Segmentation of Objects in Images and Videos

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Introduction

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- But what is an object?

- And what is the background? $\rightarrow$ Highly dependent on the context.

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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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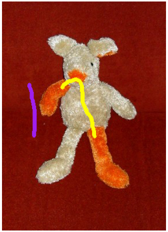


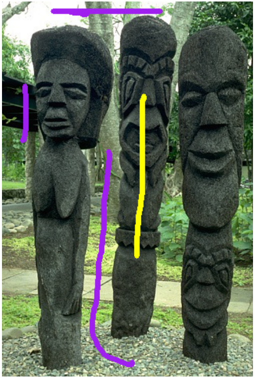
Introduction

- Humans are more accurate than computers for object location.
- Computers are more precise than humans in object delineation.

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

When do we need connectivity?

Simple connectivity is needed for delineation when object and other disconnected parts of the background have similar properties.



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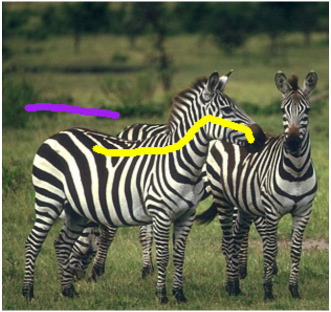

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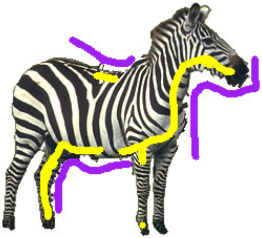

In this case, however, some markers needed to disconnect the object are not suitable for object enhancement.

How can we effectively address segmentation?

- Markers/object models can be used for object location and 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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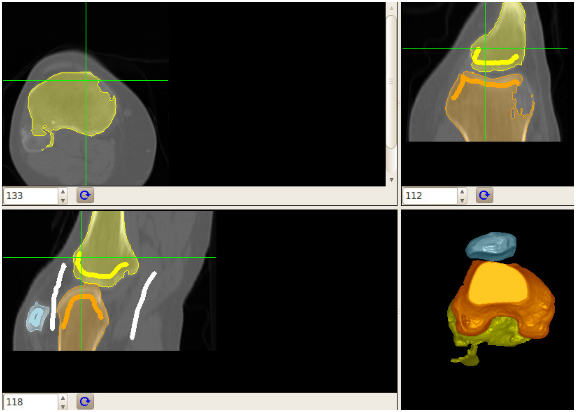
- Object delineation using the image foresting transform: boundary-based, region-based, and hybrid approaches.
- A comparative analysis between the IFT and the min-cut/max-flow algorithms for region-based segmentation.
- Fuzzy object models and video segmentation.

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).



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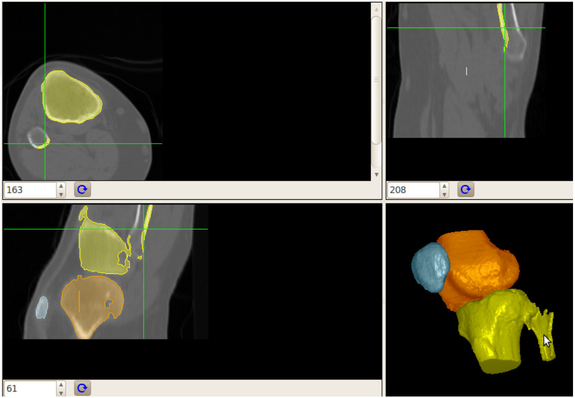

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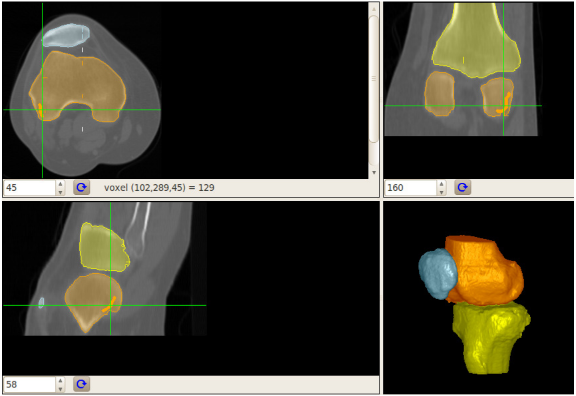

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Differential IFT with seed competition (IFTSC)

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

$$
\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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where $\mathcal{S}_i$ and $\mathcal{S}_e$ are internal and external seed sets.

