

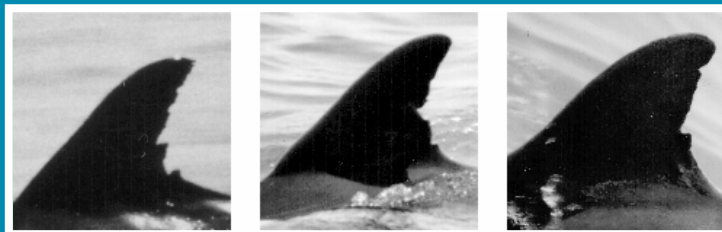
# Iterative 3-D Pose Correction and Content-based Image Retrieval for Dorsal Fin Recognition

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## Background

Studies of behavior, longevity, range, and other factors requires identification of individual animals. Identification can be based on ...

- Artificial markings (freeze branding, tagging, ...)
- Natural markings (photo-identification )



## Background

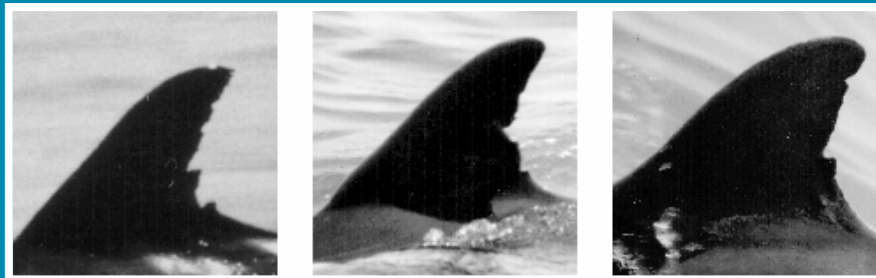
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Identification of individual animals is necessary for the study of behavioral and ecological patterns and can be based on ...

- Artificial markings
  - invasive
  - freeze branding, tagging, ...
- Natural markings
  - non-invasive
  - photo-identification (manual, computer assisted, ...)

## Photo-Identification

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Dolphin dorsal fins with distinctive natural markings

## DARWIN Project Background

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DARWIN  
Digital Analysis and Recognition of Whale  
Images on a Network

Software provides functionality to ...

- aid biologists in photo-identification of individual animals based on natural markings
- maintain photographic and observational data for research purposes

## The DARWIN Project History

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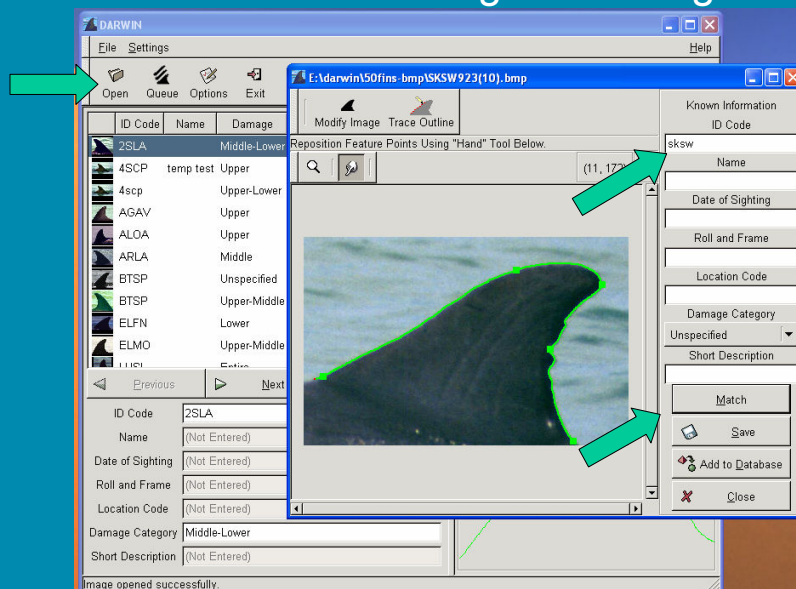
- Originated in 1993 as collaborative effort between
  - Eckerd College Computer Science (John Stewman)
  - Eckerd College Dolphin Research Group (John E Reynolds, III)
- Project Leader since 1997 (Kelly Debure)
- Initial Software Implementation
  - Mark Allen ('96)                      Windows App, signature matching
- Significant additions to the software functionality by:
  - Dan Wilkin ('98)                      Linux, signatures & pose correction
  - Zach Roberts ('00)                    Chain codes & affine transformations
  - Adam Russell ('01)                    OOP, GTK, fin features & more
  - Scott Hale ('05)                        Auto-trace of fin outline

