Evaluation of combinations of hierarchies

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HIERARCHY OF SEGMENTATIONS

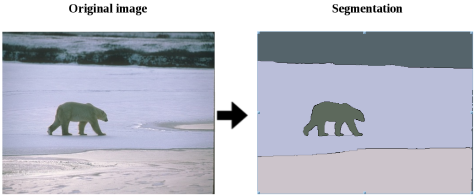
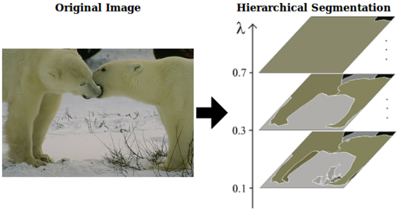
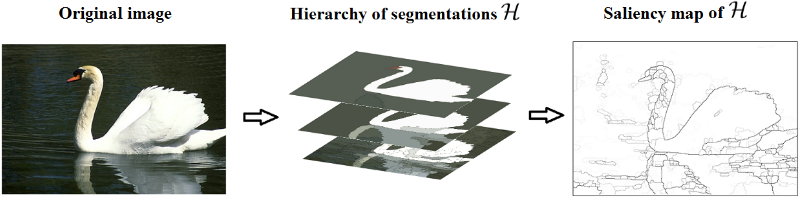


Image segmentation.



Hierarchy of image segmentations (Arbelaez)

SALIENCY MAP: AN EQUIVALENT REPRESENTATION OF HIERARCHY



Motivation to combine hierarchies

- **Why combining hierarchies?**

Original image, saliency maps of hierarchies and segmentations containing 50 regions extracted from each hierarchy. The hierarchy on the right is a combination of the hierarchies on the left and middle column.

Main contributions

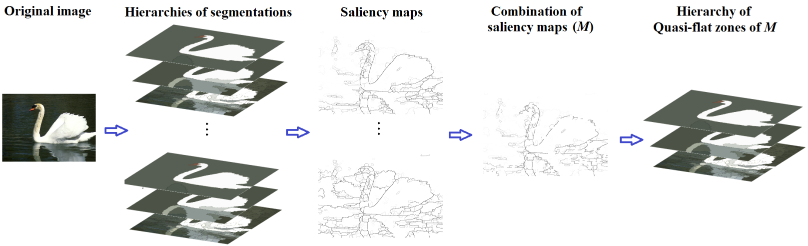
- Definition of five combinations of hierarchies
- Practical evaluation of these combinations:
  - on Berkeley dataset (500 images)
  - versus manual segmentations
- In half of the cases, the combined hierarchy scores better than any of its individual hierarchies
- Best result: combination achieved a score of **0.569** against **0.513** and **0.527** for individual hierarchies

OUTLINES

1. Method for combining hierarchies
2. Types of combinations
3. Experiments
4. Conclusion

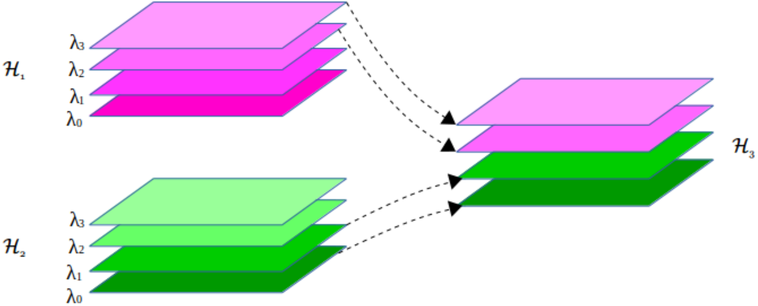
1. Method for combining hierarchies

- **How to combine hierarchies?**



- Infimum ($\curlywedge$)
- Supremum ($\curlyvee$)
- Linear combination ($\boxplus_\Theta$)
- Average (A)
- Concatenation ($\uplus_\Theta$)

Concatenation (intuitive illustration)



Combination of two hierarchical segmentations $\mathcal{H}_1$ and $\mathcal{H}_2$ at level λ_2, resulting in $\mathcal{H}_3$.

