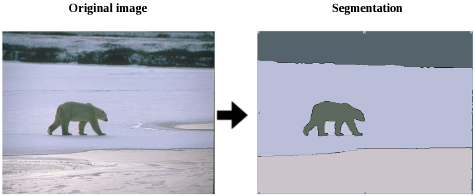
Evaluation of combinations of hierarchies

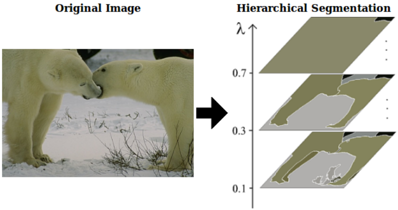
Deise SANTANA MAIA

Arnaldo de ALBUQUERQUE ARAUJO, Jean COUSTY, Laurent NAJMAN, Benjamin PERRET, Hugues TALBOT

International Symposium of Mathematical Morphology (ISMM), Fontainebleau, 2017

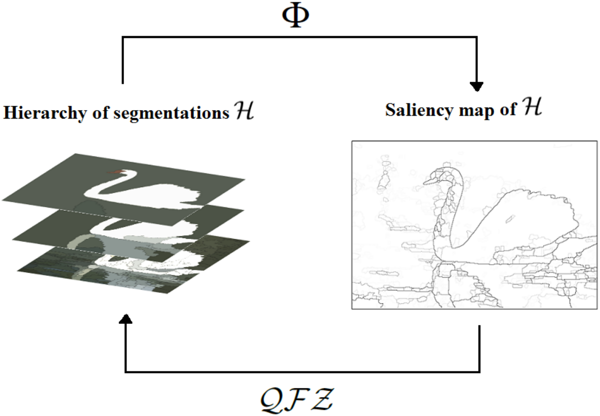
Hierarchy of segmentations





Hierarchy of segmentations

SALIENCY MAP: AN EQUIVALENT REPRESENTATION OF HIERARCHY



$$\mathcal{QFZ} = \Phi^{-1}$$

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

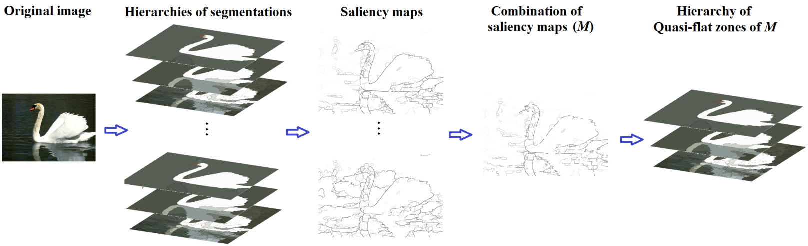
- Definition of five combinations of hierarchies
- Practical evaluation of these combinations:
  - on Berkeley dataset (500 images)
  - versus manual segmentations
- In half of the cases, the combined hierarchy scores better than any of its individual hierarchies
- Best result: combination achieved a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

Outlines

- Method for combining hierarchies
- Types of combinations
- Experiments
- Conclusion and perspectives

Method for combining hierarchies

- **How to combine hierarchies?**

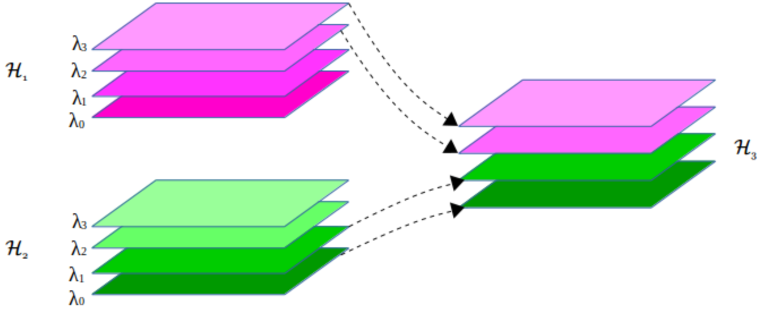


Types of combinations

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

CONCATENATION

Concatenation (intuitive illustration)

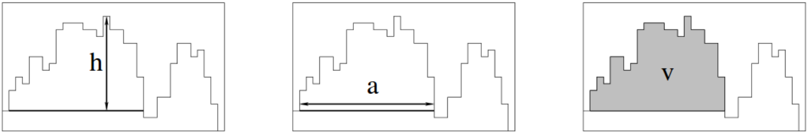


Combination of two hierarchical segmentations $\mathcal{H}_1$ and $\mathcal{H}_2$ at level λ_2, resulting in $\mathcal{H}_3$.

