Interactive and Automatic Image Segmentation

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Introduction

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- acquire and model object information;
- enhance regions wherein image properties are similar to those of the object, background, or their transition;
- locate the object and delineate its spatial extent in the image.

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In this example, delineation was solved by object enhancement followed by binarization (i.e., a spel classification), with no need for connectivity.

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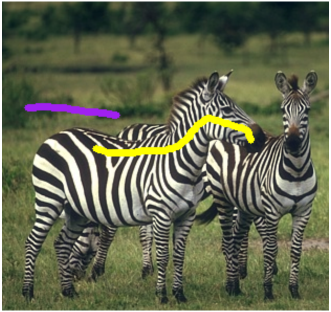

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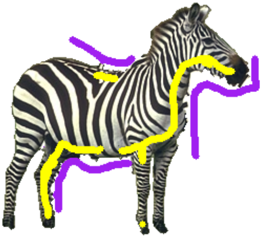

In this case, however, some markers needed to disconnect the object are not suitable for object enhancement.

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- For interactive segmentation, we can exploit a synergism between object location/correction by a human operator and computer delineation.
- For automatic segmentation, we can exploit a synergism between object location by some object model and computer delineation.
- In both cases, delineation based on optimum connectivity can be used in the image domain and/or in the feature space by simple choice of the adjacency relation.

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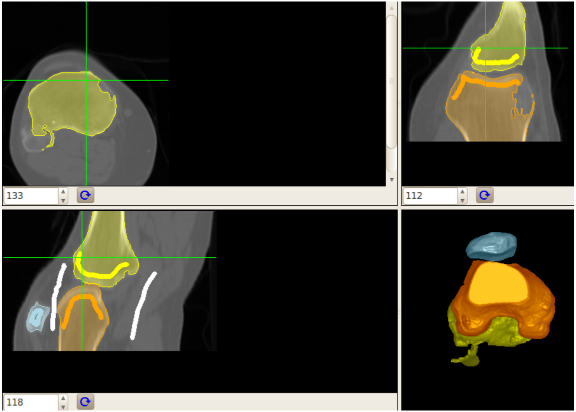
- Fuzzy object models [11, 12, 13].

Region-based object delineation

- Multiple objects can be segmented with interactive response time to the user's actions by using the differential IFT with seed competition (IFTSC)[6, 7].



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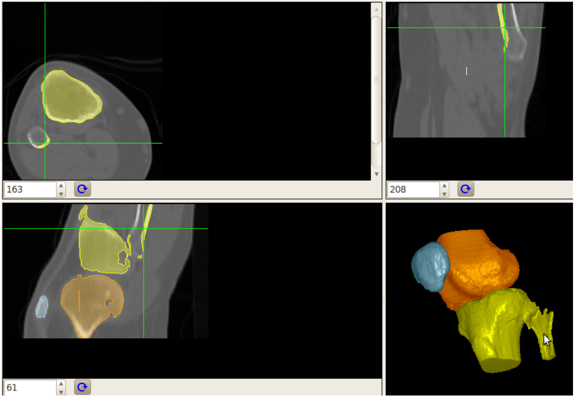

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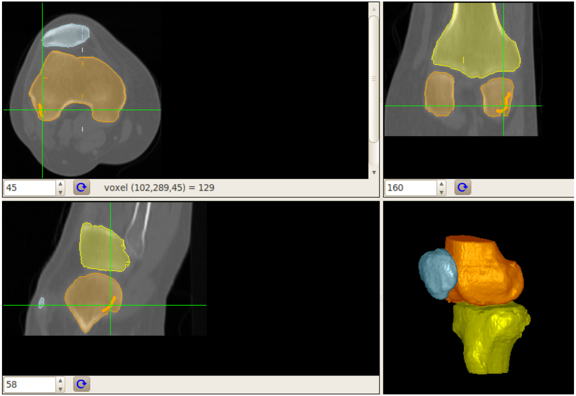

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Differential IFT with seed competition (IFTSC)

- In this case, the object is an optimum-path forest for $f_{\max}$ rooted at internal seeds.