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- The dual formulation holds for fuzzy connected segmentation.

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

Algorithm

– DIFTSC - ALGORITHM

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

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

Algorithm

– DIFT-FORESTREMOVAL

INPUT: *Maps V, P, R, adjacency $\mathcal{A}$, and set $\mathcal{R}_{\mathcal{M}}$ of selected roots.*
OUTPUT: *Maps V, P, and set $\mathcal{F}$ of frontier pixels.*
AUXILIARY: *FIFO Queue T.*

1. *Set $\mathcal{F} \leftarrow \emptyset$.*
2. **For each** $t \in \mathcal{R}_{\mathcal{M}}$, **do** *insert t in T, set $V(t) \leftarrow +\infty$ and $P(t) \leftarrow nil$.*
3. **While** $T \neq \emptyset$, **do**
4. *Remove s from T.*
5. **For each** $t \in \mathcal{A}(s)$, **do**
6. **If** $P(t) = s$, **then**
7. *Set $V(t) \leftarrow +\infty$, $P(t) \leftarrow nil$ and insert t in T.*
8. **Else If** $R(t) \notin \mathcal{R}_{\mathcal{M}}$, **then** $\mathcal{F} \leftarrow \mathcal{F} \cup \{t\}$.
9. *Set $\mathcal{R}_{\mathcal{M}} \leftarrow \emptyset$.*

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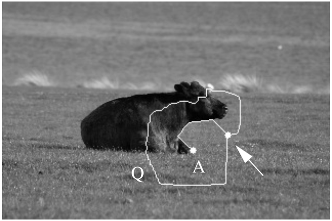
They can be implemented by a sequence of IFTs using 4- or 8-adjacency relation and suitable connectivity function.

Live-wire-on-the-fly

In live-wire-on-the-fly (LWOF), optimum paths are incrementally computed from the moving wavefront Q.



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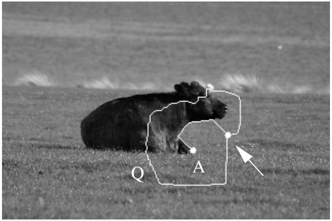

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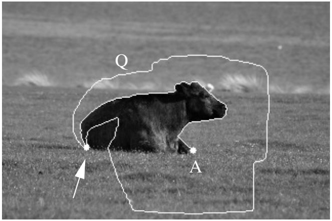

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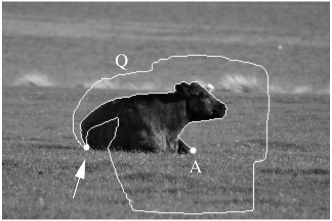

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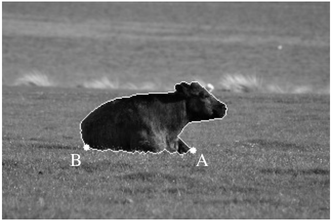

- The user selects a point A on the object's boundary, and
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- When the cursor is close to the boundary, the path snaps on to it.
- The user may accept it as a boundary segment, and
- the process is repeated from its terminus B until the user decides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

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

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

1. **If** $V(u) = +\infty$ *or* $u \in Q$, **then**
2. *Set* $s \leftarrow nil$.
3. *While* $Q \neq \emptyset$ *and* $s \neq u$, *do*
4. *Remove from* Q *a spel* s *such that* $V(s)$ *is minimum.*
5. *For each* $t \in \mathcal{A}(s)$ *such that* $V(t) > V(s)$, *do*
6. **If** $O(l) \geq O(r)$,
7. **then** *set* $tmp \leftarrow V(s) + \bar{w}^{\beta}(s,t)$
8. **Else** *set* $tmp \leftarrow V(s) + K^{\beta}$.
9. **If** $tmp < V(t)$, **then**
10. *If* $V(t) \neq +\infty$, *remove* t *from* Q.
11. *Set* $P(t) \leftarrow s$ *and* $V(t) \leftarrow tmp$.
12. *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^*:

$$
\begin{aligned}
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}
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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

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

is minimum, considering all possible cuts in the dual graph $(\mathcal{N}, \mathcal{A}')$.