3.1 Experimental Setup

- **Watershed-cut hierarchies (Beucher, 1994) built from the following attributes**
  - Area
  - Dynamics
  - Volume
  - Topological Height
  - Number of Descendants
  - Diagonal of Bounding Box
  - Number of Minima

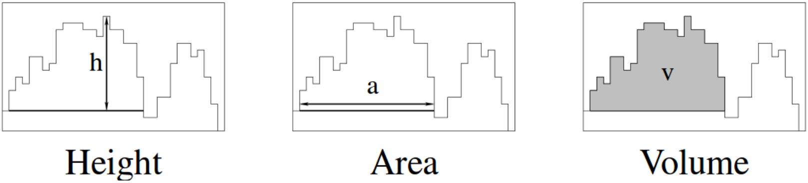


Illustration of the height, the area and the volume of a component

3.1 Setup of experiments

Image dataset

- Berkeley Segmentation Dataset and Benchmark 500 (BSDS500)

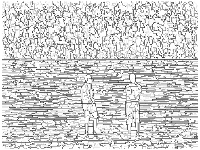
Methods for computing image gradient

- Euclidean distance on **Lab space**
- Structured Edge detector (SE) (Dollar and Zitnick, 2013)

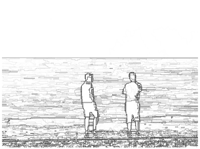
Original color image from BSDS500 and its gradient using SE

