Bioinformatics III
Structural Bioinformatics and Genome Analysis

Chapter 3 Structural Comparison and Alignment

3.1 Introduction

3.2 Main Methods

1. Basic algorithms review
   - Dynamic programming
   - Distance matrix
2. SARF2, CE, DALI, SSAP

3.3 Recent Methods

MAMMOTH, RAPIDO, SABERTOOT, TOPOFIT

2. SARF2, VAST, COMPARER

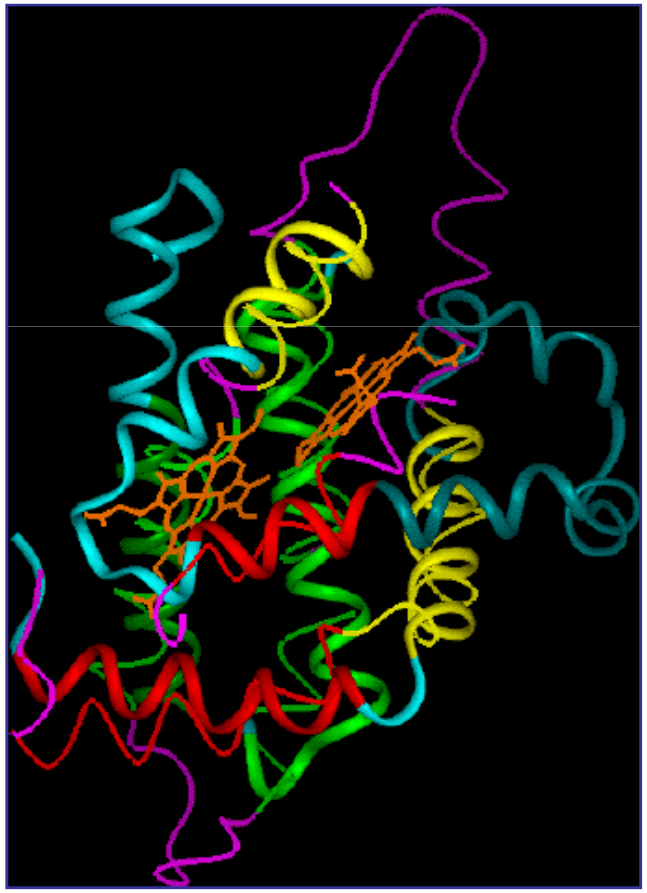
Components of structure elements to be compared:

- Local geometry (Cα, Cβ, Torsion angles)
- Side chain contacts
- Distance matrix
- Distances of inter and intra aligned fragment pairs
- Properties as SSs, hydrophobic clusters

SARF2 and VAST: predictions based on vector comparisons by converting

- Position
- Direction
- Length

Used to compare new structures to the existing DB or to view structural similarities already in the DB



http://123d.ncifcrf.gov/sarf2.html

2. SARF2 Spatial Arrangement of Backbone Fragments *(Nickolai N Alexandrov, 1998)*

Based

comparison of Cα of each residue in the SSEs of each protein

Goal

to find those SSEs which can form similar spatial arrangements but have different topological connections

How

SSEs detected through comparison with common templates for α-helices and β-strands, then larger assemblies of SSEs are constructed from the compatible pairs found

Similarity Score

Calculated as a function of rmsd and the number of matched Cα atoms

RMSD

Measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimate→ Measure of accuracy *(wikipedia)*

The significance of the comparison is considered contrasting this score with the one built up once a protein is compared with a non redundant set of structures

2. SARF2

1st step: pairs of SSEs are matched up

Shortest distance between their axes

Closest point on the axes

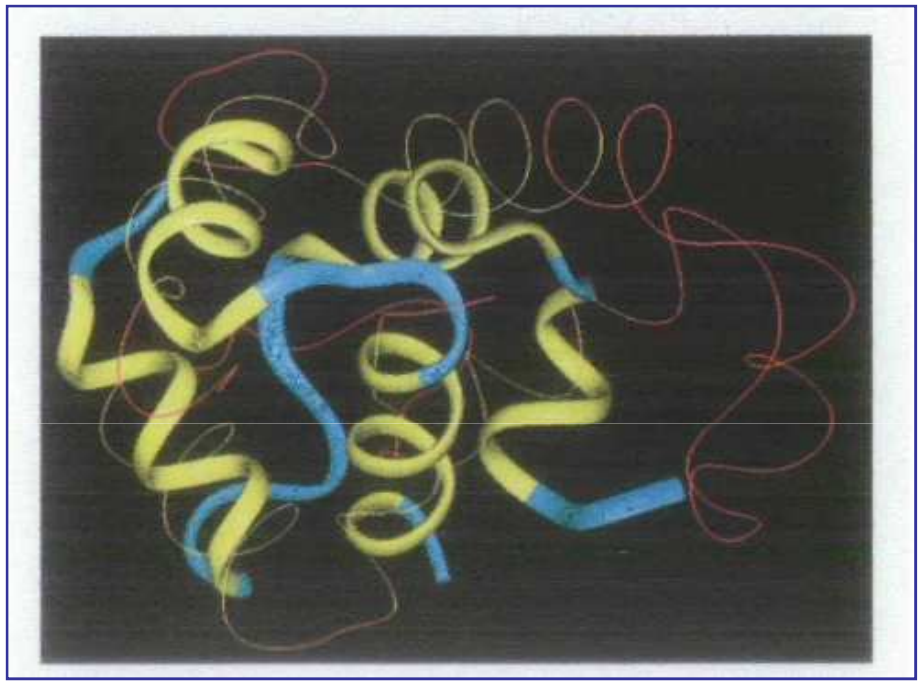
Minimum and maximum distances from each SSE

2nd Step: Largest ensembles are formed

Graph theory and maximum clique problem approximation

3rd Step: Extension of the alignment

Additional residues included



Blue ribbon shown as repressor 434 and recovering as red line.