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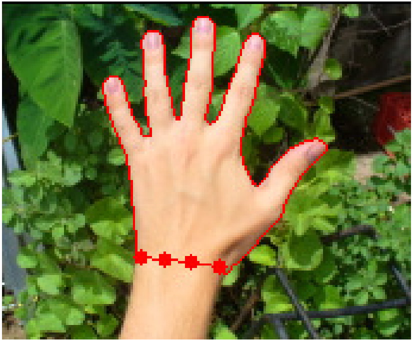
  is minimum, considering all possible cuts in the dual graph $(\mathcal{N}, \mathcal{A}')$.
- This implies that IFTSC and riverbed decide for the same optimum graph cut.
- Riverbed is more suitable than live-wire for more intricate shapes, but live-wire can jump weakly defined parts of the boundary.

Riverbed versus live-wire

- Live-wire on complex shapes requires more anchor points.

Riverbed versus live-wire



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

Riverbed versus live-wire

- 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 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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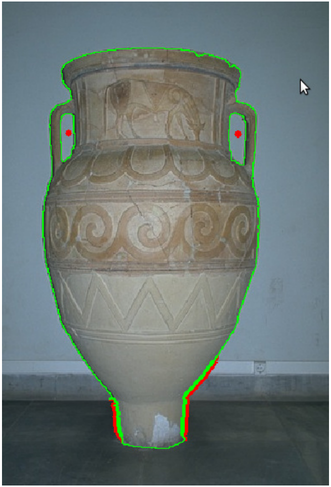

Organization of this lecture

- 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 and video segmentation.

IFTSC and min-cut/max-flow algorithms

- It can be shown that the 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.

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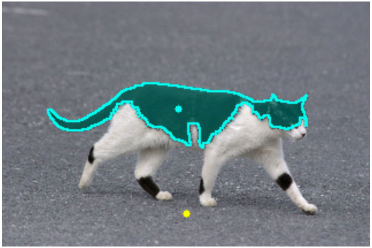
- IFTSC is also more robust with respect to seed location than GCMF, but the latter provides smoother boundaries with less leaking than the former.
- Interestingly, GCMF and LWOF are known to be related by dual graphs just as IFTSC and Riverbed.

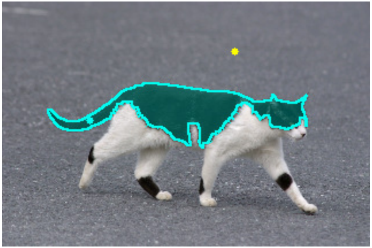
IFTSC and min-cut/max-flow algorithms

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

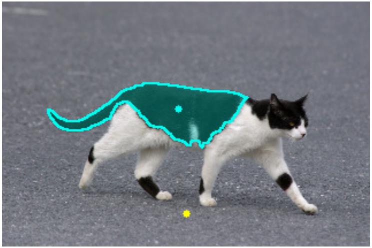
However, a same connected component is always obtained with IFTSC, independently of seed location.

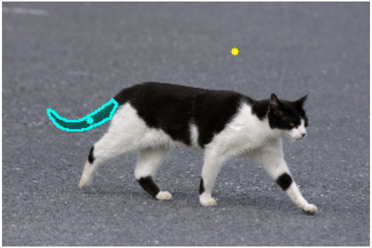




IFTSC and min-cut/max-flow algorithms

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





Graph Cuts using the Min-Cut/Max-Flow algorithm

Some GCMF approaches further change the graph topology by adding two virtual *source* and *sink* nodes, connected to every node in the graph

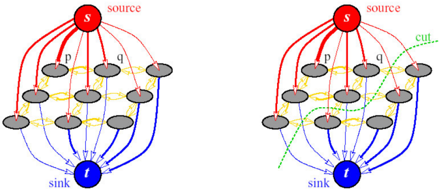


Image source: mathworks.com

and consider the following energy function in order to circumvent the drawbacks of smaller cuts

$$\sum_{\forall (s,t)\in\mathcal{A}|\ L(s)=1, L(t)=0} \bar{w}(s,t) + \lambda \left(\sum_{\forall (s)\in\mathcal{I}|L(s)=1} \bar{P}_o(s) + \sum_{\forall (t)\in\mathcal{I}|L(t)=0} \bar{P}_b(t) \right),$$

where P is an object membership map (probability map).