3.2 Visual inspection

Original image

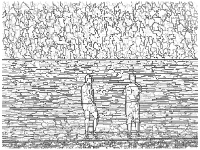


Area

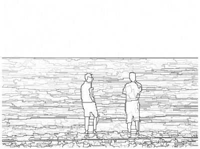


Dynamics

Infimum



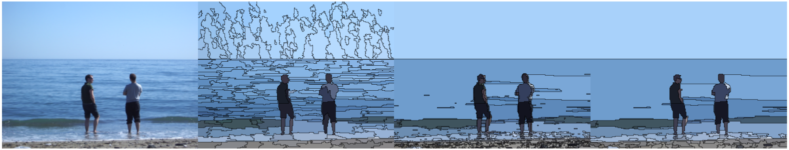
Supremum



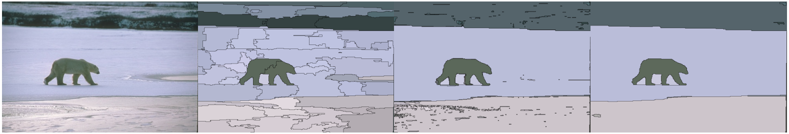
Average

3.2 Visual inspection
Infimum (⋏)

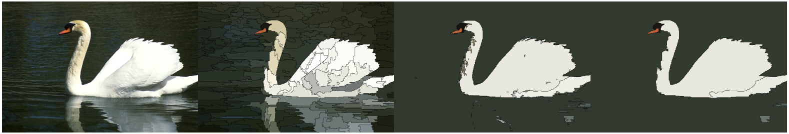
Original	Area	Dynamics	*Infimum*



	270 regions	934 regions	128 regions



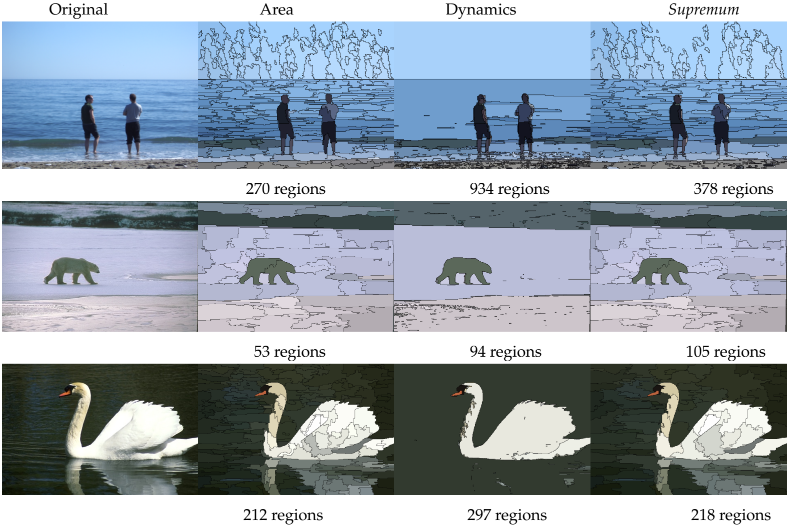
	53 regions	94 regions	13 regions



	212 regions	297 regions	7 regions

3.2 Visual inspection

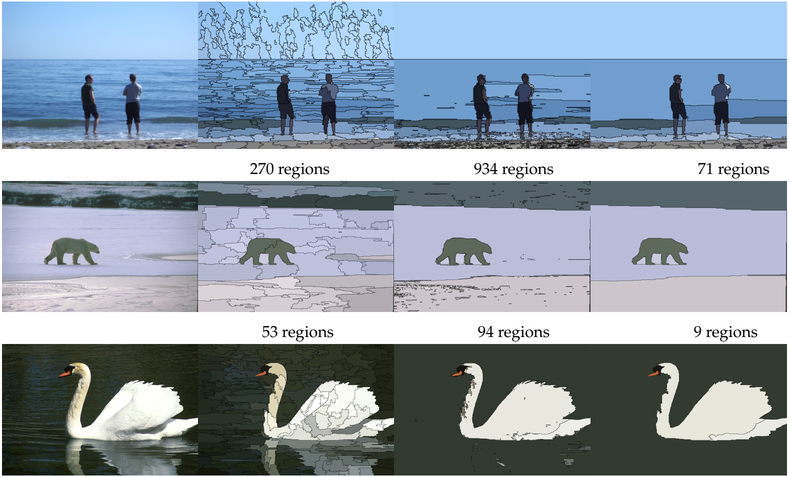
Supremum (Υ)



3.2 Visual inspection

Average (*A*)

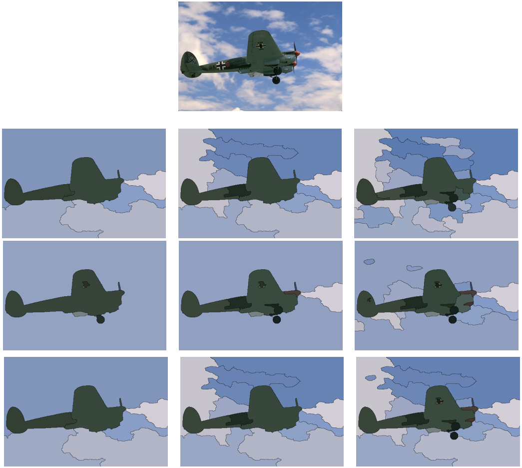
Original	Area	Dynamics	*Average*



	Area	Dynamics	*Average*
Row 1	270 regions	934 regions	71 regions
Row 2	53 regions	94 regions	9 regions
Row 3	212 regions	297 regions	5 regions

3.2 Visual inspection
Concatenation ($\uplus_{\ominus}$)

Original



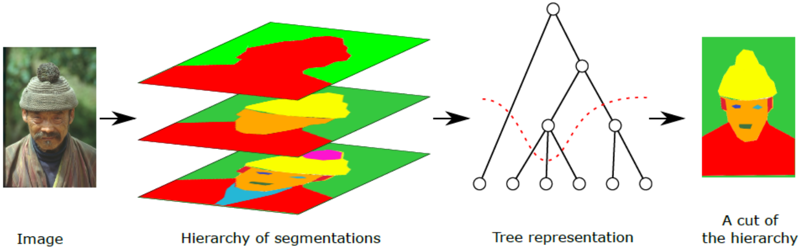
Volume

Dynamics

Volume(14) + Dyn.

