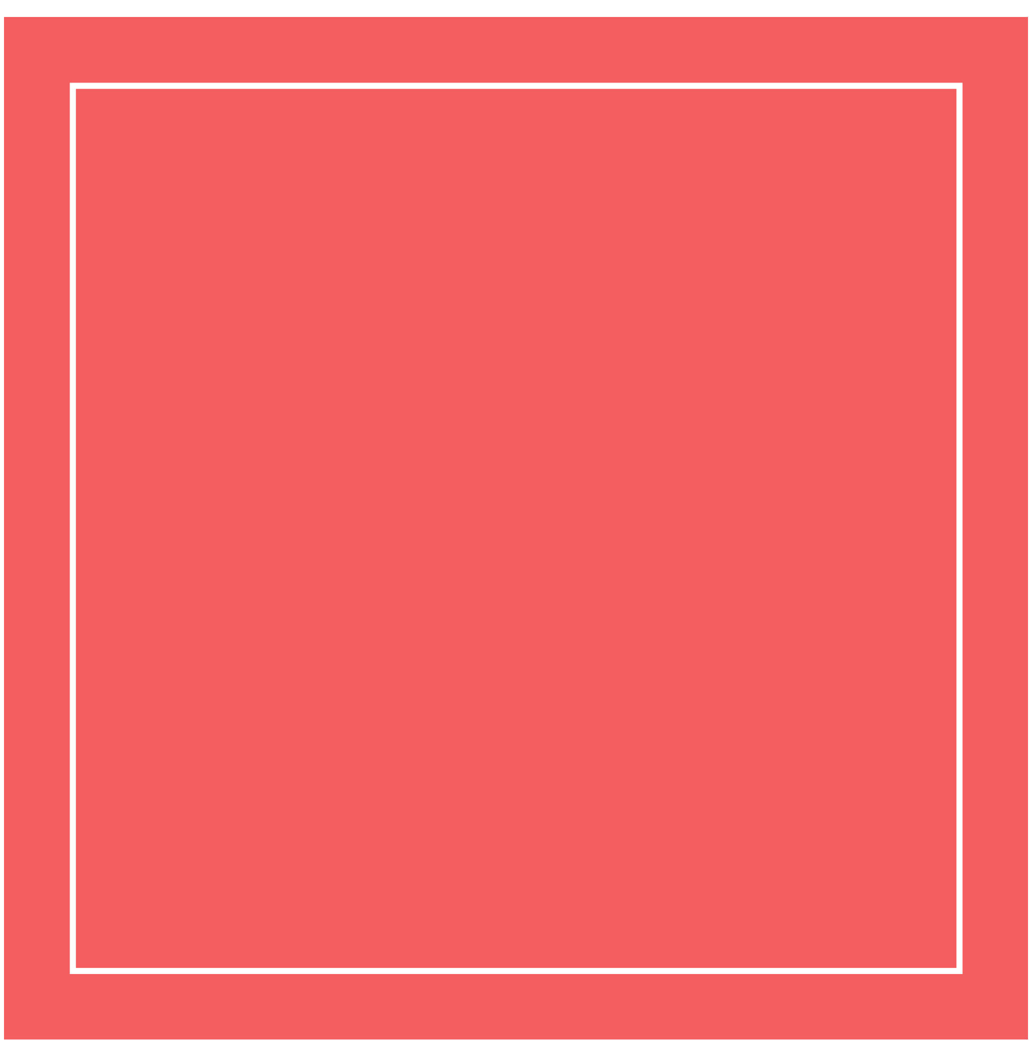


# Introduction

## **Registration**

- Registration is the process of aligning two or more images to compare or analyze changes.
- It is widely used in medical imaging to track changes over time or match images from different patients.

## **Types of Registration**

- **Rigid Registration:** Only allows movement (translation & rotation).
- **Affine Registration:** Allows movement, scaling, and skewing.
- **Non-Rigid Registration:** Allows bending and deformation, making it useful for soft tissues.

# Non-Rigid Registration

- **Rigid and affine transformations are not enough** for soft tissues that deform, like the brain, heart, or lungs.
- Non-rigid registration helps in **motion tracking and deformation analysis**, useful in surgery, disease monitoring, and biomechanical studies.