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\begin{aligned}
f_{\max}(\langle t\rangle) &= \begin{cases} 0 & \text{if } t \in \mathcal{S} = \mathcal{S}_i \cup \mathcal{S}_e \\ +\infty & \text{otherwise} \end{cases} \\
f_{\max}(\pi_s \cdot \langle s, t\rangle) &= \max\{f_{\max}(\pi_s), w(s,t)\},
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- The dual formulation holds for fuzzy connected segmentation[9].

Differential IFT with $f_{\max}$ and seed competition (IFTSC)

Algorithm

– Algorithm IFTSC

$(V, P, L, R, \mathcal{F}) \leftarrow$ DIFT-ForestRemoval$(V, P, L, R, \mathcal{A}, \mathcal{R}_{\mathcal{M}})$.
$\mathcal{F} \leftarrow \mathcal{F} \setminus \mathcal{S}$.
While $\mathcal{S} \neq \emptyset$, *remove* t *from* $\mathcal{S}$, *set* $V(t) \leftarrow 0$,
    set $L(t) \leftarrow \lambda(t)$, $R(t) \leftarrow t$, $P(t) \leftarrow nil$, *and* $\mathcal{F} \leftarrow \mathcal{F} \cup \{t\}$.
While $\mathcal{F} \neq \emptyset$, *remove* t *from* $\mathcal{F}$ *and insert* t *in* Q.
While Q *is not empty* **do**
    Remove s *from* Q *such that* $V(s)$ *is minimum.*
    For each $t \in \mathcal{A}(s)$, **do**
        Compute $tmp \leftarrow \max\{V(s), w(s,t)\}$.
        If $tmp < V(t)$ *or* $P(t) = s$, **then**
            If $t \in Q$, **then** *remove* t *from* Q.
            Set $P(t) \leftarrow s$, $V(t) \leftarrow tmp$, $R(t) \leftarrow R(s)$,
            $L(t) \leftarrow L(s)$, *and Insert* t *in* Q.

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They can be implemented by a sequence of IFTs using 4- or 8-adjacency relation and suitable connectivity function.

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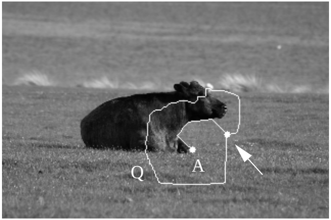

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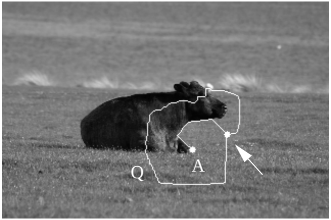

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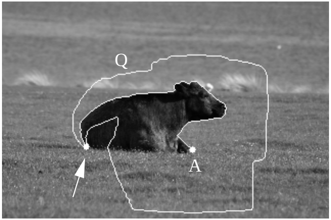

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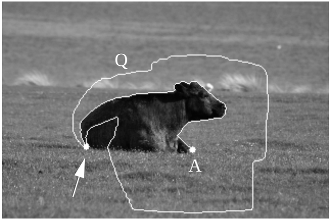

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- When the cursor is close to the boundary, the path snaps on to it.
- The user may accept it as a boundary segment, and
- the process is repeated from its terminus B until the user decides to close the contour.