7 regions 14 regions 30 regions

3.3 Assessment methodology of hierarchies of segmentations

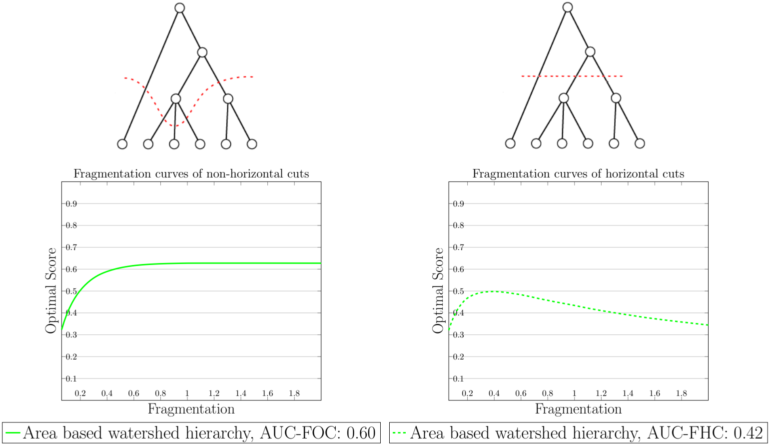


A cut in a hierarchy (Benjamin *et al*, 2017)

- Cuts can be horizontal and non-horizontal and can contain different number of regions
- The assessment is made by comparing cuts of a hierarchy to user-marked segmentation ground-truth
- Cuts are optimal for a given ground-truth similarity measure

3.3 Assessment methodology of hierarchies of segmentations

- **Fragmentation curves (Perret *et al*, 2017)**



- **Bidirectional Consistency Error (BCE)**

3.4 Evaluation: Parameter-free combinations ($\curlywedge, \curlyvee, A$) and Concatenation

- Combinations using *infimum*, *supremum* and *average*:
  - Average improved the results in 10/21 combinations, versus 11/21 and 10/21 for supremum and infimum
  - The highest score (0.568) obtained from combinations using average

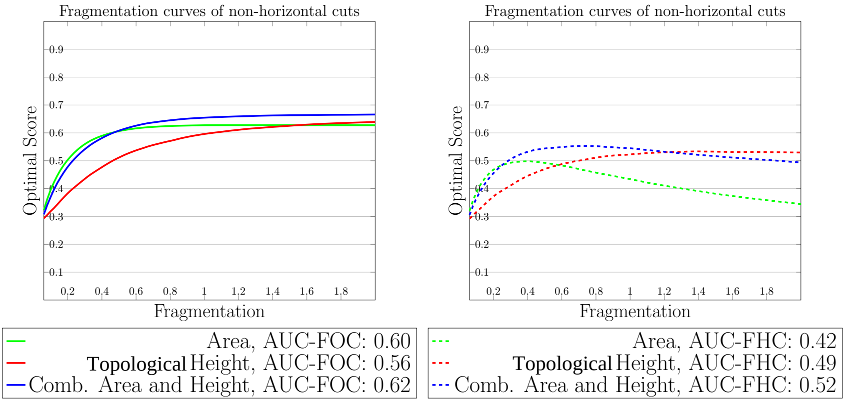
- Combination using *concatenation*:
  - 50%(5/10) of combinations presented higher scores than the individual hierarchies

- Supervised search of parameters to combine pairs of hierarchies (training set of BSDS500)

- The results were improved in 52%(11/21) of combinations

- Highest score (0.569):
  - Area / Topological height: 51%/49%
  - Dynamics / Number of Descendants: 38%/62%
  - Topological height / Number of descendants: 42%/58%

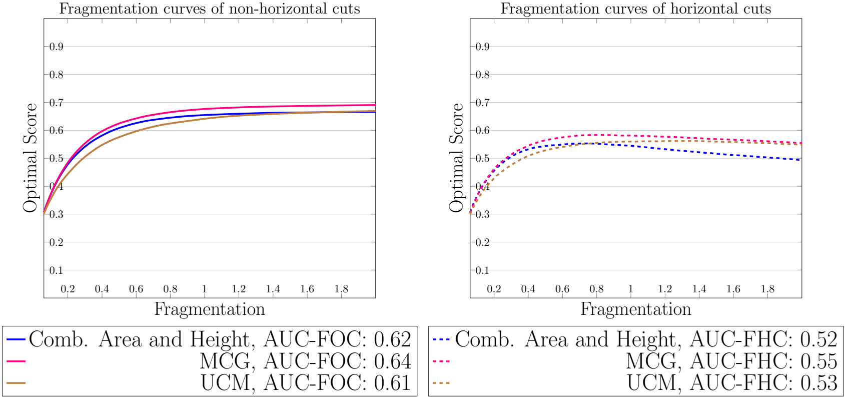
3.4 Evaluation: Supervised linear combinations