Experiments

- Experimental setup
- Visual inspection
- Assessment methodology
- Evaluation
- Comparison with other techniques

- **Watershed-cut hierarchies (CN, 2011) from the attributes**
  - Area
  - Dynamics
  - Volume
  - Topological Height
  - Number of Descendants
  - Diagonal of Bounding Box
  - Number of Minima



Height Area Volume

[CN, 2011] J. Cousty, L. Najman. Incremental algorithm for hierarchical minimum spanning forests and saliency of watershed cuts. ISMM. 2011

EXPERIMENTAL SETUP

Image dataset

- Berkeley Segmentation Dataset and Benchmark 500 (BSDS500) [AMFM, 2011]

Methods for computing image gradient

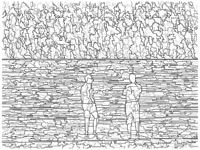
- Euclidean distance on **Lab space**
- Structured Edge detector (SE) [DZ, 2013]

Original color image from BSDS500 and its gradient using SE

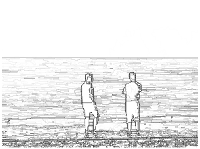
[AMFM, 2011] P. Arbelaez, M. Maire, C. Fowlkes and J. Malik. Contour Detection and Hierarchical Image Segmentation. IEEE TPAMI. 2011.
[DZ, 2013] P. Dollar and C. Zitnick. Structured forests for fast edge detection. In: Proceedings of the IEEE ICCV. 2013.

Visual inspection of Saliency Maps

Original image

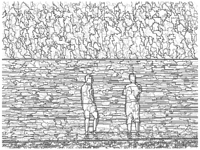


Area

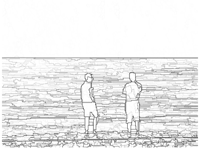


Dynamics

Infimum



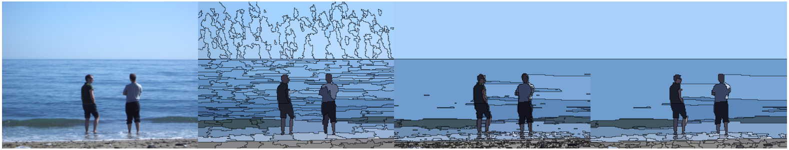
Supremum



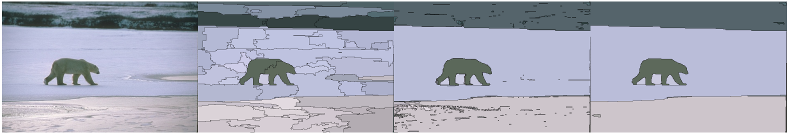
Average

Visual inspection of Segmentations
Infimum ($\curlywedge$)

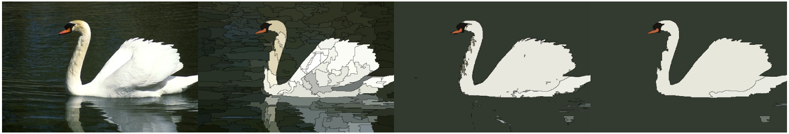
Original | Area | Dynamics | *Infimum*



270 regions | 934 regions | 128 regions



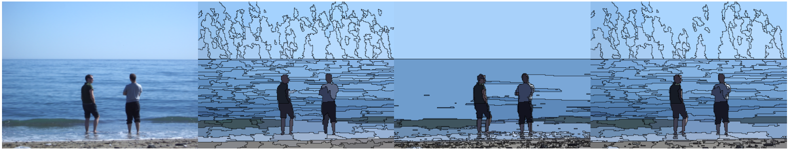
53 regions | 94 regions | 13 regions



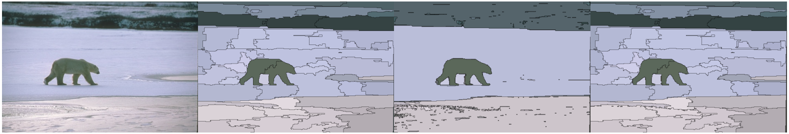
212 regions | 297 regions | 7 regions

VISUAL INSPECTION OF SEGMENTATIONS
SUPREMUM ($\curlyvee$)

