699	0.6344	0.03321	0.543215	0.601539	0.634941	0.646197	0.673699	2
28	0.312449	0.553473	0.399209	0.061478	0.312449	0.347801	0.390601	0.429834	0.553473	3
29	0.312185	0.571429	0.422921	0.074777	0.312185	0.366418	0.39071	0.483027	0.571429	3
30	0.067742	0.346939	0.156786	0.092571	0.067742	0.095136	0.130511	0.198367	0.346939	1
31	0.160099	0.362338	0.246963	0.058284	0.160099	0.206781	0.243787	0.271895	0.362338	2
32	0.416428	0.609152	0.4541	0.024398	0.416428	0.436647	0.451693	0.466282	0.609152	3
33	0.413272	0.491729	0.449394	0.025307	0.413272	0.427289	0.446607	0.474003	0.491729	3
34	0.36237	0.492734	0.413601	0.025774	0.36237	0.387056	0.409891	0.425478	0.492734	3
35	0.340682	0.42165	0.377906	0.023819	0.340682	0.353387	0.380237	0.396502	0.42165	2
36	0.285119	0.522	0.399027	0.080911	0.285119	0.371267	0.393366	0.427122	0.522	3
37	0.332915	0.491360	0.413761	0.040698	0.332915	0.373457	0.422561	0.441555	0.491360	3
38	0.385224	0.541431	0.457019	0.044611	0.385224	0.424159	0.449307	0.489196	0.541431	3
39	0.372493	0.493873	0.448173	0.032642	0.372493	0.423401	0.4554	0.476519	0.493873	2
40	0.225928	0.499008	0.341188	0.071033	0.225928	0.290847	0.340719	0.36761	0.499008	1

Figure B.7: Sensitivity Candlestick graph for AIR5 using data from P05, P25, P50, P75, P95 in *Sensitivity_ps_t* using NA1 data sets

Table B.8: Sensitivity results for 'Demon' in $Sensitivity\_ps\_t$ using NA1 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.218611	0.418258	0.304408	0.053657	0.218611	0.249467	0.309916	0.342476	0.418258	3
2	0.014822	0.473656	0.225169	0.142569	0.014822	0.079569	0.22339	0.352367	0.473656	3
3	0.056058	0.396186	0.186185	0.098239	0.056058	0.106363	0.167224	0.230608	0.396186	1
4	0.010141	0.407364	0.203061	0.12924	0.010141	0.06762	0.201324	0.329691	0.407364	3
5	0.182861	0.531171	0.366624	0.103576	0.182861	0.275414	0.395984	0.459993	0.531171	3
6	0.144215	0.498994	0.329567	0.109067	0.144215	0.218862	0.338737	0.442062	0.498994	3
7	0.280685	0.482566	0.391052	0.063101	0.280685	0.337166	0.406361	0.454667	0.482566	1
8	0	0.475783	0.229467	0.15996	0	0.069334	0.18964	0.413323	0.475783	3
9	0.097426	0.492079	0.307208	0.114546	0.097426	0.229022	0.342792	0.393119	0.492079	3
10	0.387154	0.563078	0.475336	0.053777	0.387154	0.425848	0.493316	0.512119	0.563078	1
11	0.37117	0.666382	0.486414	0.049032	0.37117	0.468629	0.48787	0.522162	0.666382	2