Live-wire-on-the-fly (LWOF)

The IFT algorithm with early termination and function f_{sum} finds optimum paths from a starting point s^* on counter-clockwise oriented boundaries.

$$
\begin{aligned}
f^{\circlearrowleft}_{sum}(\langle t \rangle) &= \begin{cases} 0 & \text{if } t = s^* \\ +\infty & \text{otherwise} \end{cases} \\
f^{\circlearrowleft}_{sum}(\pi_s \cdot \langle s, t \rangle) &= \begin{cases} f^{\circlearrowleft}_{sum}(\pi_s) + \bar{w}^{\beta}(s,t) & \text{if } O(l) \geq O(r) \\ f^{\circlearrowleft}_{sum}(\pi_s) + K^{\beta} & \text{otherwise,} \end{cases}
\end{aligned}
$$

where l and r are the spels at the left and right sides of arc $\langle s, t \rangle$. The weights $\bar{w}(s,t)$ are lower on the boundary than inside and outside it and $\beta \geq 1$ favors longer segments.

Path computation from s^* to u in LWOF

Algorithm

– Path Computation from s^* to u in LWOF

If $V(u) = +\infty$ *or* $u \in Q$, **then**
    Set $s \leftarrow nil$.
    While $Q \neq \emptyset$ *and* $s \neq u$, *do*
        Remove from Q *a spel* s *such that* $V(s)$ *is minimum.*
        For each $t \in \mathcal{A}(s)$ *such that* $V(t) > V(s)$, *do*
            If $O(l) \geq O(r)$,
                then *set* $tmp \leftarrow V(s) + \bar{w}^{\beta}(s,t)$
                Else *set* $tmp \leftarrow V(s) + K^{\beta}$.
            If $tmp < V(t)$, **then**
                If $V(t) \neq +\infty$, *remove* t *from* Q.
                Set $P(t) \leftarrow s$ *and* $V(t) \leftarrow tmp$.
                Insert t *in* Q.

Riverbed

Riverbed simulates the behavior of water flowing through a riverbed, always seeking lower ground levels, snaking through the river bends, instead of short-cutting the path as in live-wire. This leads to the following connectivity function for a starting seed point s^*:

$$f_w^{\circlearrowleft}(\langle t \rangle) = \begin{cases} 0 & \text{if } t = s^* \\ +\infty & \text{otherwise} \end{cases}$$

$$f_w^{\circlearrowleft}(\pi_s \cdot \langle s, t \rangle) = \begin{cases} \bar{w}(s,t) & \text{if } O(l) \geq O(r) \\ K & \text{otherwise.} \end{cases}$$

where l and r are the spels at the left and right sides of arc $\langle s, t \rangle$.

Riverbed

- Although $f_w^{\circlearrowleft}$ is not smooth, it selects segments such that the maximum arc weight

$$\max_{\forall (l,r)\in\mathcal{A}', L(l)=1, L(r)=0} \bar{w}(l,r)$$

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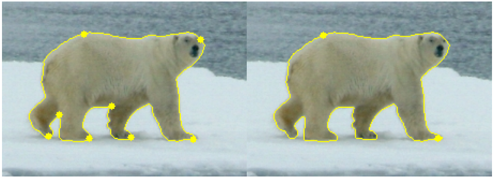
- This implies that IFTSC and riverbed decide for the same optimum graph cut[5].
- Riverbed is more suitable than live-wire for more intricate shapes, but live-wire can jump weakly defined parts of the boundary.

Riverbed versus live-wire



- Live-wire (left) and riverbed (right).

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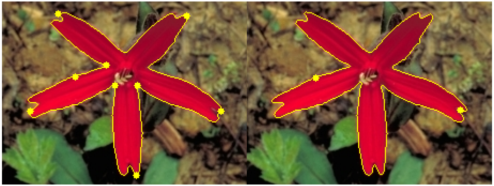

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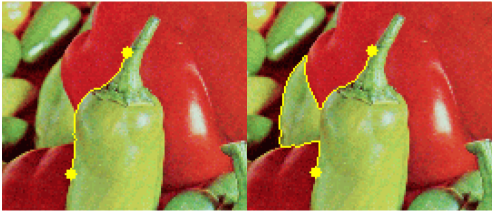

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- Live-wire can jump across weakly defined segments.

Riverbed versus live-wire

Their combination can take advantage from both approaches.