# Techniques in Non-Rigid Registration

1. Elastic & Fluid Registration
2. Finite Element Models (FEM)
3. Optical Flow
4. Spline-Based Methods
    a. Thin-Plate Splines
    b. B-Splines

# Elastic Registration

**Elastic registration** adjusts **images** by **smoothly stretching** and **bending** them to match a **reference**. It uses **flexible, physics-based models** that **mimic elasticity**, ensuring **natural transformations**. The goal is to create the **best possible alignment** by balancing **smoothness** and **accuracy**.

**Techniques Used in Elastic Registration:**

1. **Lagrangian Reference Frame** – Describes deformations based on their **initial position**.
2. **Elastic Energy Minimization** – Balances **smoothness** and **accuracy** for natural transformations.
3. **Finite Element Methods (FEM)** – Uses **mathematical models** to simulate **elastic deformations**.

# Fluid Registration

**Fluid registration** warps **images** like a **flowing liquid** for **seamless alignment**. It uses **flexible models** that **adapt naturally**. By balancing **smoothness** and **accuracy**, it ensures **precise matching**. This method is ideal for **detailed** and **dynamic transformations**.

**Techniques Used in Fluid Registration:**

1. **Navier-Stokes Equation** – Governs fluid-like deformations by solving for velocity fields instead of displacement fields.
2. **Convolution-Based Solution** – Uses eigenfunctions of the elasticity operator to speed up computation, improving efficiency.
3. **Variable Viscosity Models** – Allows different deformation strengths across image regions for more adaptive transformations.

# Registration Using FEM

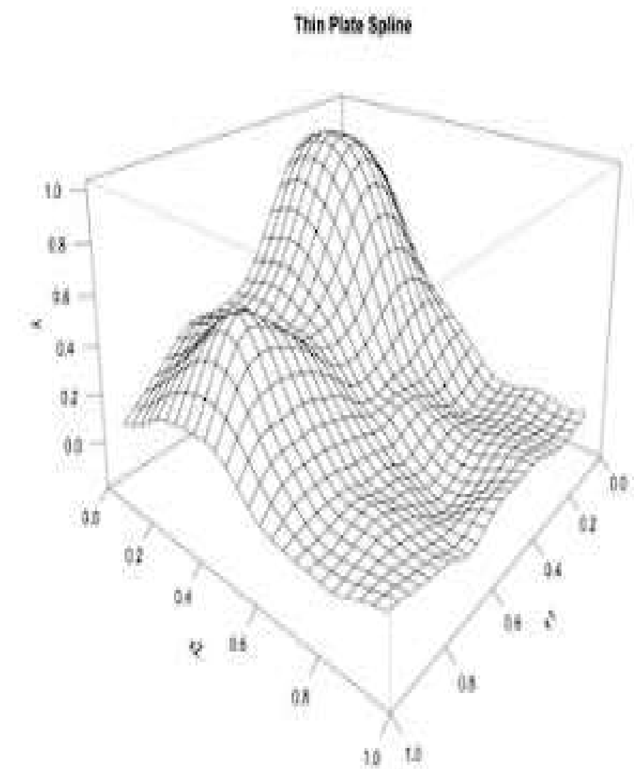
**Finite Element Methods (FEM)** help model **elastic deformations** in **image registration**. **Edwards et al.** proposed a method for **surgery guidance** by dividing images into a **triangular mesh**. **Nodes** represent different **tissues—bones (rigid), soft tissues (elastic),** and **cerebrospinal fluid (fluid). Rigid nodes** stay **fixed**, while **elastic** and **fluid nodes** deform for **realistic alignment**.

# Registration Using Optical Flow

**Optical flow** tracks **pixel movements** between images to estimate **deformation**. It calculates **motion** by analyzing **brightness changes**, helping **align images** smoothly and accurately. This method is widely used in **medical imaging** and **video processing**.

# Thin-Plate Splines (TPS)

**Thin-Plate Splines (TPS)** is a method for **smooth and flexible transformations** in **image registration** and **shape matching**. It minimizes **bending energy** to ensure **natural deformations** while preserving structure. TPS is widely used in **medical imaging, computer vision,** and **biometric recognition**.