Fragmentation curves of area, topological height and their linear combination

3.5 Comparison with other techniques

- Multiscale combinatorial grouping - MCG (Pont-Tuset *et al*, 2015)
- Ultrametric Contour Map - UCM (Arbelaez *et al*, 2011)



Fragmentation curves of linear combination of area and topological height, UCM and MCG.

4 Conclusion

- Our results show the potential of combination of hierarchies through the evaluation of combinations of watershed-cut hierarchies
- Half of the combinations presents better results compared to the ones of the individual hierarchies

Merci!

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Pont-Tuset, J., Arbeláez, P., Barron, J. T., Marques, F., Malik, J. Multiscale Combinatorial Grouping for Image Segmentation and Object Proposal Generation. IEEE PAMI. 2015.

Combining n-weight functions

Infimum

$$\forall e \in E, \curlywedge(\Phi(\mathcal{H}_1),\ldots,\Phi(\mathcal{H}_n))(e) = min\{[\Phi(\mathcal{H}_1)](e),\ldots,[\Phi(\mathcal{H}_n)](e)\} \tag{1}$$

Supremum

$$\forall e \in E, \curlyvee(\Phi(\mathcal{H}_1),\ldots,\Phi(\mathcal{H}_n))(e) = max\{[\Phi(\mathcal{H}_1)](e),\ldots,[\Phi(\mathcal{H}_n)](e)\} \tag{2}$$

Linear combination

$$\forall e \in E, \oplus_\Theta(\Phi(\mathcal{H}_1),\ldots,\Phi(\mathcal{H}_n))(e) = \sum_{i\in\{1,\ldots,n\}} \alpha_i.[\Phi(\mathcal{H}_i)](e),\ \alpha_i \in \mathbb{R} \tag{3}$$

Average

$$\forall e \in E, A(\Phi(\mathcal{H}_1),\ldots,\Phi(\mathcal{H}_n))(e) = \frac{1}{n}\sum_{i\in\{1,\ldots,n\}} \Phi(\mathcal{H}_i)(e),\ \alpha_i \in \mathbb{R} \tag{4}$$

Concatenation
Given a sequence $(w_1, \dots, w_n)$ of n weight maps and a series $(\lambda_1, \dots, \lambda_{n-1})$ of $n-1$ threshold values in $\mathbb{R}$ such that $\lambda_1 < \lambda_2 < \dots < \lambda_{n-1}$, we define the *concatenation of* $(w_1, \dots, w_n)$ *parametrized by* $(\lambda_1, \dots, \lambda_{n-1})$, thanks to the combining n-weight function $\uplus_\Theta$, by:

$$\forall e \in E, \uplus_\Theta(w_1, \dots, w_n)(e) = max\{T(w_1(e), 0, \lambda_1), \dots, T(w_n(e), \lambda_{n-1}, \infty)\} \quad (5)$$

where, given a, b, and $c \in \mathbb{R}$, we have $T(a, b, c)$ equals to 0 if a is lower than b and equals to $min(a, c)$ otherwise.
Consequently, given a sequence of hierarchies $(\mathcal{H}_1, \dots, \mathcal{H}_n)$ and threshold values $\Theta = (\lambda_1, \dots, \lambda_{n-1})$, *the concatenation of* $(\mathcal{H}_1, \dots, \mathcal{H}_n)$ *with parameter* Θ is $\mathcal{H}_{\uplus_\Theta}(\mathcal{H}_1, \dots, \mathcal{H}_n)$.