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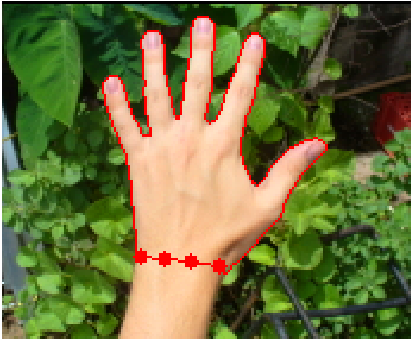

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- Riverbed asks for more user intervention on poorly defined parts.

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- Live-wire on complex shapes requires more anchor points.
- Riverbed asks for more user intervention on poorly defined parts.
- Their combination requires only two segments (live wire in cyan, riverbed in red).

Live Markers

Live Markers is another hybrid approach[10] that takes advantage from the superior ability of LWOF on weakly defined segments and from IFTSC to handle complex 2D/3D shapes of multiple objects.

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The markers may be selected by the user or may come from the live-wire segments.

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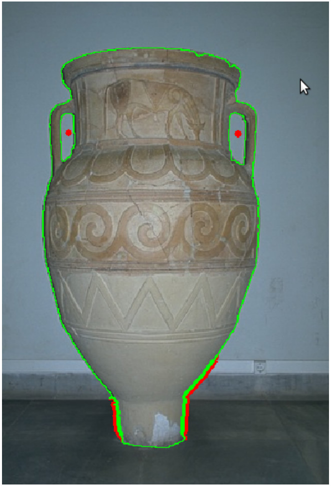

Organization of this lecture

- Object delineation using the image foresting transform.
- A comparison between IFTSC and object delineation using the min-cut/max-flow algorithm (GCMF).
- Fuzzy object models.

IFTSC and min-cut/max-flow algorithms

- From lecture 1, we know that IFTSC computes the graph cut whose minimum arc weight

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- Similar region-based delineation could be obtained by GCMF as a graph cut whose sum of arc weights

$$\sqrt[\beta]{\sum_{\forall (s,t)\in\mathcal{A}| \; L(s)=1, L(t)=0} \bar{w}^{\beta}(s,t)}$$

is minimum for $\beta \geq 1$, with lower values favoring smaller cuts and higher values making both equivalent[8].

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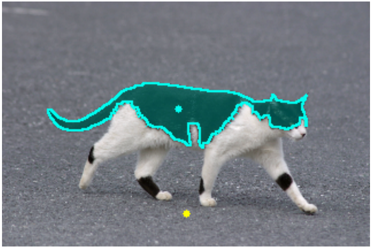
- IFTSC can handle multiple object delineation in $O(|\mathcal{N}|)$.
- GCMF is not viable for multiple objects and takes $O(|\mathcal{N}|^{2.5})$ for single object delineation.
- IFTSC is also more robust with respect to seed location than GCMF, but the latter provides smoother boundaries with less leaking than the former.

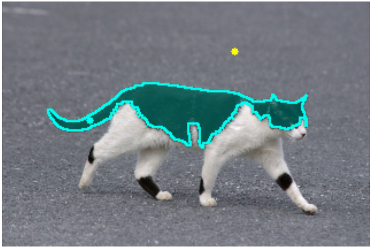
IFTSC and min-cut/max-flow algorithms

A lower β value allows GCMF (left) to obtain a smoother boundary, reducing the leaking of IFTSC (right).

IFTSC and min-cut/max-flow algorithms

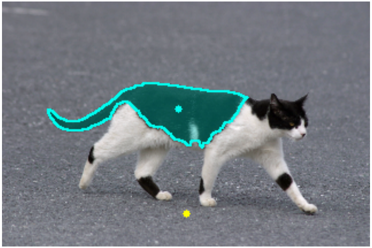
However, a same connected component is always obtained with IFTSC, independently of seed location.