# B-Splines

**B-Splines** (Basis Splines) are used for **smooth and flexible transformations** in **image registration** and **shape modeling.** They provide **local control** over deformations, ensuring **precision and continuity**. B-Splines are widely applied in **medical imaging, computer graphics,** and **geometric design**.

# Intersubject Registration (ISR)

- Intersubject registration is a non-rigid image registration technique that aligns anatomical structures across **different individuals**
- **ISR accounts for anatomical variability between subjects**, enabling cross-population comparisons.
- Used in **population studies, medical atlases, and disease analysis**.
- **Key Characteristics:**
  1. **High Degrees of Freedom:**
     - ISR transformations have more flexibility than intrasubject registration to accommodate inter-individual shape variations.
  2. **Less Constraint on Deformation:**
     - Unlike intrasubject registration, where deformations are limited to biological consistency, ISR allows greater anatomical adaptation.

# Techniques Used in ISR

1. **Elastic & Fluid Registration**

- **Elastic Registration** – Treats tissue like **rubber**, allowing smooth stretching.
- **Fluid Registration** – Enables **highly flexible deformations**, essential for aligning different individuals.

2. **Probabilistic Atlases**

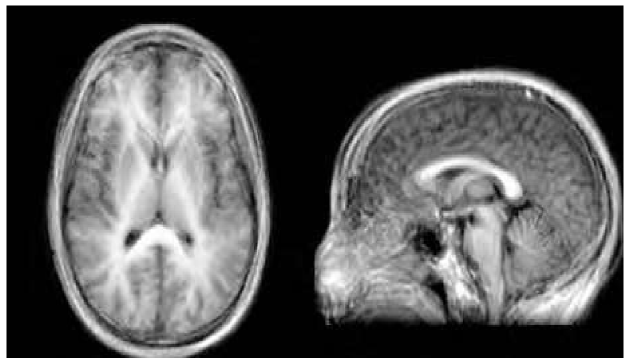
- Combines images from multiple subjects to **better represent population data**.
- Used in **International Consortium for Brain Mapping (ICBM)** for studying brain structure variations.

3. **Statistical Shape Models**

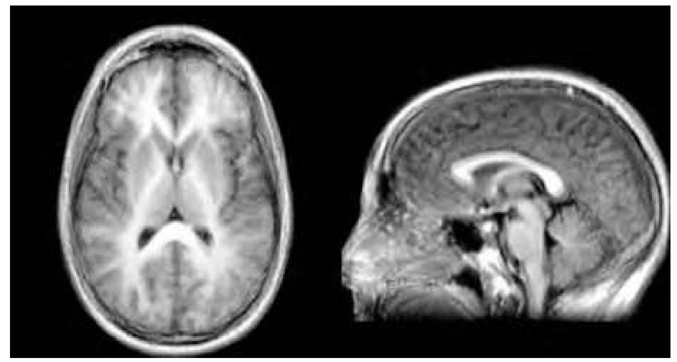
- Helps measure **local and global shape differences** in organs.

# Brain Atlas Construction

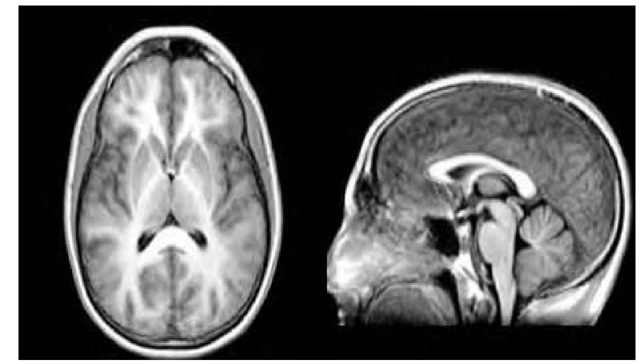
- Seven subjects' MRI scans were mapped to a reference space.



rigid registration



affine registration



nonrigid registration

- Non-rigid registration produced the most accurate atlas.