## The DARWIN Project

### Goals:

- provide access to a database of digital images of dolphin dorsal fins
- storage and retrieval of observational data which accompanies each fin
- enable access to images and data across a network
- reduce the tedium of manual cataloging and identification of individual dorsal fins

## The DARWIN Digital Catalog

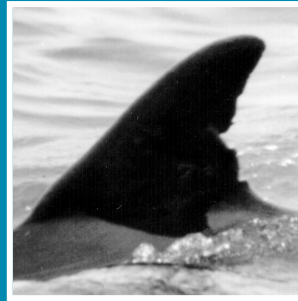


Add new fin to database, or query with unknown

## Query Generation

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- The user searches for an unknown fin's identity in a database of previously identified fins using a *semi-automated sketch-based query*.
- The outline is transformed into a representation suitable for efficient comparison with outlines in the database



## Query Generation

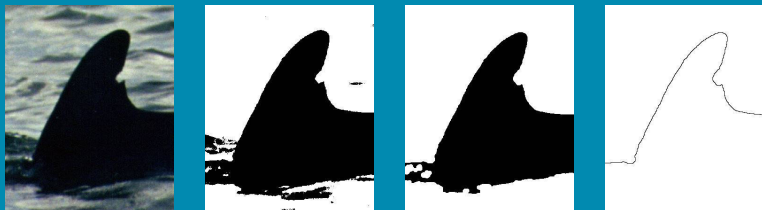
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The fin outline is initially *auto-traced* using ...

- Intensity Image
- Automatic Threshold
- Region Grouping & Morphological Processing

... and returns the longest upward bulging boundary

Active Contours are used to reposition this initial boundary.



The user may manually adjust or retrace the outline.

## Query Generation

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- Fin outline is detected initially by *auto-trace* using ...
  - Intensity Image
  - Automatic Threshold
  - Canny Edge Detection
  - Region Grouping
  - Longest Upward bulging boundary
- or outline is roughly traced by user



## Query Generation

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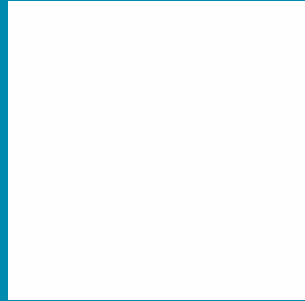
- Fin outline is detected initially by *auto-trace* or is roughly traced by user
- Active contours move the points from the initial locations to the actual edge of the fin



## Query Generation

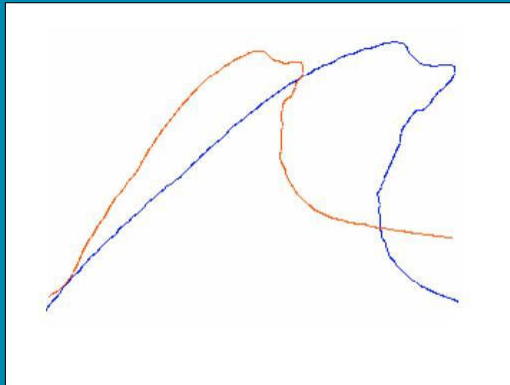
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- Fin outline is detected initially by *auto-trace* or is roughly traced by user
- Active contours move the points from the initial locations to the actual edge of the fin
- An *outline* of the dorsal fin is produced and compared against the outlines of other dorsal fins in the catalog



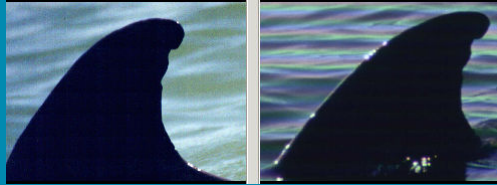
## Outline Comparison

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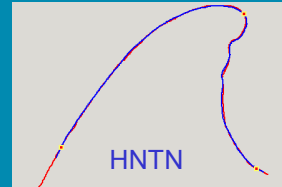
To identify fins in the database which most closely resemble the “unknown” fin, outlines must be compared in a manner that corrects for 3-D pose differences