Yellow fragments can be superimposed with rmsd = 2.61

52 Cα matched found

No evolutionary relationship but structural stability is apparent

3. Structural Comparison and Alignment
3.2 Main Methods

- From PDB services

- **ENDscript**
  A Web server for searching homologous sequences and giving information on secondary structure elements, accessibility, hydropathy and protein-protein contacts
- **ESPript**
  Easy Sequencing in Postscript
- **Non-covalent bond finder**
  Software for finding non-covalent interactions for use with Chime 2 or higher
- **Procheck**
  A program that checks the stereochemical quality of a protein structure
- **ProFit**
  A program for fitting protein structures on to each other
- **SARF2**
  A program which searches for similar structural motifs (via an analysis of backbone fragments) in protein structures
- **STRAP**
  Structural Alignment Program for Proteins, interactive extendable and scriptable editor for large protein alignments which integrates amino acid sequence, secondary structure, 3D-structure and genomic- and mRNA-sequence; Windows, Mac OSX, Unix, Linux
- **Surface Racer**
  A program that calculates exact accessible surface area, molecular surface area and average curvature of molecular surface, and analyzes cavities in the protein interior inaccessible from the outside.
- **SURFNET**
  A program which generates surfaces and void regions between molecular surfaces
- **WHAT_CHECK**
  A system for protein structure validation derived from the WHAT IF program
- **WHAT IF**
  A protein structure analysis program that may be used for mutant prediction, structure verification and molecular graphics

3. CE

Based

Target function: heuristics assumes continuity and optimal path existence

Compare octameric fragments – an aligned fragment pair (AFP)

Distance matrices: distances between each $X\alpha$ of each octamer fragment combination from both proteins is plotted and represented

Combinations of AFP "representing" possible continuous alignment path are selected and extended

Find the optimal path through the AFPs

Optimize the alignment through dynamic programming

Measure the statistical significance of the alignment

3. CE

Assumed rules

Remove highly homologous chains

The rmsd between two chains < 2Å

The length difference between two chains < 10%

The number of gap positions in alignment between two chains < 20% of aligned residue positions

At least 2/3 of the residue positions in the represented chain are aligned

3. CE

Alignment algorithm

Input and output of alignment algorithm

Input: two proteins: $A = \{a_1, \cdots, a_m\}$ $B = \{b_1, \cdots, b_n\}$

Output: An alignment

$$L(A,B) = \{(a_{i_1}, b_{j_1}), \cdots, (a_{i_L}, b_{j_L})\},$$

$$i_1 < i_2 < \cdots < i_L, j_1 < j_2 < \cdots < j_L$$

and scores

Constraints:

min rmsd:

$$rmsd = \min_T \sqrt{\frac{\sum_{k=1}^{L} (a_{i_k} - Tb_{j_k})^2}{L}}$$

max L

min Gaps:

$$Gaps = \sum_{t=1}^{L-1} [(i_{t+1} - i_t - 1) + (j_{t+1} - j_t - 1)]$$

Penalization gaps: Computational speed lost of non topological alignments and insertions of more than 30 residues

3. CE

Two methods for detecting structural homology

1. **From ONLY structural information**
   Alignment Path
   Distance Measure for Similarity Evaluation

2. **From structural information AND adding composite properties**

(i) Octamer A and Octamer B satisfy a similarity criterion: AFP

(ii)Three threshold

1st detecting AFP

2nd detecting the correctness of a next candidate AF relative to the current one

3rd evaluating all alignments to find the optimal ones

(iii) Statistical significance

Numerical table

Two distributions corresponding to both proteins rmsd and Gaps values for the non redundant set

Assuming normality the final z-score is calculated by combining both z-scores

3. CE Method 1. From ONLY structural information

Alignment Path

Selection of starting point by the ones leading the longest alignment found

Longest continuous path P of AFPs in a similarity matrix S

Protein A length: n^A

Protein B length: n^B

Similarity matrix size: $(n^A - m)$ $(n^B - m)$

AFPs *i* and *i*+1 extension if and only if

Condition (1): No Gaps between AFPs *i* and *i*+1

$$P^A_{i+1} = P^A_i + m \qquad P^B_{i+1} = P^B_i + m$$

Condition (2): Gaps inserted in protein A

$$P^A_{i+1} > P^A_i + m \qquad P^B_{i+1} = P^B_i + m$$

Condition (3): Gaps inserted in protein B

$$P^A_{i+1} = P^A_i + m \qquad P^B_{i+1} > P^B_i + m$$

3. CE Method 1. From ONLY structural information

Condition (4): Gaps on protein A ; Condition (5): Gaps on Protein B

$$P_{i+1}^{A} \leq P_{i}^{A} + m + G \qquad P_{i+1}^{B} \leq P_{i}^{B} + m + G$$

Distance Measure for Similarity Evaluation: 2 distances are measured and the rmsd

i. Using an independent set of inter-residue distances: to evaluate combination of two AFPs