# Application

- **Brain Atlases & Medical Research** – Standardized brain atlases help researchers compare structural and functional differences between normal and diseased brains. They aid in studying neurological disorders and guiding interventions.
- **Comparing Healthy vs. Diseased Patients** – Techniques like MRI and PET scans help analyze differences in brain morphology and activity in conditions like Alzheimer’s and Multiple Sclerosis. These comparisons assist in early diagnosis and treatment planning.
- **Automated Segmentation & Labeling** – AI-driven segmentation techniques automatically identify and label brain structures, reducing manual effort. This enhances precision in analyzing brain abnormalities and tracking disease progression.

# Analysis of Motion and Deformation Using Nonrigid Registration

- It refer to **changes in the shape, position, or structure of organs/tissues** over time.
- Non-rigid registration helps in **tracking and analyzing these changes**.
- **Why is it Important?**

    a. Detects **tumor growth or shrinkage**.

    b. Monitors **organ movement** (e.g., brain shift, heart motion).

    c. Helps in **surgical planning & disease progression analysis**.

# Role of Non-Rigid Registration in Motion & Deformation Analysis

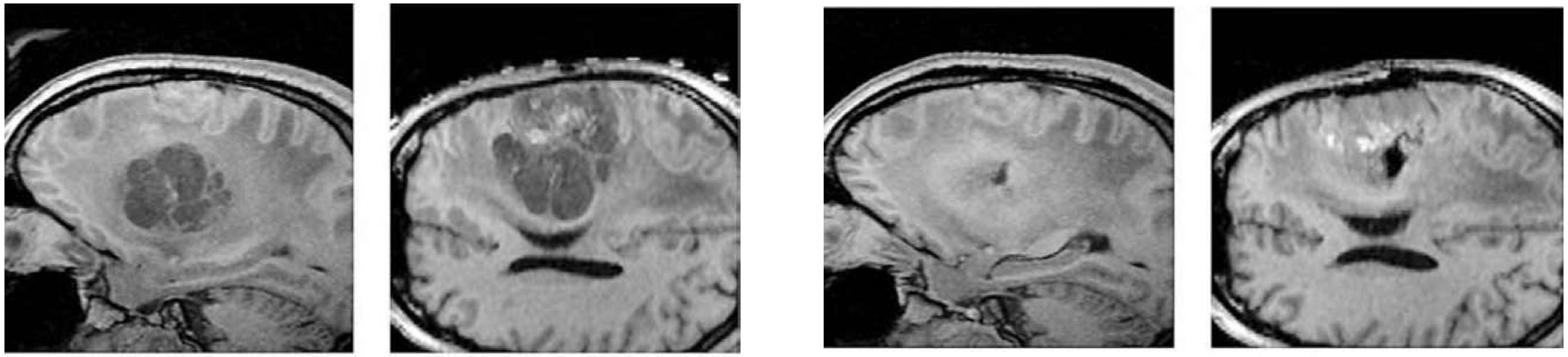
**Why Use Non-Rigid Registration?**

- **Rigid registration** cannot track soft tissue deformations.
- **Non-rigid registration** provides a **flexible model** to analyze motion & shape changes.
- It helps doctors **quantify how organs/tissues deform over time**.

**Key Features of Non-Rigid Registration for Motion Analysis:**

- **Creates a deformation field** (shows how much a structure has changed).
- **Measures volume & shape changes** (e.g., tumor growth).
- **Aligns pre- and post-surgical images** to track shifts in anatomy.

# **Example:** Brain Shift in Surgery



(a) (b) (c) (d)

preoperative MR images

postoperative MR images

# Intrasubject Registration

- Intrasubject registration aligns images of the same subject taken at different times or using different imaging modalities.
- Since the human body is non-rigid, simple transformations (like rotation and scaling) are not enough—non-rigid registration is needed to account for tissue deformation.

**<u>Techniques Used in Non-Rigid Intrasubject Registration</u>**

- B-Spline Free Form Deformation (FFD):
  - Uses a grid of control points to deform the image smoothly.
  - Great for modeling soft tissue deformations.
- Demons Algorithm:
  - Iterative method that updates transformation based on image intensity differences.