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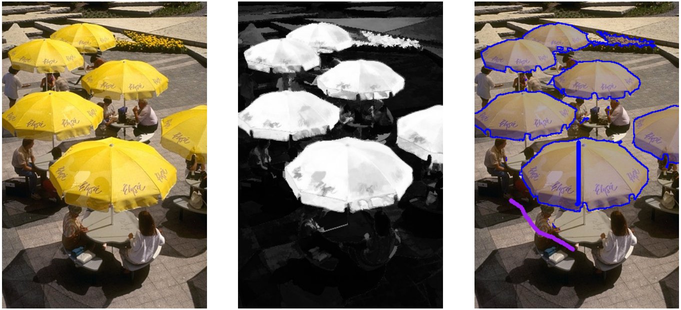
- Moreover, the addition of the virtual nodes makes it difficult to guarantee that the resulting segmentation will be spatially connected to the user-drawn markers.



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- Lower λ values imply the regular GCMF minimum cut measure while higher values lead to simple thresholding of P.

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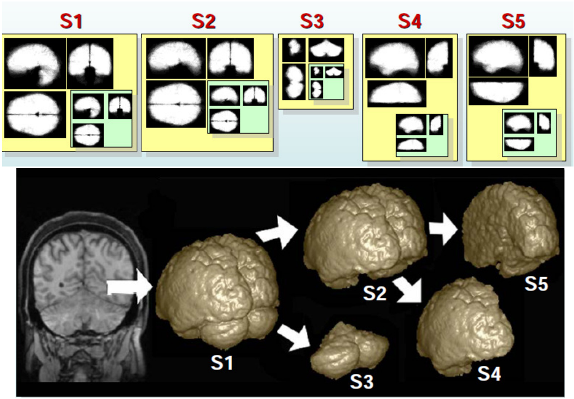
- Segmentation is solved by translating the model and executing delineation at each location.
- It is possible to considerably speed-up this object search process by using multiple scales of the image and models.

Fuzzy object models

Examples of objects and their fuzzy models.

Medical imaging: Object modeling and image segmentation



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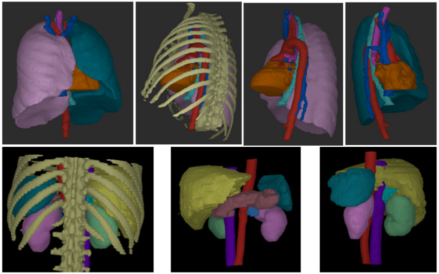

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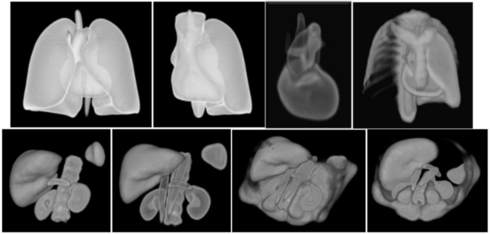

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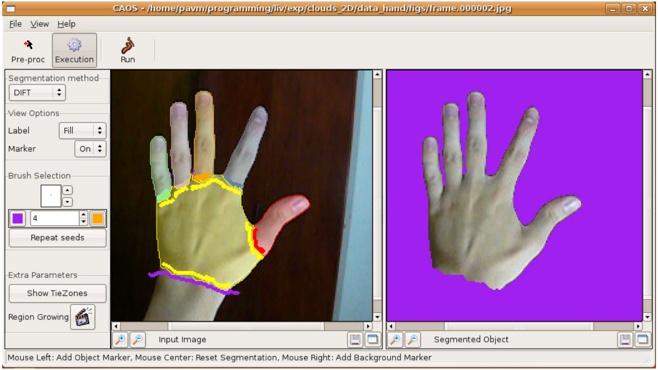
The cloud system model

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



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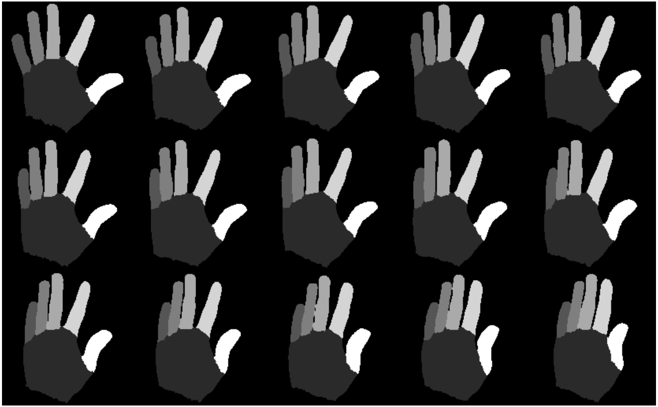