## Outline Comparison – The Goal



Database fins

Unknown fins



Registered Outlines



## Outline Comparison

- Outlines are transformed so that it appears the two fins were photographed in the same pose
- Common feature points are located on the fin outlines to provide a basis for this transformation

### Possible Feature Points:

Starting point of the leading edge

Tip of dorsal fin

Most prominent notch

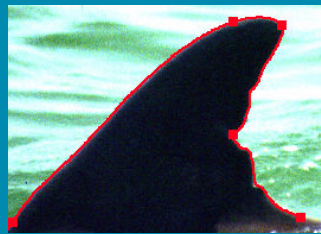




## Outline Representation

A dorsal fin outline is represented by a ...

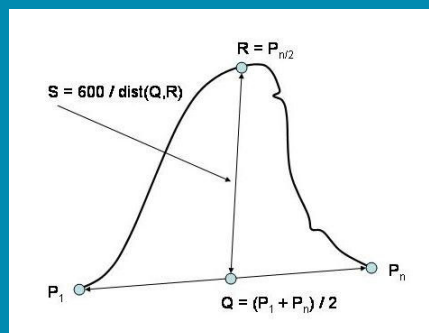
- Sequence of edge points in 2-D Cartesian coordinates
- Sequence of orientations (Chain Code)
- Sequence of orientation changes (Relative Chain Code)
- Set of key feature points
  - Beginning of Leading Edge
  - Tip of Fin
  - Largest Trailing Edge Notch
  - End of Trailing Edge



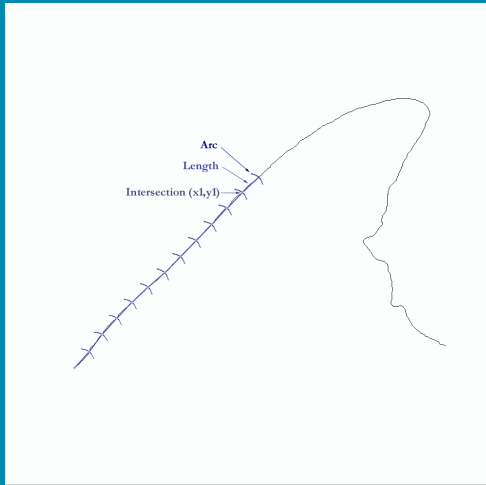
## Initial Scale Normalization

A dorsal fin outline is normalized to a “standard” scale ...

- Height = 600 units
- Height is estimated from baseline to a point near the tip
- All point coordinates are scaled up or down appropriately



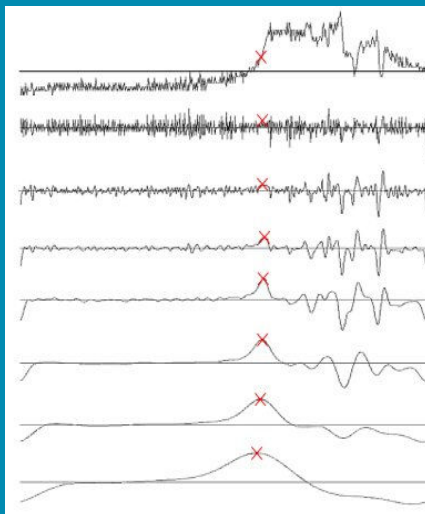
## Even Spacing & Chain Codes



For a set length  $L = 3$ , partition the normalized outline into segments of equal length ...