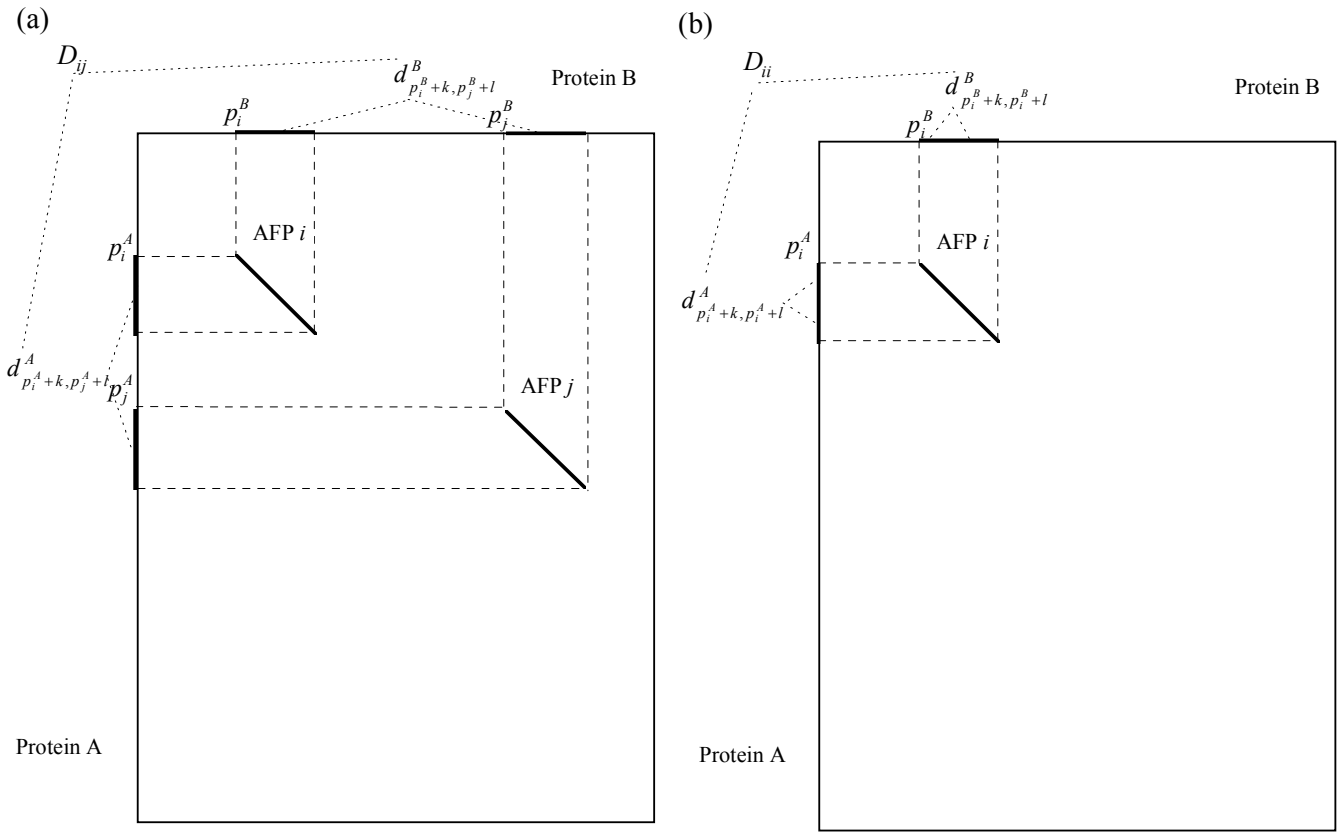
$$D_{ij} = \frac{1}{m}\left(\left| d^{A}_{P_i^A P_j^A} - d^{A}_{P_i^B P_j^B} \right| + \left| d^{A}_{P_i^A+m-1,\ P_j^A+m-1} - d^{B}_{P_i^B+m-1,\ P_j^B+m-1} \right| + \sum_{k=1}^{m-2} \left| d^{A}_{PA_i+k,\ P_j^A+m-1-k} - d^{B}_{P_i^B+k,\ P_j^B+m-1-k} \right| \right)$$

ii. Using a full set of inter-residue distances: to evaluate a single AFP

$$D_{ij} = \frac{1}{m^2}\left(\sum_{k=0}^{m-1} \sum_{l=0}^{m-1} \left| d^{A}_{P_i^A+k,\ P_j^A+l} - d^{B}_{P_i^B+k,\ P_j^B+l} \right| \right)$$

3. CE

Calculation of distance: a)D_{ij} for alignment represented by two AFPs i and j from the path, b) D_{ii} for a single AFP i from the path



3. CE

iii. RMSD obtained from structures optimally superimposed: to select the best alignments and for the optimization of gaps in the final alignment

When adding the next AFP three strategies can be followed

All possible AFPs which extend the path and satisfy the similarity criteria
Only the best AFP which extend the path and satisfy the similarity criteria
Intermediate criteria

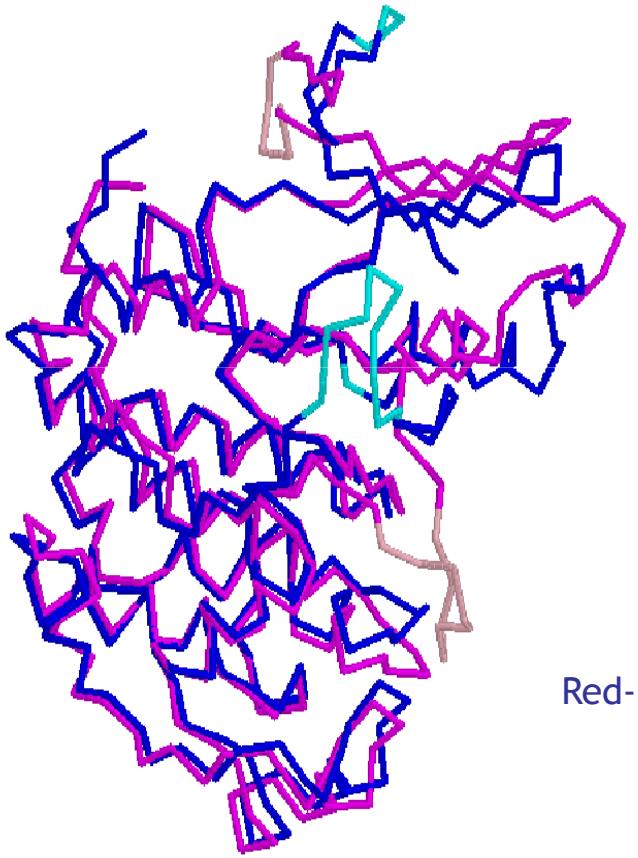
Three heuristic and three conditions to decide

Condition (6): Single AFP < 3Å $D_{nn} < D_0$

Condition (7): AFP against the path < 4Å $\frac{1}{n-1} \sum_{i=0}^{n-1} D_{in} < D_1$