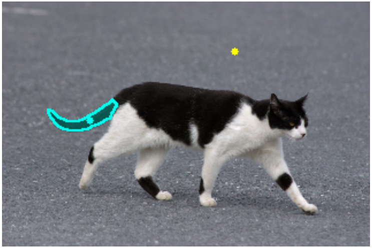




IFTSC and min-cut/max-flow algorithms

The same does not happen in GCMF, when β is not high enough.





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Registration is an expensive task that may force delineation to fit with the model irrespective to the local image information.

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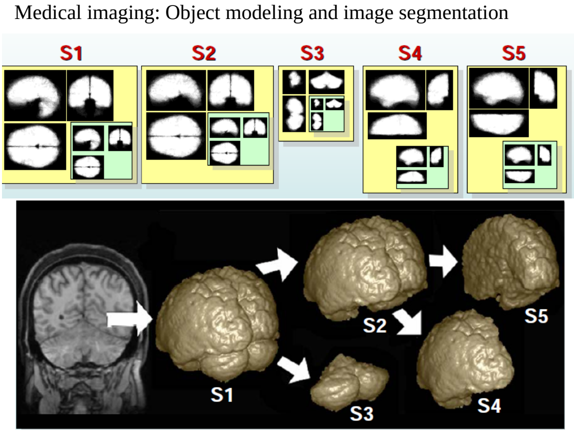
- Segmentation is solved by translating the model and executing delineation at each location.
- It is possible to considerably speed-up this object search process by using multiple scales of the image and models.

Fuzzy object models

Examples of objects and their fuzzy models.



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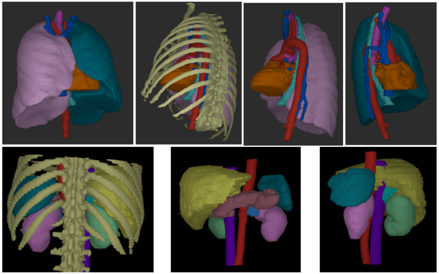

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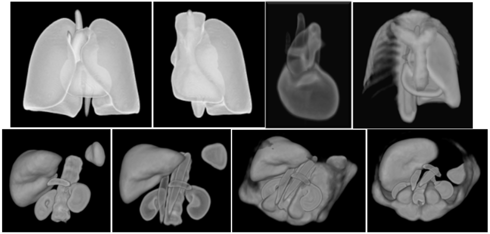
Fuzzy object models

Examples of objects and their fuzzy models.



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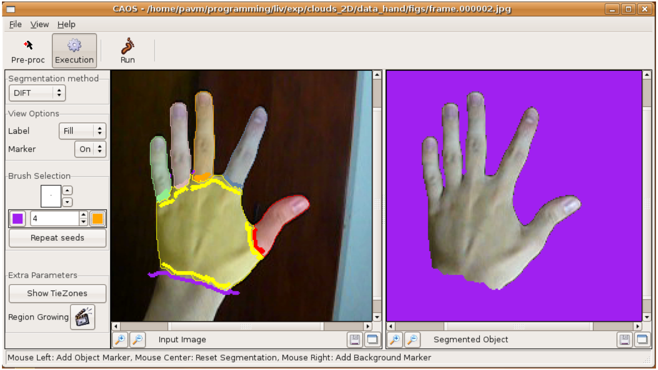
The cloud system model

A set of training objects is first provided by interactive IFTSC segmentation.



Each image with multiple objects forms an object system with a common reference point (e.g., the geometric center of the objects).