1. Let point P be the first outline point  $(x_0, y_0)$
2. Find the point Q where an arc of radius L, centered at P intersects the outline.
3. Store the new point Q, the bearing from P to Q, and the change in bearing at P.
4. Move P to Q and repeat

## Unsupervised Detection of Fin Tip Using Wavelet Decomposition

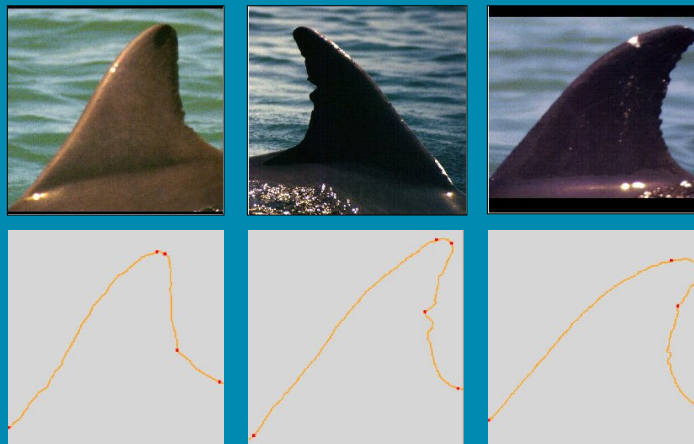


- Perform a wavelet decomposition of the absolute chain code
- The original chain code is on top, with increasingly coarse details following.
- The position of the tip is found on the coarsest (bottom) level, and tracked to the finer levels. The tracking of the tip is marked at each level.

## Outline Representation



## Unsupervised Feature Point Detection



## Outline Comparison

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Comparison of Outlines involves ...

- Measuring Goodness of Fit
- Mapping one fin to another
  - Correcting / Compensating for 3-D Pose
  - Handling Occlusions and noise

## Goodness of Fit

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- Measuring fit between fins
  - Mean Squared Error
  - Distance is measured between *corresponding* pairs of points along the fin outlines
- Uses of the measurement
  - Refining fin to fin mapping
  - Ranking query results – Identifying the dolphin
- Related Issue
  - How to determine *corresponding* pairs of points

## Corresponding Points on Two Curves

- Insufficient
  - Similarly indexed points
  - Point on curve A where a perpendicular to point on curve B intersects it
- Sufficient
  - Points on curves A and B where perpendicular to medial axis point intersects them

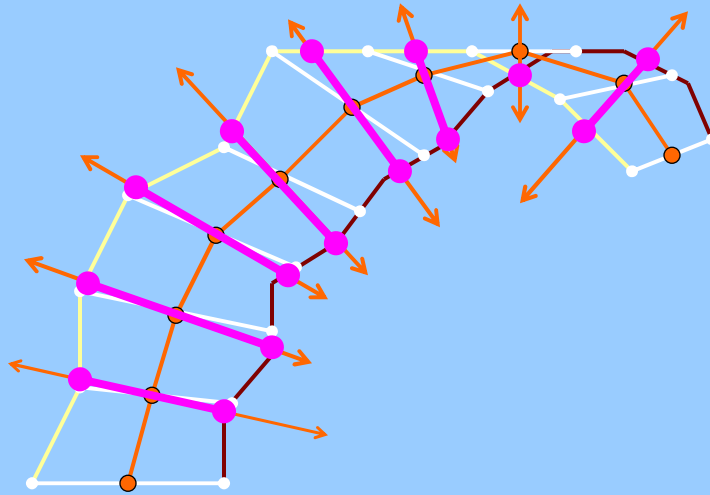


## Finding Corresponding Points

- Find ratio of arc lengths of two fin outlines
- For each point on fin B
  - Find point on fin A at a proportional distance along it
  - Find midpoint between these two and save as point on "medial axis"
- For each point on medial axis
  - Intersect perpendicular to medial axis at this point with both outlines, locating points  $P_A$  &  $P_B$
  - The distance between  $P_A$  and  $P_B$  is sufficient for use in measuring goodness of fit

## Finding *Corresponding* Points

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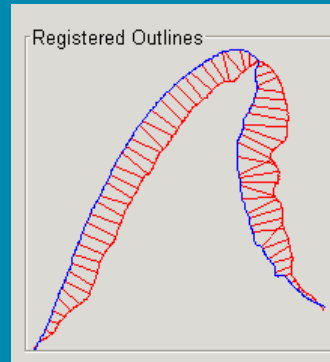
## Finding *Corresponding* Points