Condition (8): Whole path $\frac{1}{i^2} \sum_{i=0}^{n} \sum_{j=0}^{n} D_{ij} < D_1$

3.CE Optimization of the Final Path



The 20 best alignments with a Z score > 3.5 are assessed
based on RMSD and the best kept: approx. one error in 1000 structures

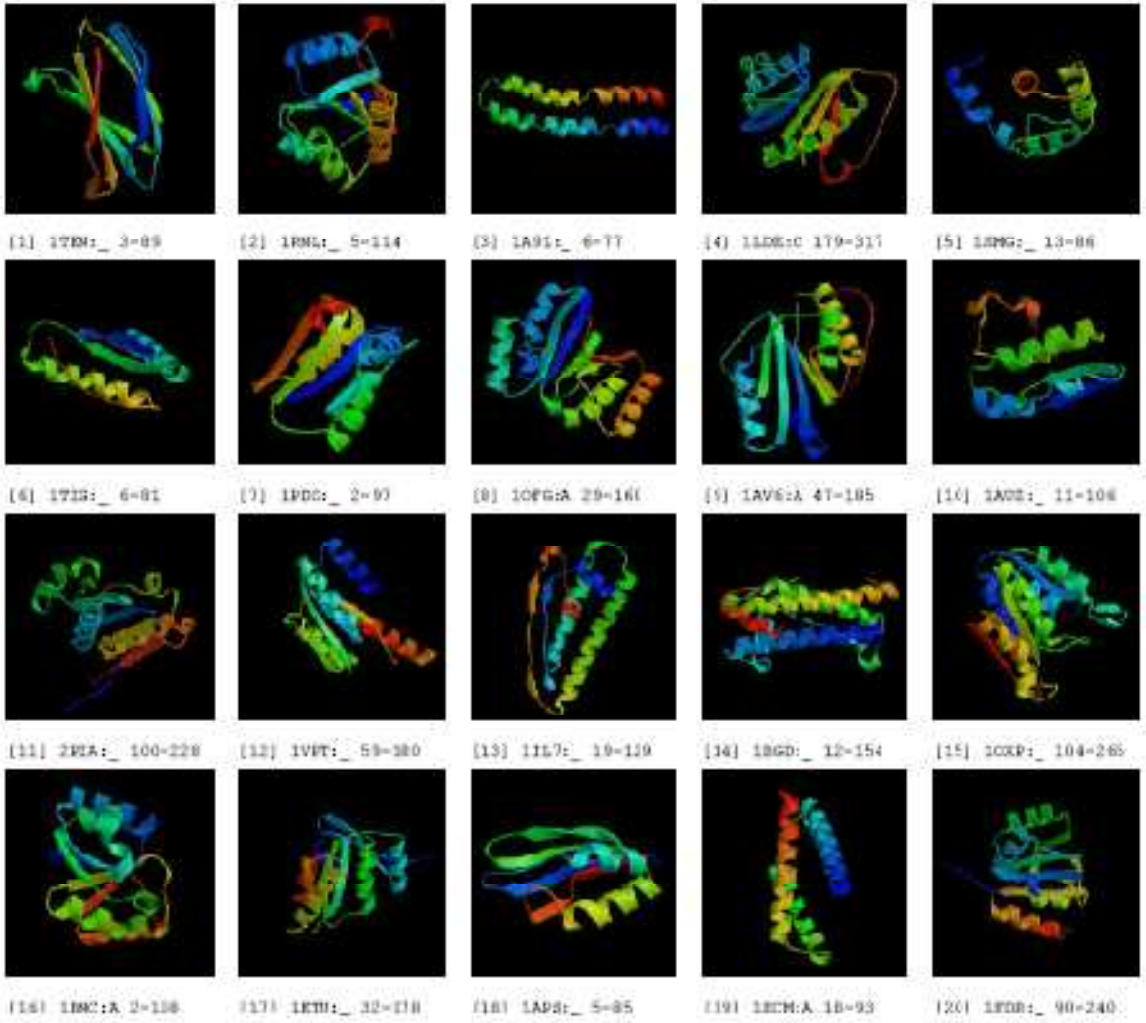
Iterative optimization using dynamic programming is performed using residues for the superimposed structures

Red-brown and light blue : Insertions

Will not find non-topological alignments (outside the bounds of the dotted lines)
CE works on chains and not in domains

3. Structural Comparison and Alignment
3.2 Main Methods

3.CE Optimization of the Final Path



- Gaps included and analyzed for relocation in both directions m/2
- RMSD improvements in superimposed structures
- New boundaries adopted
- Dynamic programming on the distance matrix using residues from the 2 superimposed structures

3. CE Method 2. From structural information AND adding composite properties

Similarity is calculated by adding the following properties represented as scores

P_{ij} measures the match between residues i and j from two proteins A and B

d_{ij} distance between residues i and j in proteins A and B after CE superimposition

Structure: Property 1, defined by coordinates of Cα

$$P_{ij} = \begin{cases} c_1 - d_{ij}, & \text{if } c_1 - d_{ij} > c_2 \\ c_2, & \text{otherwise} \end{cases}$$

Sequence: Property 2, value of PET91 matrix for amino acids at positions i and j

Secondary structure: Property 3

$$P_{ij} = \begin{cases} 1, & \text{if } s_i = s_j \\ 0, & \text{otherwise} \end{cases}$$

Solvent Exposure: Property 4

$$P_{ij} = E_0 - |E_i - E_j|$$

Conservation Index: Property 5

$$P_{ij} = 20 - |I_i - I_j|$$

3. CE Method 2. From structural information AND adding composite properties

The calculus is done residue by residue

Dynamic programming to find the optimal alignment for the whole polypeptide chain