EVALUATION OF PARAMETER-FREE COMBINATIONS ($\curlywedge, \curlyvee, A$)

$\mathcal{H}_1 \mathcal{H}_2$	Area	DBB	Dyn	Height	Desc	Min	Vol
Area	- 0.513	$\curlyvee$ 0.515	A 0.566	A 0.567	$\curlyvee$ 0.515	A 0.529	$\curlywedge$ 0.529
DBB		- 0.514	A 0.566	A **0.568**	$\curlyvee$ 0.516	A 0.526	$\curlyvee$ 0.529
Dyn			- 0.510	$\curlywedge$ 0.522	A 0.567	A 0.563	$\curlyvee$ 0.551
Height				- 0.527	A **0.568**	A 0.563	A 0.554
Desc					- 0.514	A 0.530	$\curlywedge$ 0.529
Min						- 0.531	$\curlyvee$ 0.540
Vol							- 0.541

Combining n-weight functions and highest AUC-FOHC scores obtained from $c(\Phi(\mathcal{H}_1), \Phi(\mathcal{H}_2))$. For each pair of hierarchies, we have the global combination function which provided the highest AUC-FOHC score and the score obtained from this combination.

EVALUATION OF UNSUPERVISED CONCATENATION OF HIERARCHIES

	Area	DBB	Dyn	Height	Desc	Min	Vol
AUC-FOC	0.603	0.592	0.541	0.560	0.604	0.609	0.617
AUC-FHC	0.423	0.435	0.480	0.493	0.425	0.453	0.465
AUC-FOHC	0.513	0.514	0.510	0.527	0.514	0.531	0.541

AUC-FOC, AUC-FHC and AUC-FOHC scores of individual hierarchies computed over the test set of BSDS500.

$\mathcal{H}_2$	Dynamics					Height				
$\mathcal{H}_1$	Area	DBB	Desc	Min	Vol	Area	DBB	Desc	Min	Vol
AUC-FOC	0.579	0.561	0.586	0.589	0.591	0.579	0.574	0.580	0.582	0.585
AUC-FHC	0.472	0.462	0.462	0.483	0.498	0.472	0.475	0.473	0.485	0.500
AUC-FHCO	**0.525**	0.511	0.526	**0.536**	**0.545**	0.525	0.524	0.527	**0.534**	**0.542**

AUC-FOC, AUC-FHC and AUC-FHCO scores of $\uplus_\Theta(\Phi(\mathcal{H}_1), \Phi(\mathcal{H}_2))$, where different values of Θ were used for each concatenation. The AUC-FHCO scores in bold are the ones which are higher than the AUC-FHCO scores of individual $\mathcal{H}_1$ and $\mathcal{H}_2$ hierarchies.

Evaluation of supervised linear combinations

$\mathcal{H}_1 \mathcal{H}_2$	Area	DBB	Dyn	Height	Desc	Min	Vol
Area	- 0.513	$\alpha = 92$ 0.512	$\alpha = 60$ 0.568	$\alpha = 51$ **0.569**	$\alpha = 0$ 0.514	$\alpha = 11$ 0.531	$\alpha = 0$ 0.541
DBB		- 0.514	$\alpha = 43$ 0.566	$\alpha = 35$ 0.566	$\alpha = 19$ 0.512	$\alpha = 7$ 0.531	$\alpha = 2$ 0.541
Dyn			- 0.510	$\alpha = 3$ 0.527	$\alpha = 38$ **0.569**	$\alpha = 51$ 0.564	$\alpha = 24$ 0.558
Height				- 0.527	$\alpha = 42$ **0.569**	$\alpha = 51$ 0.560	$\alpha = 36$ 0.560
Desc					- 0.514	$\alpha = 25$ 0.530	$\alpha = 0$ 0.541
Min						- 0.531	$\alpha = 12$ 0.542
Vol							- 0.541

Parameters α and AUC-FOHC scores of each linear combination $\boxplus_{(\alpha)}(\Phi(\mathcal{H}_1), \Phi(\mathcal{H}_2))$. The AUC-FOHC scores in bold are the highest scores achieved with linear combination of hierarchies.