# Applications

- **Motion Correction in Medical Imaging**
  - Breast MRI (Mammography): Contrast-enhanced breast scans require precise alignment to detect cancer.
  - Cardiac Imaging : Aligns heart images from different cardiac cycles.
- **Preoperative and Postoperative Image Alignment**
  - Neurosurgery: The brain shifts after skull opening, requiring real-time correction.
- **Disease Progression Tracking in Longitudinal Studies**
  - Alzheimer’s Disease: Aligns MRI scans to measure brain atrophy.
  - Tumor Growth Monitoring: Measures how a tumor shrinks or grows.

# Example : Contrast Enhanced MRI Mammogı

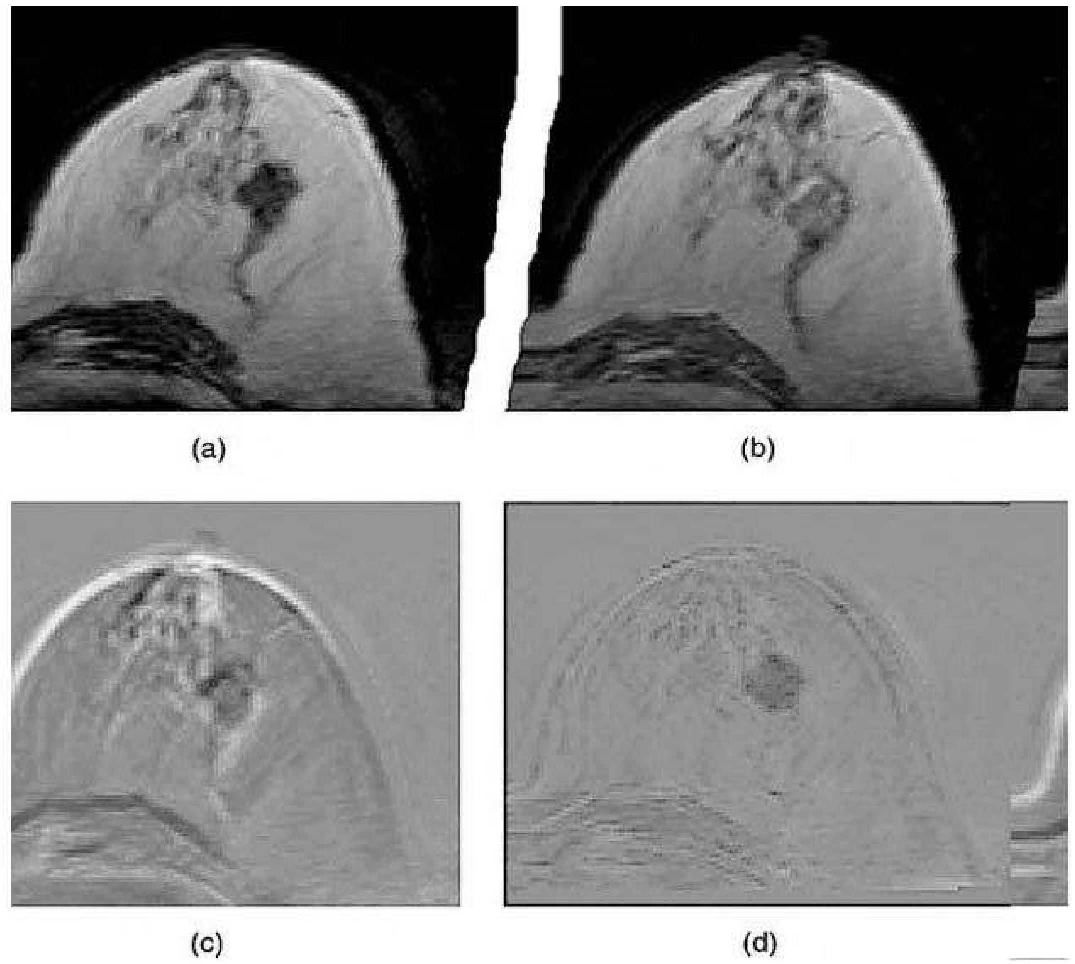



**Fig :** A contrast-enhanced MR mammography: (a) precontrast, (b) postcontrast and after subtraction (c) without registration, and (d) with nonrigid registration

# Conclusion

- **Rigid registration** is widely used, but it cannot handle soft tissue deformations.
- **Non-rigid registration** is essential for tracking anatomical changes in surgery, disease progression, and biomechanics.