The composite property that measure structural similarity at residue level is defined

$$\tilde{P}_{ij} = \sum_k w_k * P_{ij}^k$$

Gap initialization penalty of 10 and gap extension penalty of 1

$$a^D = \sum_i a_i^D$$

$$a^D = \begin{cases} 1, & \text{if } a_i^1 \neq -1 \text{ and } a_i^1 \neq a_i^2 \\ 0, & \text{otherwise} \end{cases}$$

3. CE Method 2. From structural information AND adding composite properties

Method	PKA (1CDK:A) vs MAPK (1GOL:_) length of alignment = 248	PKA (1CDK:A) vs CDK2 (1FIN:A) length of alignment = 251
Dali	34 (13.7%)	30 (12.0%).
STR	8 (3.2%)	8 (3.2%)
STR+SEQ+CONS	3 (1.2%)	5 (2.0%)
SEQ	98 (39.5%)	76 (30.3%)
SS	76 (30.6%)	77 (30.3%).
CONS	84 (33.9%)	107 (42.6%)
EXP	45 (18.1%)	62 (24.7%)
STR+SEQ	4 (1.6%)	6 (2.4%)

STR: structure based on the rmsd calculated for the superposition of Cα atoms after optimal alignment found using the CE algorithm

SEQ: sequence based on PET91 amino-acid similarity measure by Jones and Thornton (1992)

SS: secondary structure based on the SSEs by Kabsch and Sander (1983)

EXP: solvent exposure based on the definition of Lee and Richards (1971)

CONS: conservation index based on sequences compiled for proteins with known structure
()Absolute difference between alignments

3. DALI, Distance Alignment Matrix (Holm and Sander, 1993a)

Based: use of distance matrices to represent each structure as a 2D array for aligning protein structures. Monte Carlo Simulation

Allowance: gaps of any length

reversal of chains in any direction

free topological connectivity

Two categories of searches

Finding predefined structural patterns in a database

Finding the largest common structure between two proteins

How:

- Submatrices of hexapeptides-hexapaptides contact patterns and their distances between Ca-Ca in the 3D are plotted
- Similarities in both matrices, for protein A and B, are paired and combined into larger combined sets of pairs (overlapping)

Similarity score optimized by Monte Carlo simulation and defined as equivalent intramolecular distances

3. DALI Method

Substructures of protein A and B matching by Additive similarity score

$$S = \sum_{i=1}^{L} \sum_{j=1} \Phi\ (i,j)$$

The larger the value of S, better set of residue equivalences

Based on Similarity measure of the Ca-Ca distances

$$\Phi^E(i,j) = \Phi^E - \left| d_{ij}^A - d_{ij}^B \right|$$

Geometrical distortions effects are reduced by including the elastic similarity of the residue-pairs score

$$\Phi^E\ (i,j) = \begin{cases} \left(\Phi^E - \dfrac{\left| d_{ij}^A - d_{ij}^B \right|}{d_{ij}^*} \right) w\ (d_{ij}^*), & i \neq j \\ \Phi^E, & i = j \end{cases}$$

Envelope function to weight the contribution of pairs in the long distance range

$$w(r) = e^{\frac{r^2}{a^2}}$$

3. DALI

Summarized Method

Hexapeptides-hexapeptides contact patterns: equivalents fragments

Identification of new matching contact patterns sharing the previous equivalent fragment: (a,b)-(b,c)-(c,d)….

Iterative improvement to maximize the similarity of the alignment built up

Outcomes visualized

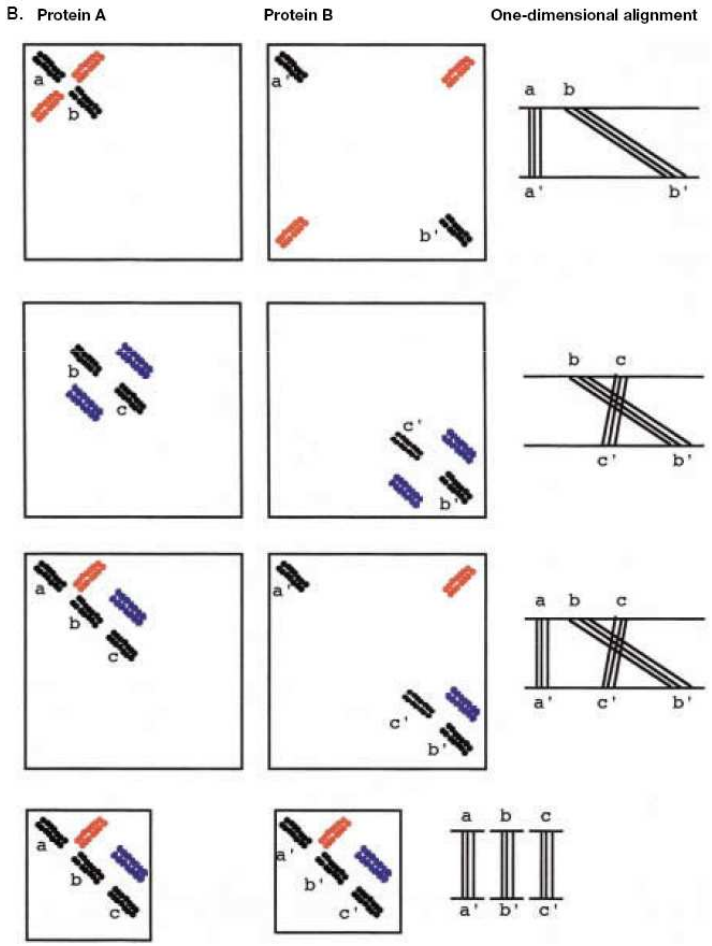
Matches substructures are patches

Main diagonal is formed when overlapping and centered

Locally similar backbone conformations: SSEs
Out of the diagonal: Tertiary structure similarities

Common motifs and structural motifs are represented as disjoint regions of the backbone

3. DALI



Protein A: Helices a, b

Protein B: Helices a' , b'

For each protein: sets of submatrices (6x6) overlapped from the whole matrix

Comparisons and combination: building up the complete alignment

Parallel alignment: insertions and deletions are removed

SS: all against all with < 30% sequence identity

Expressed as the number of standard deviations from the average score derived from the DB distribution