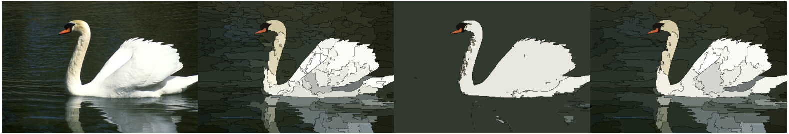
Original | Area | Dynamics | *Supremum*



270 regions | 934 regions | 378 regions

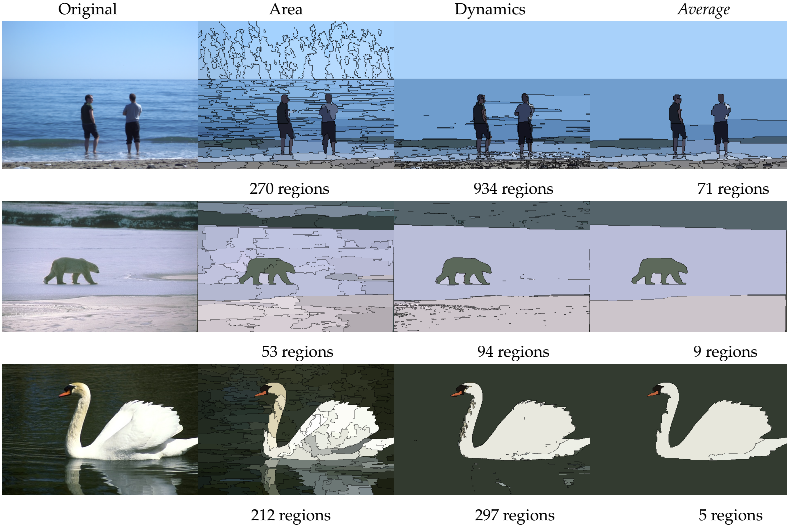


53 regions | 94 regions | 105 regions



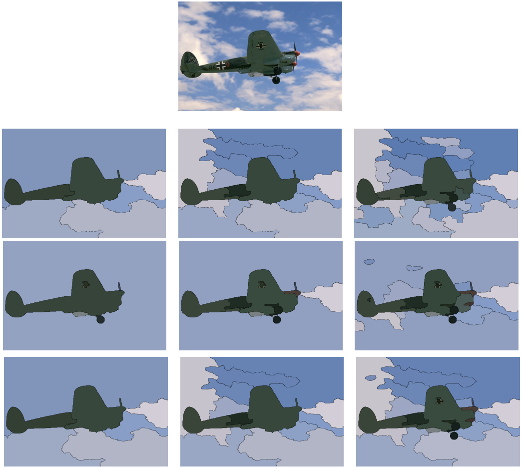
212 regions | 297 regions | 218 regions

Visual inspection of Segmentations
Average (A)



Visual inspection of Segmentations
Concatenation ($\uplus_\ominus$)

Original



Volume

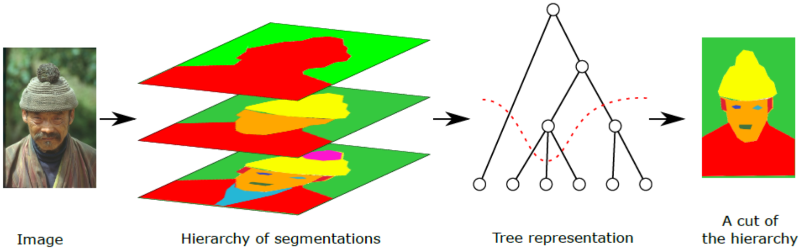
Dynamics

Volume(14) + Dyn.

7 regions | 14 regions | 30 regions

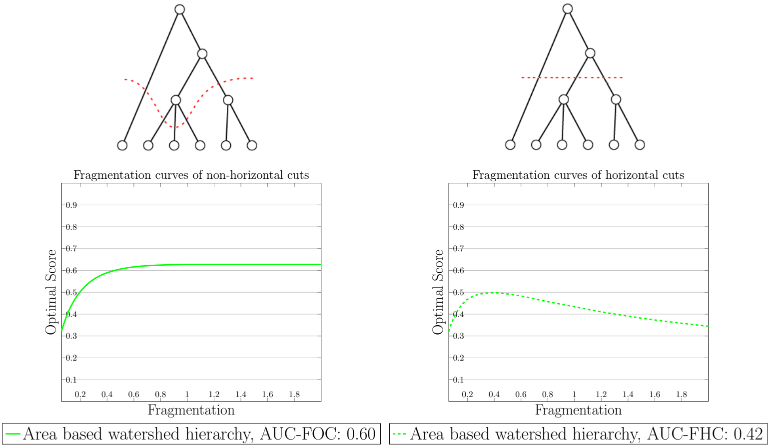
Assessment methodology of hierarchies of segmentations

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



Assessment methodology of hierarchies of segmentations

- **Fragmentation curves [PCGM, 2017]**



- **Bidirectional Consistency Error (BCE)**

[PCGM, 2017] B. Perret, J. Cousty, S.J.F. Guimaraes and D.S. Maia. Evaluation of hierarchies of watersheds for natural image analysis. Submited. https://hal.archivesouvertes. fr/hal-01430865/document

Evaluation: Parameter-free combinations 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