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- Requires four traversals of outlines
  - Once each to find arc lengths
  - Once to find medial axis points
  - Once of medial axis to find *corresponding* points
- Efficiency is  $O(c)$  for outline with  $c$  points
  - $c$  is a constant, typically 400 to 600 for normalized fin outline
  - $c$  does not depend on image resolution or size of database

## Corresponding Points

- Red segments indicate distances between pairs of corresponding points
- Each segment is through a medial axis point and perpendicular to the medial axis at that point
- Point pairs are not ideal but are “close enough” for an accurate measure of fit



## Mapping Assumptions

- Fins are Planar and Rigid
- Fin outlines change infrequently
- True 3-D pose determination is unimportant
  - a 2-D projection of a plausible 3-D pose is sufficient
- Three fin features can be reliably found
  - (LEBegin, Tip, Notch) or (LEBegin, Tip, TTEnd)
- Foreshortening is negligible
- Truly similar fins will produce better pose corrections

## Mapping Transformations

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- Unknown fin (A) is mapped to known fin (B)
- Three non-collinear points on each fin
  - Form two triangles ( $t_A$  &  $t_B$ )
  - Define a 2-D skew transformation
- The transformation
  - Exactly maps  $t_A$  to  $t_B$
  - Can be used to map all outline points of fin A to a 2-D projection of numerous 3-D poses of A best approximating fin B

## Mapping Methods

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- Original method
  - Performed once using fixed feature points (LEBegin, Tip, Notch)
- Best of 13 method
  - Performed with 13 variations of fins
    - Features (LEBegin\*, Tip, Notch)
    - LEBegin\* = shortened leading edges
- Iterative method based on Newton Raphson
  - Iteratively shortens leading and trailing edges and performs limited shifts of unknown fin Tip
  - Features (LEBegin\*, Tip\*, TTEnd\*)



## Original Mapping Method

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- Performed once using fixed feature points
  - (LEBegin, Tip, Notch)
- Advantage
  - Fast
- Disadvantages
  - Non intuitive alignments occur
  - Sensitive to feature misplacement / occlusion (especially LEBegin and Tip)

## Best of 13 Mapping Method

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- Tests 13 mappings of query fin ( $F_q$ ) to database fin ( $F_d$ )
  - Uses features (LEBegin\*, Tip, Notch)
  - Entire  $F_q$  to entire  $F_d$
  - Six shortened  $F_q$  versions to entire  $F_d$
  - Six shortened  $F_d$  versions to entire  $F_q$ 
    - Shortening in multiples of 5% of leading edge index range
- Advantages
  - Relatively fast
  - Produces excellent alignments of leading edges
- Disadvantages
  - Sensitive to misplacement of Tip and Notch

## Iterative Mapping Method

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- Iterative method based on Newton Raphson
  - Shortens leading and trailing edges and shifts tip
  - Uses features (LEBegin\*, Tip\*, TEEnd\*)
  - Test interval 1% of leading edge index range
  - Adjustment (jump) interval 16% down to 1%
- Advantages
  - Excellent intuitive alignments in almost all cases
  - Mostly insensitive to initial feature placement
- Disadvantages
  - Slowest method
  - Can stick in local minima of error function

## Iterative Mapping Method

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The goal is to *minimize* the error function

$$f(r,s,t,u,v)$$

which is the *mean squared error* between a database fin and the unknown fin which has been mapped to it.

$r$  = position of unknown fin LEbegin  
 $s$  = position of database fin LEbegin  
 $t$  = position of unknown fin Tip  
 $u$  = position of unknown fin TEend  
 $v$  = position of database fin TEend

## Iterative Mapping Method

First step of each iteration : compute

$$f(r, s, t, u, v)$$

And compute six estimates of the change in  $f$  near the current values of the parameters

$$\begin{aligned} f(r+e, s, t, u, v) &: \text{shorten unknown leading edge?} \\ f(r, s+e, t, u, v) &: \text{shorten database leading edge?} \\ f(r, s, t-e, u, v) &: \text{shift unknown tip forward?} \\ f(r, s, t+e, u, v) &: \text{shift unknown tip rearward?} \\ f(r, s, t, u-e, v) &: \text{shorten unknown trailing edge?} \\ f(r, s, t, u, v-e) &: \text{shorten database trailing edge?} \end{aligned}$$