3. DALI Method

Adjacent strands in a b-sheet (distance is 4-5 Å) match within 1 Å

Strands-helix or helix-helix (distance is 8-15 Å) match within 2 Å

Aligns related proteins pairs and detects common 3D folding motifs in database search

Fast enough to scan the entire PDB looking for protein similar to a probe structure

FSSP (Fold Classification based on Structure-Structure alignment of Proteins) and DALI domain dictionary

Drawback: there is not an algorithm for direct alignment because it should find the closest alignment of 2 sets of points in 3D space and that is computationally a difficult problem

3.SSAP, Sequential Structure Alignment Program/Secondary Structure Alignment Program (Taylor and Orengo,1989)

Based:

Double dynamic programming (DDP) to obtain the optimal alignment in terms of matrices of:

A first matrix to get the **selected matches**. Distances between Cb- Cb of positions *i* and *j* of the proteins A and B to all the other proteins positions

A second matrix to get the **scores S_{ik}**. For every pair of positions *i* and *k* of proteins A and B, vectors between Cb at positions I and j are compared based on the first matrix (directionality)

Method

Each amino acid in each sequence is given a local environment

LE = ΣR + bonds angles + interatomic distances + degree of burial in hydrophobic core + type of secondary structure

3.SSAP

Interactomic vectors between positions *i* and *j* of the protein n:

Average vector $\vec{v}_{nij}$

Error associated $\vec{r}_i = \frac{1}{n}\sum_{n=1}^{N} \vec{v}_{nij}$

$$e_{ij} = \frac{1}{N}\sum_{n=1}^{N} (\vec{r}_{ij} - \vec{x}_{ij})^2$$

Score $S_{ijmn} = (\vec{r}_{ij} - \vec{r}_{mn})^2$

Difference between the overage vectors of the two pairs residues in the two proteins

$$S_{ij} = \vec{A}_i - \vec{A}_j + \vec{r}_{ij}$$

Shift vector to build up a consensus vector

$$\vec{A}'_j = A_j + \frac{\vec{s}_{ij}}{e_j \mid j - i \mid^{\frac{x}{2}}}$$

Additional weight A reflecting the conservation of the error associated

3.SSAP

2rhe00	87.7	86.9	83.9	90.7	79.8	80.4	80.0	86.9	78.5	78.5
1cd800		84.7	76.0	87.4	80.1	79.4	80.2	87.5	78.6	78.4
3fabH1			77.0	85.7	78.2	79.8	79.2	88.6	73.0	79.3
3fabH2				74.4	85.5	84.1	86.8	77.7	91.0	84.8
3fabL1					80.6	76.5	80.0	86.9	79.1	76.6
3fabL2						86.4	88.4	80.3	86.5	86.0
1fc1A1							87.7	80.4	85.0	86.2
1fc1A2								80.9	88.2	89.1
2fb4H1									78.2	79.7
2fb4H2										84.8
3hlaB0										

Domains structures within these family

Local environments of given amino acid of both proteins are compared to find out the match residues
A scoring matrix is derived and the highest scoring region is chosen as the one that defines the optimal structural alignment

Those residues must be the ones having similar buried areas and torsion angles

3.SSAP

PDB code	Title	SSAP	Equivalent
1p11 452	Anthranilate isomerase	86.48 (76.9)	157
5timA 249	Triosephosphate isomerase	85.74 (100)	157
1wsyA 246	Tryptophan synthase	84.58 (68.8)	157
1ald 363	Aldolase A	84.25 (77.8)	157
5rubA 434	Rubisco	77.36 (68.5)	155
4enl 436	Enolase	75.75 (65.9)	141
2taaA 478	Taka-amylase	74.35 (62.9)	128
1ximA 392	Xylose isomerase	73.78 (70.8)	122
1dri 271	D-Ribose binding protein	69.76 (62.1)	139
1cseE 274	Subtilisin Carlsberg	69.23 (61.5)	122
2cmd 312	Malate dehydrogenase	68.78 (58.7)	133
2liv 344	Leucine binding protein	68.12 (60.6)	148
3grs 461	Glutathione reductase	66.53 (59.6)	133
1ldb 291	Lactate dehydrogenase	66.51 (59.9)	120
5p21 166	Ras p21 protein	65.85 (68.3)	122