12	0.559439	0.687201	0.640962	0.038556	0.559439	0.606328	0.651756	0.67329	0.687201	1
13	0.427357	0.667793	0.505135	0.072133	0.427357	0.451945	0.484964	0.550382	0.667793	3
14	0.124855	0.53387	0.361805	0.138742	0.124855	0.221889	0.410622	0.484566	0.53387	3
15	0.164821	0.678849	0.305679	0.123447	0.164821	0.3565	0.308403	0.610606	0.678849	3
16	0.498856	0.645245	0.567829	0.04946	0.498856	0.519495	0.560479	0.610973	0.645245	1
17	0.34468	0.622299	0.525239	0.079356	0.34468	0.474925	0.537933	0.613529	0.622299	1
18	0.136472	0.494744	0.311623	0.102503	0.136472	0.206295	0.346231	0.392878	0.494744	2
19	0	0.516102	0.156428	0.12597	0	0.074472	0.114573	0.223675	0.516102	3
20	0.401746	0.554901	0.476991	0.042418	0.401746	0.451117	0.461268	0.520175	0.554901	1
21	0.299563	0.608011	0.457484	0.084199	0.299563	0.405648	0.427676	0.523998	0.608011	1
22	0.350656	0.667062	0.479866	0.064582	0.350656	0.438868	0.477767	0.52722	0.667062	1
23	0.306153	0.532649	0.434267	0.053632	0.306153	0.409199	0.426494	0.475875	0.532649	1
24	0.320564	0.643652	0.526222	0.066295	0.320564	0.498931	0.527713	0.567722	0.643652	1
25	0.393436	0.629623	0.540733	0.063131	0.393436	0.49519	0.560412	0.589388	0.629623	1
26	0.516613	0.703611	0.607522	0.049268	0.516613	0.567560	0.592514	0.618665	0.703611	3
27	0.466049	0.660424	0.599166	0.046656	0.466049	0.560706	0.617614	0.634109	0.660424	3
28	0.28275	0.562293	0.456718	0.063448	0.28275	0.423501	0.471442	0.49266	0.562293	2
29	0.377922	0.613059	0.488279	0.072498	0.377922	0.414375	0.503213	0.553888	0.613059	1
30	0	0.08432	0.018005	0.029468	0	0	0	0.042714	0.08432	3
31	0	0.290242	0.071213	0.07979	0	0	0.066933	0.126727	0.290242	3
32	0.426277	0.580069	0.512657	0.037328	0.426277	0.493052	0.50539	0.538128	0.580069	1
33	0.418012	0.58827	0.50246	0.047897	0.418012	0.447787	0.507349	0.53354	0.58827	1
34	0.325436	0.509676	0.44527	0.045866	0.325436	0.414375	0.43993	0.476244	0.509676	2
35	0.273569	0.462879	0.369052	0.056964	0.273569	0.327566	0.362598	0.431262	0.462879	3
36	0.448035	0.560476	0.509175	0.030046	0.448035	0.484797	0.509635	0.531926	0.560476	1
37	0.337217	0.520351	0.43997	0.049956	0.337217	0.407014	0.461538	0.478867	0.520351	2
38	0.418395	0.574346	0.507301	0.045094	0.418395	0.46914	0.508657	0.544163	0.574346	1
39	0.311929	0.552593	0.446897	0.065064	0.311929	0.38412	0.451673	0.486113	0.552593	3
40	0.112533	0.496729	0.272173	0.112653	0.112533	0.187803	0.266392	0.345862	0.496729	3