And determine which change direction most reduces  $f$

## Iterative Mapping Method

Second step of each iteration is to adjust (or jump) the selected parameter as far a possible to a new value that produces a lower value of the error function

For example, if the selected parameter is  $s$

$$\begin{aligned} \text{while } ( f(r, s-jump, t, u, v) >= f(r, s, t, u, v) ) \\ \quad jump = jump / 2 \\ \quad s = s - jump \end{aligned}$$

Has two effects

1. The value of  $s$  for the next iteration has been set
2. The size of  $jump$  has possibly decreased (an expected outcome as the fins better align and  $f$  is minimized)

## Iterative Mapping Method

SKSW – Database and Query (Unknown) fin images



## Iterative Mapping Method

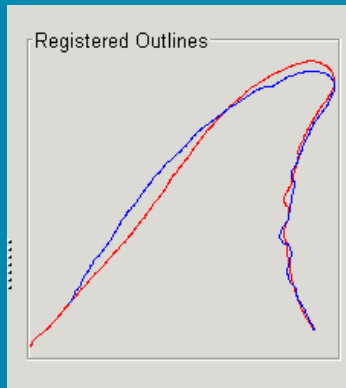
SKSW – Initial Alignment



## Iterative Mapping Method

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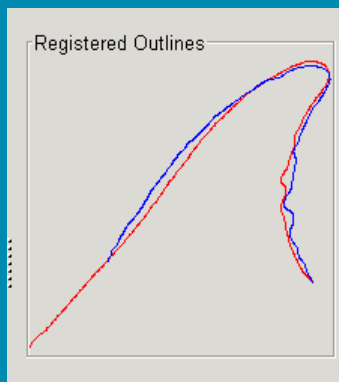
SKSW – 2<sup>nd</sup> Iteration



## Iterative Mapping Method

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SKSW – 3<sup>rd</sup> Iteration



## Iterative Mapping Method

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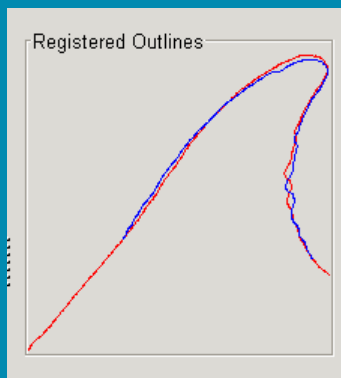
SKSW – 4<sup>th</sup> Iteration



## Iterative Mapping Method

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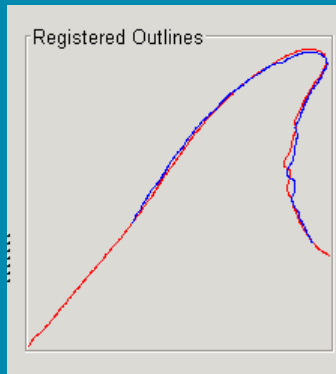
SKSW – 5<sup>th</sup> Iteration



## Iterative Mapping Method

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SKSW – 6<sup>th</sup> Iteration



## Iterative Mapping Method

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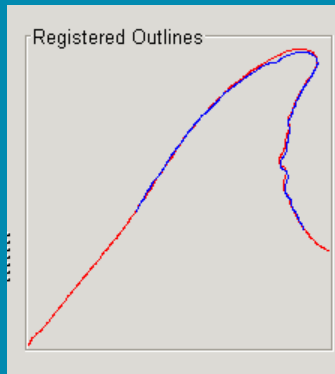
SKSW – 7<sup>th</sup> Iteration



## Iterative Mapping Method

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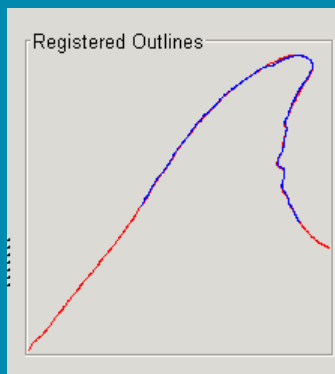
SKSW – 8<sup>th</sup> Iteration