Two levels of dynamic programming

1. Comparing residues environmnet between pairs of residues

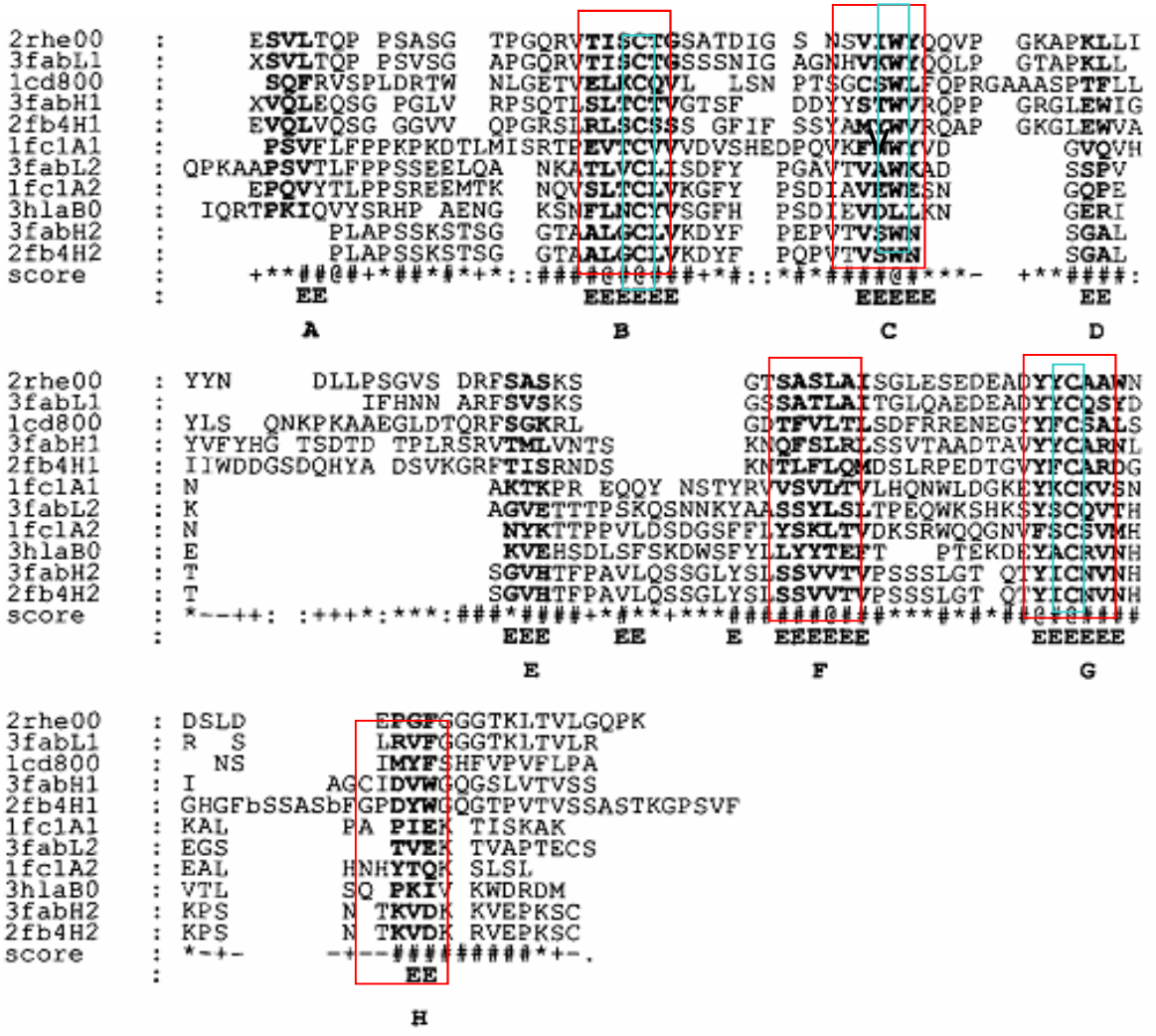
2. Obtaining an alignment from accumulated data on residues pairs

Related folds have more variation on the loops and orientation of Secondary Structures

The SSAP cut off

Similarity of 70%: fold families 150
Similarity of 70-80%: analogous folds (variations in loops and orientation of secondary structure)
Similarity of 80%: fold families 200
Similarity of >80: homologous fold (divergence from a common ancestor)

3.SSAP

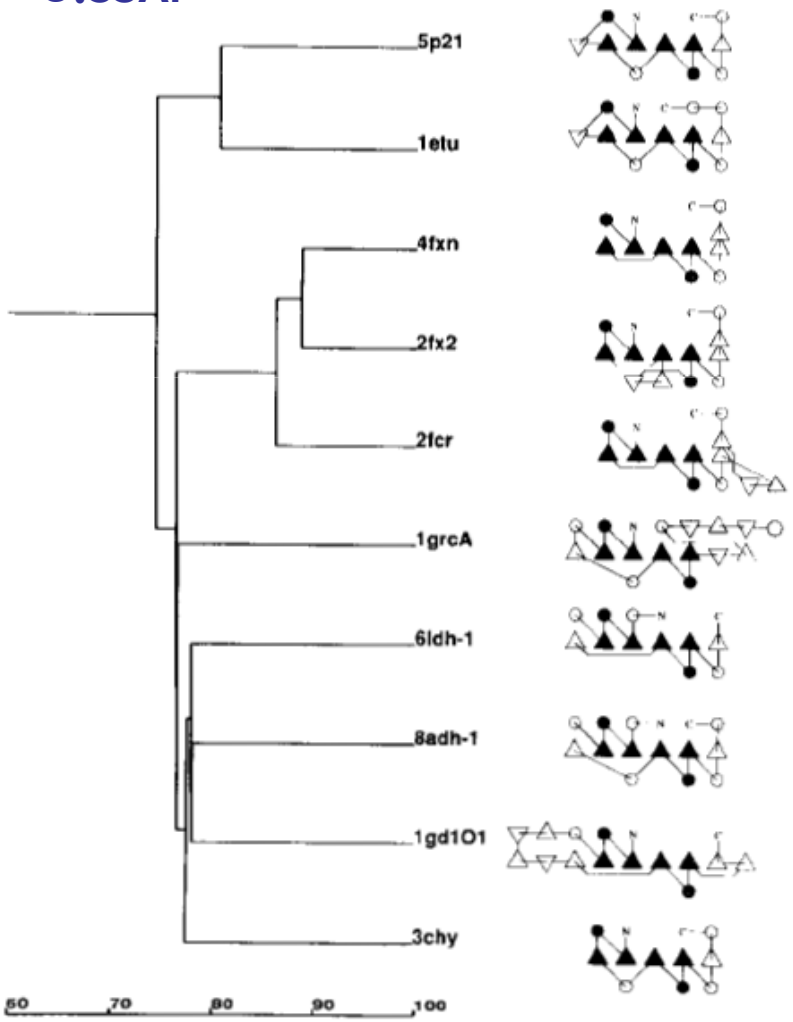


Multiple protein structure alignment derived from pairwise simple alignment concatenation

β Strands constant domains of inmunoglobulins (A, B, C, D, E, F, G, H)

Residues in equivalent SSs regions derived from hydrogen bonds patterns are highlighted

3.SSAP



The comparison of relationship improves the alignment of distantly related structures

The structural relationships fold shape are more easily recognized although secondary structure changes reduce the number of superimposable residues between not close related proteins