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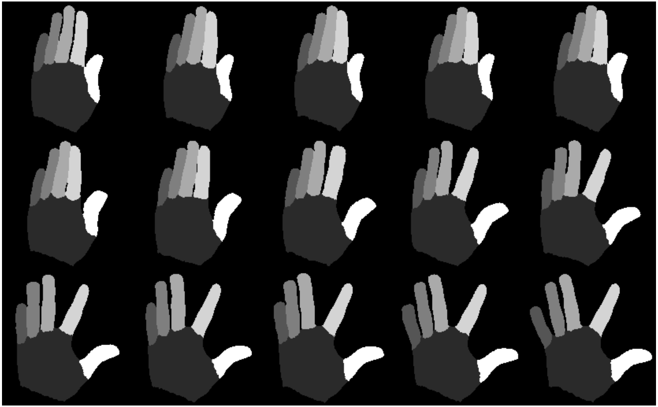

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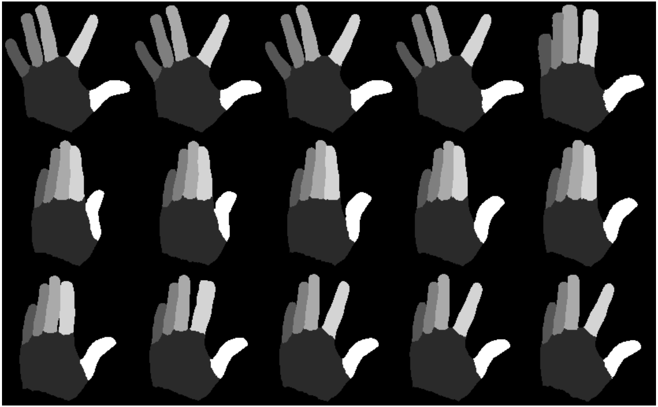

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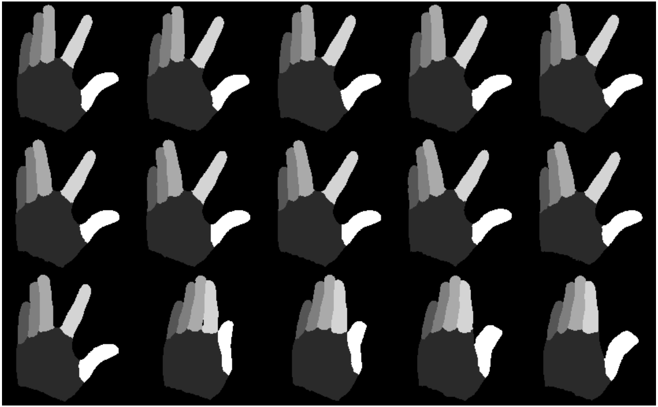

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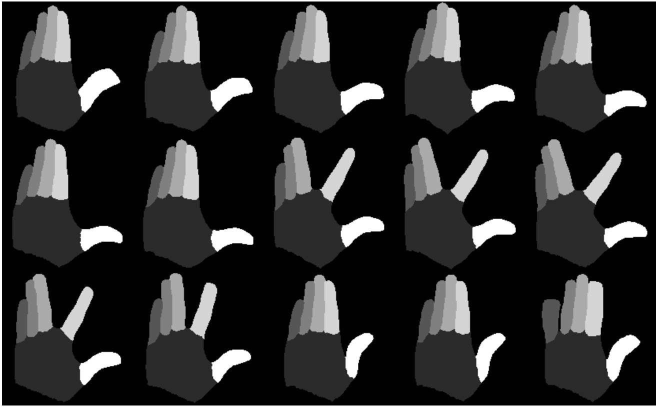

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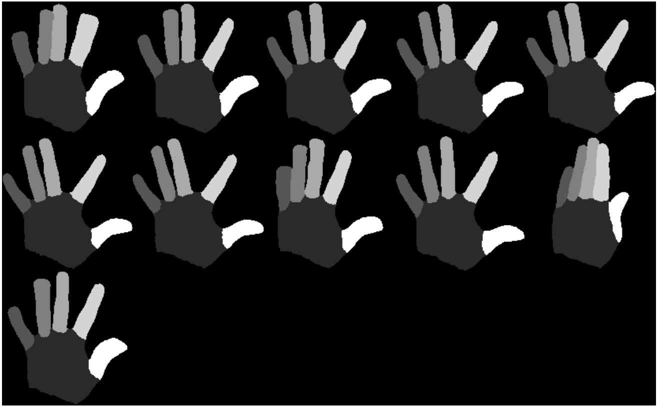