## Iterative Mapping Method

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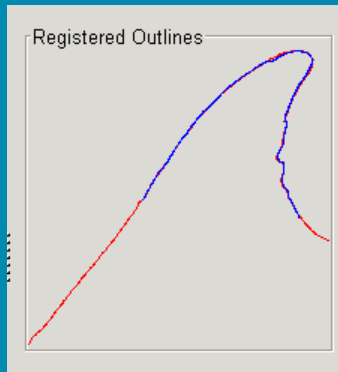
SKSW – 13<sup>th</sup> Iteration





## Iterative Mapping Method

SKSW – Final (19<sup>th</sup>) Iteration



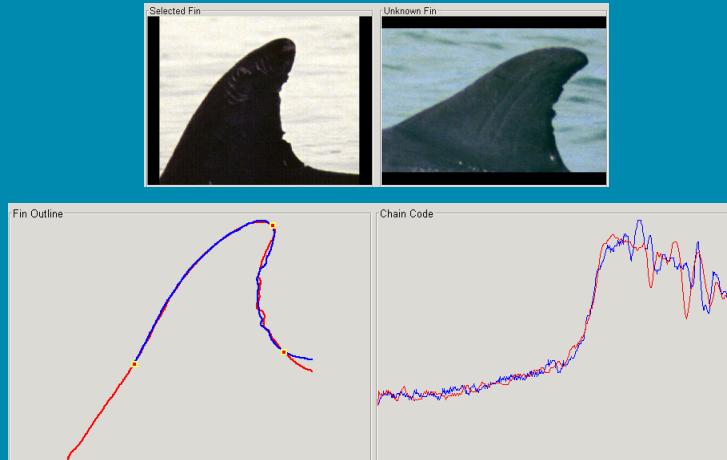
## Iterative Mapping Method

SKSW – Mapped Outlines and Chain Codes

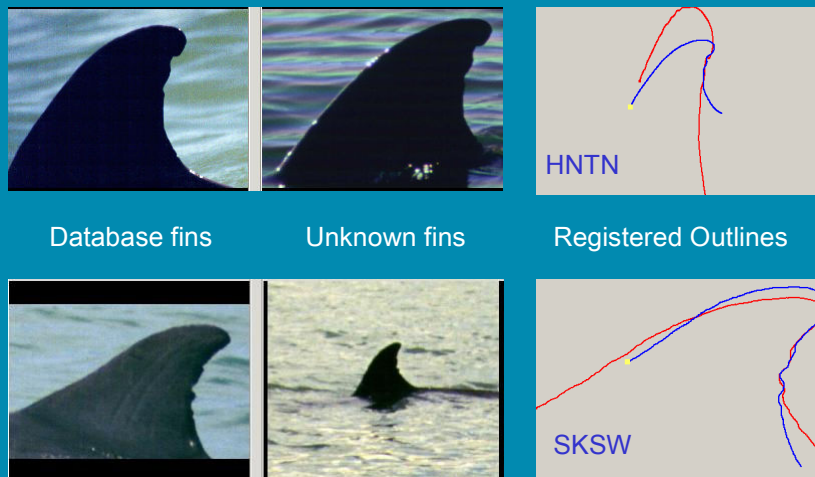


## Iterative Mapping Method

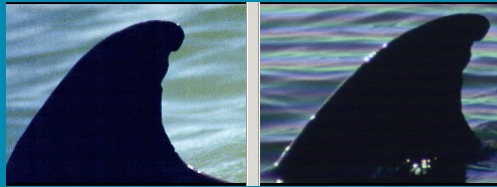
SKSW to ELMO – Mapped Outlines and Chain Codes



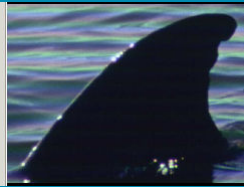
## Outline Comparison – Original Method



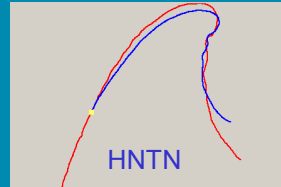
## Outline Comparison – Best of 13 Method