Figure B.8: Candlestick graph for Demon using data from P05, P25, P50, P75, P95 in $Sensitivity\_ps\_t$ using NA1 data sets

Table B.9: Sensitivity results for 'SICLE' in $Sensitivity\_ps\_t$ using NA1 data sets

ROI	Minimum	Maximum	Average	Standard deviation	5th percentile	25th percentile	Median	75th percentile	95th percentile	Rank
1	0.242733	0.460923	0.349677	0.056571	0.242733	0.311002	0.344991	0.396216	0.460923	1
2	0.066009	0.431757	0.2896	0.105463	0.066009	0.223831	0.309483	0.393099	0.431757	2
3	0.031211	0.280598	0.154006	0.069358	0.031211	0.09346	0.148668	0.206665	0.280598	3
4	0.281286	0.48187	0.375688	0.052112	0.281286	0.33575	0.385856	0.413666	0.48187	2
5	0.374472	0.515603	0.445002	0.045932	0.374472	0.404233	0.453091	0.48734	0.515603	1
6	0.251877	0.490578	0.399558	0.063474	0.251877	0.357544	0.407567	0.449396	0.490578	1
7	0.286325	0.501055	0.3872	0.04993	0.286325	0.346242	0.389645	0.430104	0.501055	2
8	0.122275	0.417011	0.29364	0.069425	0.122275	0.229789	0.294303	0.381146	0.417011	2
9	0.188987	0.482086	0.308408	0.076419	0.188987	0.254143	0.300693	0.377591	0.482086	2
10	0.393515	0.515115	0.446863	0.037636	0.393515	0.408818	0.438202	0.476726	0.515115	2
11	0.460215	0.527629	0.490996	0.021796	0.460215	0.477782	0.488436	0.511934	0.527629	1
12	0.588202	0.678244	0.626667	0.026134	0.588202	0.601793	0.627021	0.644903	0.678244	3
13	0.492101	0.664297	0.562023	0.047682	0.492101	0.535662	0.547283	0.590012	0.664297	1
14	0.290139	0.662271	0.504912	0.10266	0.290139	0.432306	0.499587	0.60004	0.662271	1
15	0.236555	0.595321	0.458743	0.097053	0.236555	0.401013	0.466256	0.535918	0.595321	1
16	0.407822	0.543671	0.466683	0.039455	0.407822	0.45192	0.48626	0.526809	0.543671	2
17	0.407523	0.602185	0.493802	0.05296	0.407523	0.446593	0.491711	0.533985	0.602185	2
18	0.271282	0.504167	0.345066	0.067122	0.271282	0.293356	0.314212	0.394004	0.504167	1
19	0.051478	0.461923	0.185593	0.100281	0.051478	0.116552	0.180249	0.23486	0.461923	1
20	0.380738	0.491423	0.43234	0.030725	0.380738	0.408757	0.438828	0.453012	0.491423	2
21	0.332172	0.515806	0.409438	0.051696	0.332172	0.371008	0.399835	0.44829	0.515806	2
22	0.364373	0.49683	0.448324	0.037502	0.364373	0.426975	0.460929	0.474288	0.49683	2
23	0.338353	0.478651	0.413808	0.03813	0.338353	0.381342	0.414347	0.439368	0.478651	2
24	0.331392	0.574801	0.468257	0.05366	0.331392	0.444813	0.476005	0.501628	0.574801	2
25	0.308649	0.530606	0.443378	0.058255	0.308649	0.397908	0.445444	0.497547	0.530606	2
26	0.632961	0.722329	0.674736	0.023246	0.632961	0.655354	0.678523	0.687891	0.722329	1
27	0.584374	0.680031	0.636181	0.025661	0.584374	0.617571	0.640986	0.657909	0.680031	1
28	0.315297	0.570626	0.462518	0.066337	0.315297	0.41932	0.464547	0.516043	0.576626	1
29	0.360656	0.579202	0.47466	0.063664	0.360656	0.426619	0.475764	0.546304	0.579202	2
30	0	0.369202	0.117402	0.100761	0	0.023511	0.120809	0.162211	0.369202	2
31	0.01663	0.357396	0.290148	0.062782	0.01663	0.202806	0.26148	0.320437	0.357396	2
32	0.376966	0.50245	0.467994	0.030022	0.376966	0.452688	0.478917	0.488929	0.50245	2
33	0.428506	0.532035	0.476457	0.02836	0.428506	0.454909	0.474561	0.498156	0.532035	2
34	0.365467	0.52674	0.453233	0.035756	0.365467	0.43573	0.461454	0.472509	0.52674	1
35	0.367133	0.465383	0.416571	0.023756	0.367133	0.398336	0.422199	0.43249	0.465383	1
36	0.372123	0.518266	0.442195	0.034311	0.372123	0.422196	0.432047	0.468548	0.518266	2
37	0.394602	0.485084	0.451983	0.026621	0.394602	0.432729	0.45986	0.474411	0.485084	1
38	0.444877	0.547949	0.506804	0.028075	0.444877	0.487384	0.502094	0.531383	0.547949	2
39	0.43774	0.52288	0.491507	0.025428	0.43774	0.47364	0.493006	0.513112	0.52288	1
40	0.235567	0.433843	0.336377	0.062576	0.235567	0.276232	0.328827	0.383717	0.433843	2
41	0.349677	0.462506	0.329839	0.055524	0.349677	0.282334	0.325035	0.361864	0.462506	1
42	0.245297	0.439882	0.361796	0.056588	0.245297	0.316455	0.36597	0.410097	0.439882	1
43	0.266982	0.442063	0.388178	0.056714	0.266982	0.314784	0.366856	0.423643	0.442063	1

Figure B.9: Sensitivity Candlestick graph for SICLE using data from P05, P25, P50, P75, P95 in $Sensitivity\_ps\_t$ using NA1 data sets

REFERENCES

[1] P.M. Bossuyt, J.B. Reitsma, D.E. Bruns, C.A. Gatsonis, P.P. Glasziou, L.M. Irwig, J.G. Lijmer, D. Moher, D. Rennie, and H.C.W. de Vet. Towards complete and accurate reporting of studies of diagnostic accuracy: The stard initiative. *Clinical Chemistry*, 49(1):1–6, Jan. 2003.