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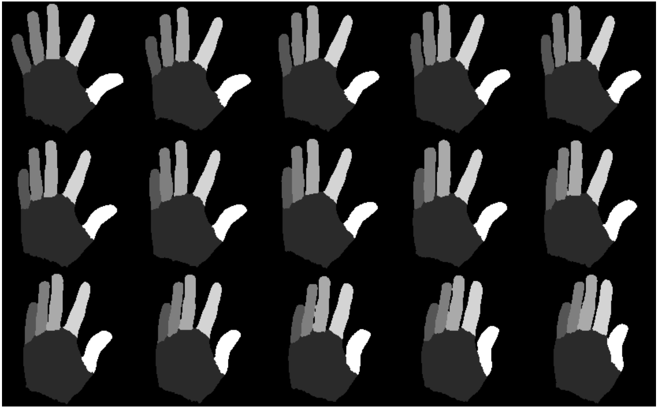

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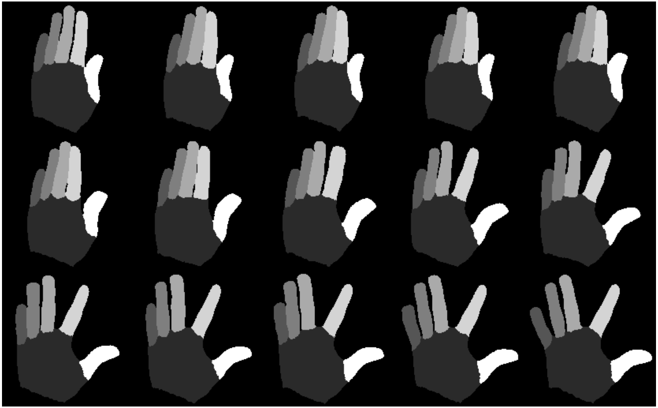

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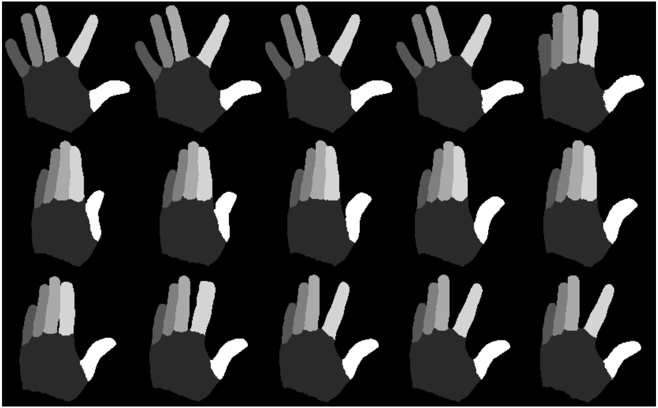

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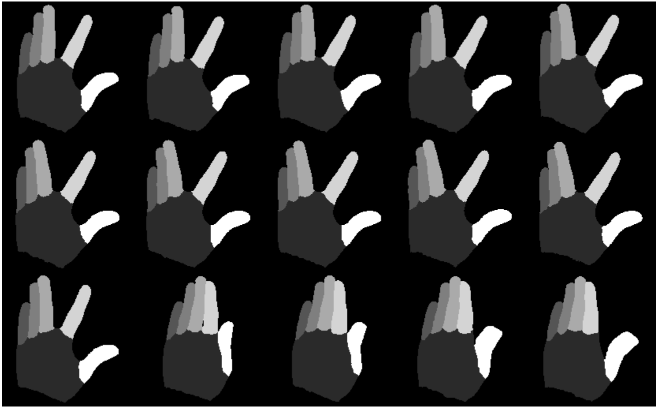

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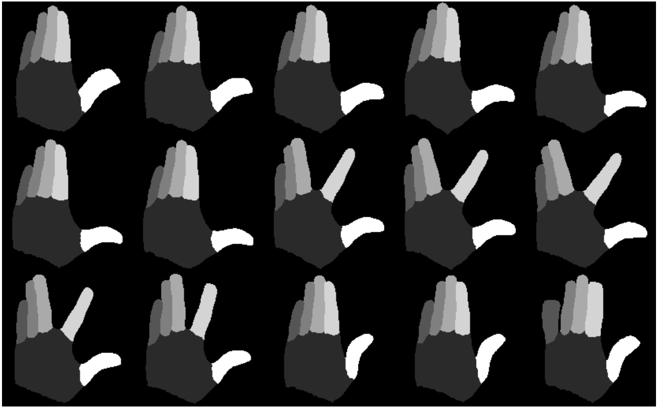