Database fins



Unknown fins

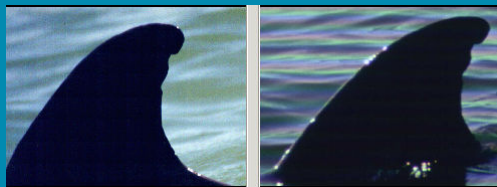


Registered Outlines

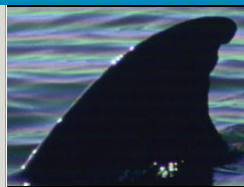


SKSW

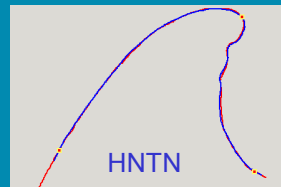
## Outline Comparison – Iterative Method



Database fins



Unknown fins



Registered Outlines



SKSW

## Outline Comparison and Query Ranking by Method

SKSW

Database Image



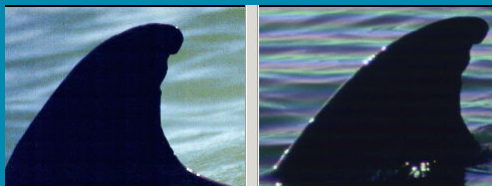
Query Image



## Outline Comparison and Query Ranking by Method

HNTN

Database Image



Query Image

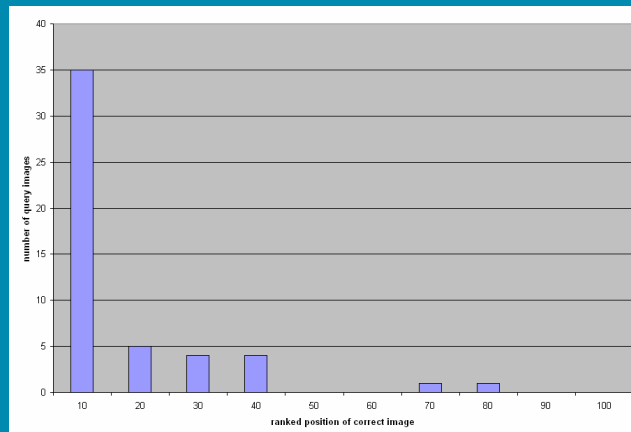


## Outline Comparison and Query Ranking by Method



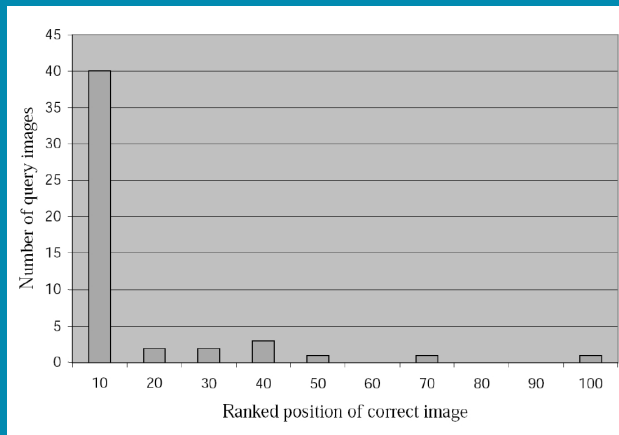
## Best of 13 Matching Results

Ranking of correct identity (success of query) as a percentage of total database size



## Iterative Matching Results

Ranking of correct identity (success of query)  
as a percentage of total database size



## Conclusions

The iterative 3-point mapping corrects well for 3-D pose differences and produces intuitive corrections even when fins differ significantly

The medial axis approach to choosing corresponding curve points is “good enough”

Ranking of results based on mean squared error does not capture essential small scale differences between fins

Query efficiency is  $O(N)$  and depends only on the number of images in the database

## Current and Future Focus

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Identification of fin region and silhouette in image using color information, not just grayscale

Ranking of results using better measures of small scale variation along fin outlines

Export of sighting data for import into commercial database software

Support for user defined catalog organization

Evaluation and implementation of new features based on user feedback

## Thanks

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Contact us at ...

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