[2] P.M. Bossuyt, J.B. Reitsma, D.E. Bruns, C.A. Gatsonis, P.P. Glasziou, L.M. Irwig, D. Moher, D. Rennie, H.C.W. de Vet, and J.G. Lijmer. The stard statement for reporting studies of diagnostic accuracy: Explanation and elaboration. *Clinical Chemistry*, 49(1):7–18, Jan. 2003.

[3] Gang Song Phillip A. Cook Arno Klein Brian Avants, Nicholas Tustison and James C. Gee. A reproducible evaluation of ants similarity metric performance in brain image registration. *NeuroImage*, 54(3):2033–2044, 2010.

[4] G. E. Christensen and H. J. Johnson. Consistent image registration. *IEEE Trans. Med. Imaging*, 20(7):568–582, July 2001.

[5] G. E. Christensen and H. J. Johnson. Invertibility and transitivity analysis for nonrigid image registration. *Journal of Electronic Imaging*, 12(1):106–117, Jan. 2003.

[6] Gary E. Christensen, Xiujuan Geng, Jon G. Kuhl, Joel Bruss, Thomas J. Grabowski, John S. Allen, Imran A. Pirwani, Michael W. Vannier, and Hanna Damasio. Introduction to the non-rigid image registration evaluation project (nirep). In *3rd International Workshop on Biomedical Image Registration*, LCNS 4057, pages 128–135. Springer-Verlag, July 2006.

[7] J. Michael Fitzpatrick. The Retrospective Image Registration Evaluation Project. http://www.insight-journal.org/RIRE/, March 2007.

[8] Xiujuan Geng. *Transitive Inverse-Consistent Image Registration and Evaluation.* PhD thesis, Department of Electrical and Computer Engineering, The University of Iowa, Iowa City, IA 52242, December 2007.

[9] P. Hellier, C. Barillot, L. Corouge, B. Gibaud, G. Le Goualher, D. L. Collins, A. Evans, G. Malandain, N. Ayache, G. E. Christensen, and H. J. Johnson. Retrospective evaluation of inter-subject brain registration. *IEEE Transactions on Medical Imaging*, 22(9):1120–1130, 2003.

[10] H. J. Johnson and G. E. Christensen. Consistent landmark and intensity-based image registration. *IEEE Trans. Med. Imaging*, 21(5):450–461, 2002.

[11] K. Murphy, B. van Ginneken, J.P.W. Pluim, S. Klein, and M. Staring. Semi-automatic reference standard construction for quantitative evaluatoin of lung CT registration. In *MICCAI*, volume 5242, pages 1006–1013, 2008.

[12] K. Murphy, B. van Ginneken, J.M. Reinhardt, S. Kabus, K. Ding, X. Deng, and J.P.W. Pluim. Evaluation of methods for pulmonary image registration: The EMPIRE10 study. In *Grand Challenges in Medical Image Analysis*, 2010.

[13] Klein S Staring M de Hoop BJ Viergever MA Pluim JP.l Murphy K, van Ginneken B. Semi-automatic construction of reference standards for evaluation of image registration. *Med Image Anal*, Aug 2010.

[14] Chris Newman. *SQLite*. Sams Publishing, Indianapolis, IN, USA, 2005.

[15] Michael Owens. *The Definitive Guide to SQLite*. Apress, New York, USA, 2006.

[16] J.P.W. Pluim, J.B.A. Maintz, and M.A. Viergever. Mutual-information-based registration of medical images: a survey. *IEEE Transactions on Medical Imaging*, 22(8):986–1004, 2003.

[17] Klik M Prokop M. van Rikxoort EM, van Ginneken B. Supervised enhancement filters: application to fissure detection in chest ct scans. *IEEE Trans Med Imaging*, 27(1):1–10, 2008.

[18] Viergever MA Prokop M van Ginneken B. van Rikxoort EM, de Hoop B. Automatic lung segmentation from thoracic computed tomography scans using a hybrid approach with error detection. *Med Phys*, 36(7):2934–2947, 2009.

[19] Ying Wei. Non-rigid image registration with anatomical and functional mri. Master's thesis, Department of Electrical and Computer Engineering, The University of Iowa, Iowa City, IA 52242, June 2009.

[20] Jay West, J. Michael Fitzpatrick, et al. Comparison and evaluation of retrospective intermodality brain image registration techniques. *J. Comp. Asst. Tomog.*, 21(4):554–566, 1997.