SSAP Dendrogram : Structural relationship of inmunoglobulins domains

Helices ●

Strands ▲

3. Structural Comparison and Alignment
3.2 Main Methods

ALGORITHM	DESCRIPTION	FOCCUS	STATISTICAL ANALYSIS	ADVANTAGES	DRAWBACKS
DALI	[a]Distance Matrix Alignment	Complete sequence. Distances between all Cα atoms	Score derived from all against all comparisons. Z-score as the number of standard deviations from the average score derived from the DB distribution.	One single frame of representation. Speed of execution Ability to recognize distant relationships	Not algorithm for direct alignment. Statistical significance based on rmsd value which is considered suboptimal Non topological regions are not detected
CE	[b]Combinatorial Extension of the Optimum Path	Distance between Cα of octameric fragments (combinatorial properties)	Tabulation of rmsd of the distributions of both proteins Z-score as result of combination of both z-scores	Computational Speed High percentage of homology detection	Reduction in the accuracy Domains miss recognition "Non topological" recognition or detection
SSAP	[c]Sequential Structure Alignment Program	Domain level Intraprotein Cβ-Cβ vectors comparison	Scores compared against CATH database.	Dealing with internal domains Generation of multiple alignment by pairs alignments concatenation	Global alignment is missed once the whole structure is broken down into small SSEs Lost of details when just Cβ-Cβ are compared
VAST	[d]Vector Alignment Search Tool	SSEs Vectors comparisons	P-value calculated for the best substructure superposition as if randomly obtained multiplied of alternative substructure alignments possible.	Computational time saved: SSEs converted into vectors	The whole 3D structure can not be used but just the predefined SSEs. Not complete SSEs Cα coordinates represented but just the beginning and the ends
SARF2	[e]Spatial Arrangement of Backbone Fragments	Superimposables SSEs comparing typical αhelix and βstrands templates	Score as a function of rmsd and the number of matched Cα atoms Comparison of scores obtained from non redundant set of structures	Computational time saved: SSEs converted into vectors Difficult cases detection	The whole 3D structure can not be used but just the predefined SSEs. Not complete SSEs Cα coordinates represented but just the beginning and the ends
COMPARER	[f]Comparer	Comparison of residues properties and relationships	Two scores E and A are contrasted, residues equivalences and gaps penalties respectively	Residues properties and relationships and segments relationships are studied at once	DP NOT applicable to relationships due to the dependence of the scores for a given relationship on the assignment of other relationships

3. GANGSTA, Genetic Algorithm for Non-sequential, Gapped protein STructure Alignment (Kolbeck B et al 2006)

Based:

Non-sequential protein structure alignment using a two-level hierarchical approach
Sequential alignment: respecting the sequential order of the SSEs in the polypeptide chains of the considered protein pair non-sequential alignment: ignoring the order

Method:

First level, pairwise contacts and relative orientations between SSEs are maximized using a genetic algorithm (GA) and protein graph representation

Second level, pairwise residue contact maps resulting from the best SSE alignments are optimized

GANGSTA+

Combinatorial algorithm for non-sequential structural alignment of proteins and similarity search in database SSE pairs can optionally be aligned in reverse orientation

3. MAMMOTH, **MA**tching **M**olecular **M**odels **O**btained from **TH**eory

Based:

Developed for comparing models coming from structure prediction (**TH**eory)

Tolerant of large unalienable regions

To work well with experimental models (especially when looking for remote homology)

Genomic scale normalization: is being facilitated by a highly complete database of mammoth-based structure annotation for the predicted structures of unknown proteins covering 150 genomes

Method:

Heptapeptides from protein A and B are compared

Similarity score between two heptapeptides is calculated using a unit-vector RMS (URMS) method (molecular dynamics trajectories)

Scores stored in a similarity matrix, and with dynamic programming the optimal residue alignment is calculated

Similarity scores are derived from the likelihood of obtaining a given structural alignment by chance

3. RAPIDO, Rapid Alignment of Proteins In terms of Domains, (Mosca, Schneider TR 2008)

Based:

Web server for the 3D alignment of crystal structures of different protein molecules (taking into account conformational changes)

Method

Identifies similar fragments in the two proteins using difference distance matrices

Matching Fragment Pairs (MFPs) are represented as nodes in a graph for the identification of the longest path on a DAG (Directed Acyclic Graph)

Method

Final step of refinement to improve the quality of the alignment

After aligning a genetic algorithm is applied for the identification of conformationally invariant regions (groups of atoms whose interatomic distances are constant)

IRs represent reliable sets of atoms for the superposition of the two structures that can be used for a detailed analysis of changes in the conformation

RAPIDO can identify structurally equivalent regions on fragments that are distant in terms of sequence and separated by other movable domains !!!!!!!

3. SABERTOOTH

Based

Vectorial representation

Structural profiles to perform structural alignments

The underlying structural profiles expresses the global connectivity of each residue

Method

Recognizes structural similarities with accuracy comparable to SARF2,

Algorithm has favorable scaling of computation time with chain length

Algorithm is independent of the details of the structural representation

The framework can be generalized to sequence-to-sequence and sequence-to-structure comparison within the same setup

3. TOPOFIT, novel common volume superimposition (Valentin A and col.2004)

Based

Model based common sub-groups to produce structural alignment

Structurally related proteins have a common spatial invariant part (set of tetrahedrons or common spatial sub-graph volume

Identifies common, invariant structural parts between proteins

Method

Similarity of protein structures is analyzed using three-dimensional Delaunay triangulation patterns derived from backbone representation

Method

The superimposition of those groups patterns allows to identify a common number of equivalent residues in the structural alignment

Identifies a feature point on the RMSD/Ne curve (structures correspond to each other including backbone and inter-residue contacts)

Larger RMSD corresponds to a growing number of mismatches between the patterns

The topomax point is present in all alignments from different protein structural classes

Understanding the molecular principles of 3D structure organization and functionality
Helps to detect conformational changes, topological differences in variable parts