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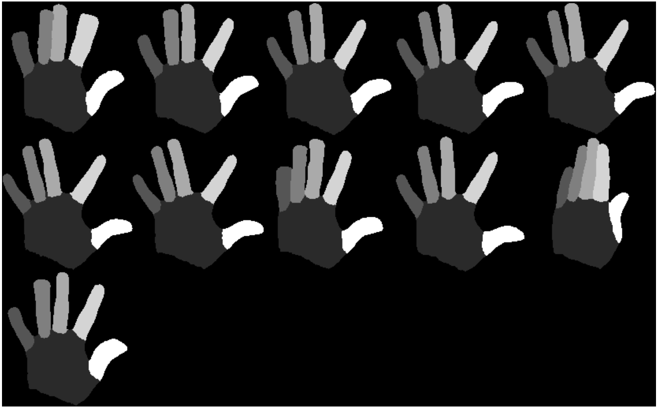

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- Each object system becomes a node of a complete graph, where the weight of each arc derives from the similarities between the corresponding objects in shape, size and position.

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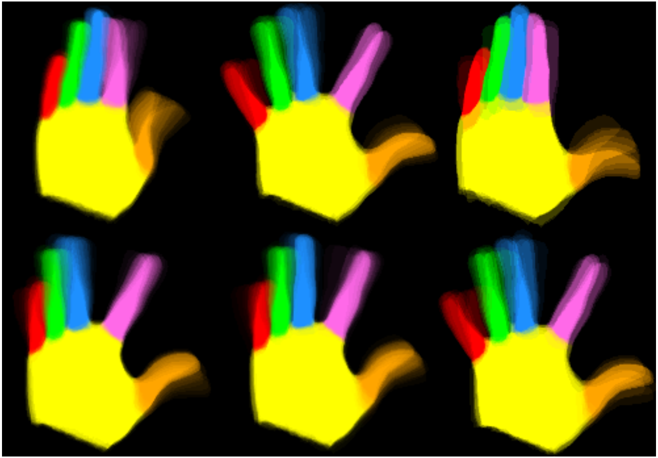
Groups of object systems in which the corresponding objects have similar shapes, sizes and positions form different cloud system models, as follows.

- Each object system becomes a node of a complete graph, where the weight of each arc derives from the similarities between the corresponding objects in shape, size and position.
- The groups are found as maximal cliques in which all arc weights are higher than a threshold.

The cloud system model

The object systems in each group are finally translated to a same reference point and the corresponding object masks are averaged, forming a set of cloud systems.



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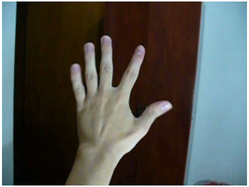
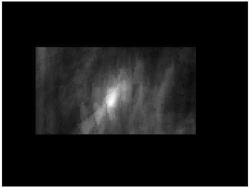
- A fuzzy membership map (object clouds), which indicates an object uncertainty region with values strictly lower than 1 and higher than 0.
- A delineation algorithm (IFTSC), whose execution is constrained in the uncertainty region.
- A criterion function, which assigns a score to any set of delineated objects.

The cloud system model

Segmentation using CSM consists of a search for the translation to the image location which produces the highest score, when the reference point of the most suitable cloud system is at that position.





show video handsearch.mpg

Conclusion

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- The synergistic combination between object models and delineation methods makes automatic segmentation feasible.
- When any automatic segmentation method fails, we have also developed solutions to reduce it into an optimum-path forest with minimum number of roots[18], so this facilitates corrections by the differential IFTSC algorithm[6, 7].

Next lecture

- The Image Foresting Transform.
- Interactive and automatic segmentation methods.
- Clustering and classification.
- Connected filters.

Thanks for your attention

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