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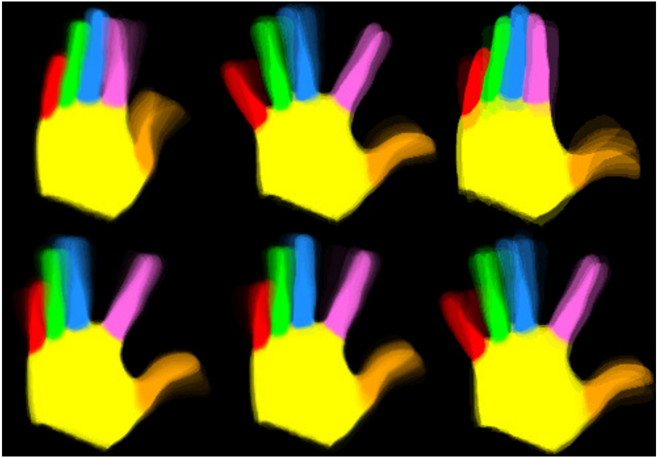
Groups of object systems in which the corresponding objects have similar shapes, sizes and positions form different cloud system models, as follows.

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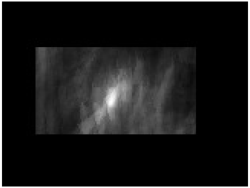
- A fuzzy membership map (object clouds), which indicates an object uncertainty region with values strictly lower than 1 and higher than 0.
- A delineation algorithm (IFTSC), whose execution is constrained in the uncertainty region.
- A criterion function, which assigns a score to any set of delineated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

The cloud system model in video

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The cloud system model in video

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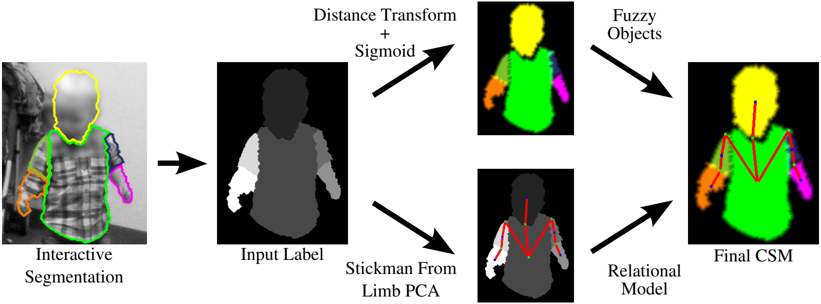
- Hence, we have first tackled the problem of dealing with articulated objects (i.e., the human body).
- Given the wide range of possible body poses, we start from a single segmentation mask obtained interactively in the first frame.
- The remainder of the video is automatically segmented using CSM.

The cloud system model in video

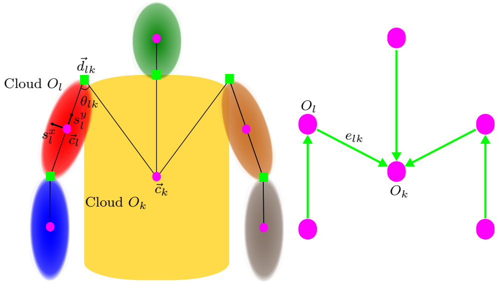
Creation of a CSM from a single segmentation mask in the first frame.



This process outputs a CSM with one cloud per body part.

The cloud system model in video

To deal with articulation, we have coupled the CSM with a relational model that is used to reposition the clouds during the search in a new test frame.



- The torso translates over the image and carries along the head and limbs.
- While the torso can be globally rotated, the remaining body part joint angles are relative between the connected parts.
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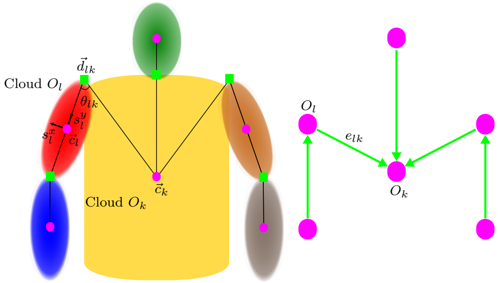
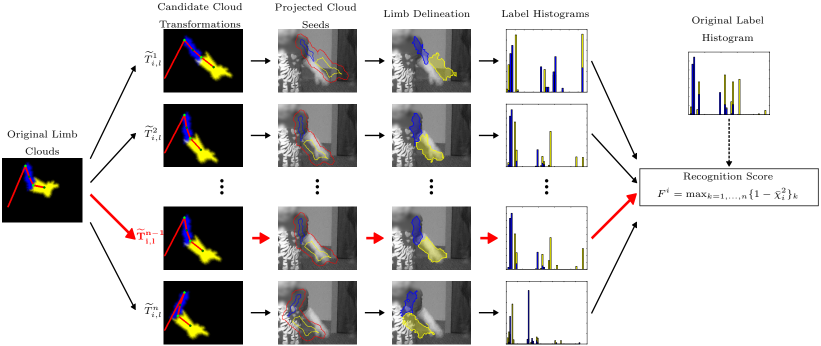


- The torso translates over the image and carries along the head and limbs.
- While the torso can be globally rotated, the remaining body part joint angles are relative between the connected parts.
- The scale is relative to the first frame for all body parts.
- The search for the body in a new frame consists of finding an optimal configuration for those parameters using multi-scale parameter search (MSPS).

The cloud system model in video

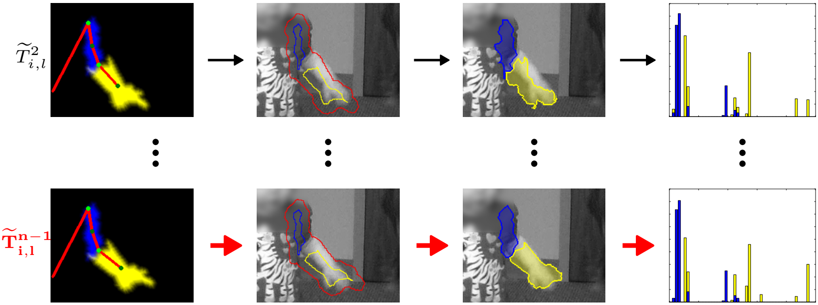
For every configuration of the relational model parameters chosen by MSPS, the CSM performs delineation and evaluates the criterion function.



In this case, the criterion function considers the χ^2 distance between color histograms extracted from both the first and the current frame.

The cloud system model in video

Delineation uses the regular IFTSC with the pixels surrounding the uncertainty region as seeds.



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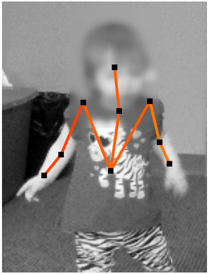

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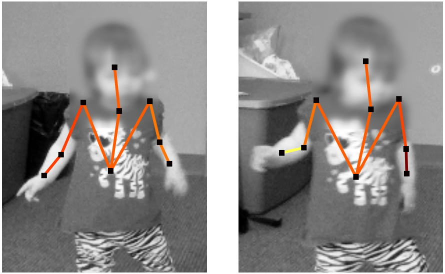

- We use the 2D body pose to detect arm asymmetry during unsupported gait, a possible sign of autism in toddlers, from videos of real in-clinic ASD assessments.

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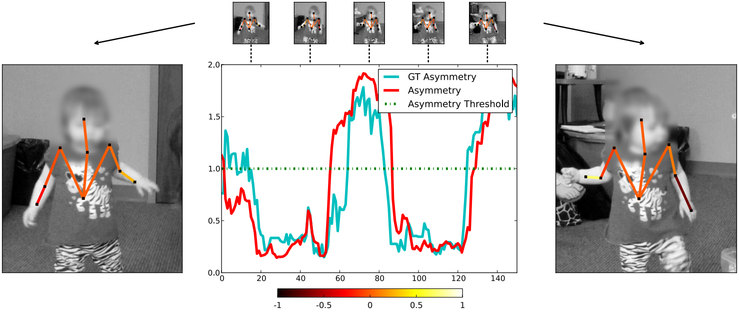
We provide quantifiable measures to aid the clinician in his/her assessment, which can be used for both research and diagnosis.



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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, so this facilitates corrections by the differential IFTSC algorithm.