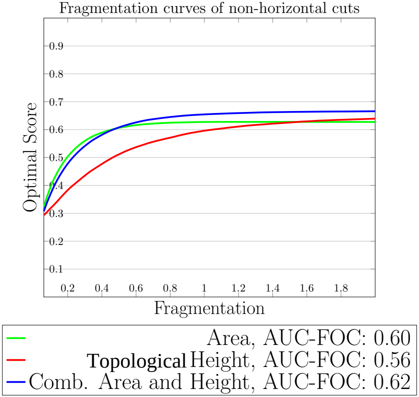
- Combination using *concatenation*:
  - 50%(5/10) of combinations presented higher scores than the individual hierarchies

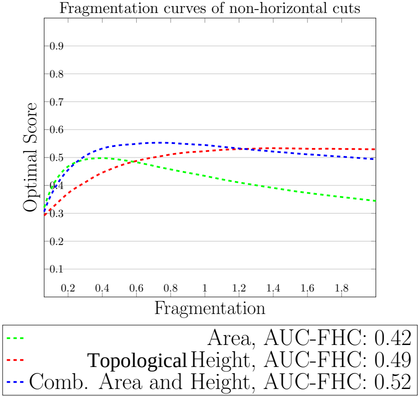
- Supervised search of parameters to combine pairs of hierarchies (training set of BSDS500)

- 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%

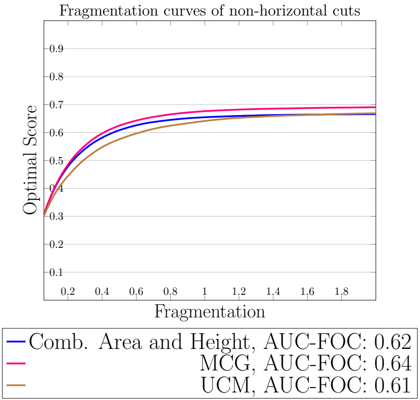
Evaluation: Supervised linear combinations

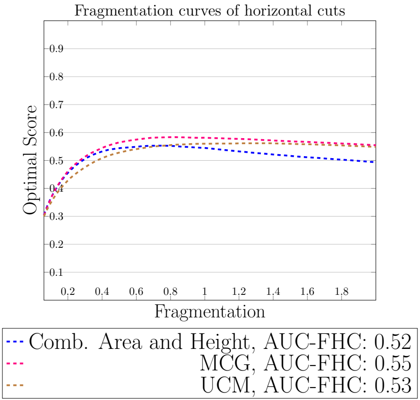




Comparison with other techniques

- Multiscale combinatorial grouping - MCG [PABMM, 2015]
- Ultrametric Contour Map - UCM [AMFM, 2011]

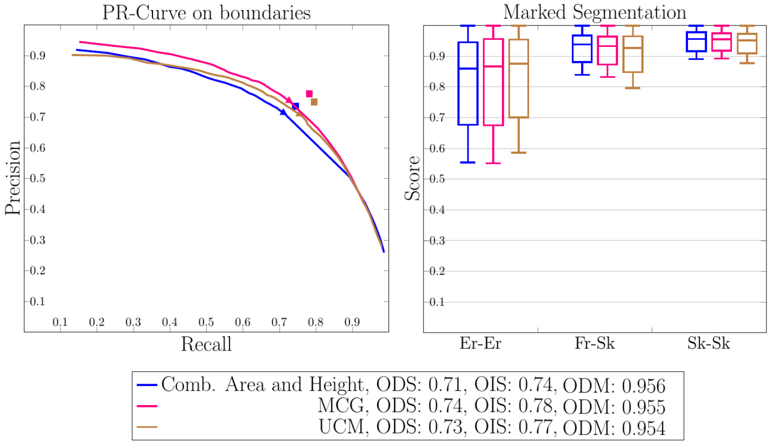




[PABMM, 2017] J. Pont-Tuset, P. Arbelez, J.T. Barron, F. Marques and J. Malik. Multiscale combinatorial grouping for image segmentation and object proposal generation. IEEE PAMI. 2015.
[AMFM, 2011] P. Arbelaez, M. Maire, C. Fowlkes and J. Malik. Contour detection and hierarchical image segmentation. IEEE PAMI. 2011.

Comparison with other techniques

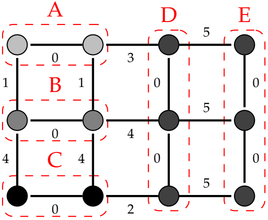
- Multiscale combinatorial grouping - MCG [PABMM, 2015]
- Ultrametric Contour Map - UCM [AMFM, 2011]



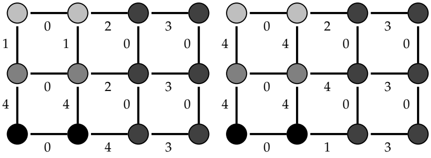
[PABMM, 2017] J. Pont-Tuset, P. Arbelez, J.T. Barron, F. Marques and J. Malik. Multiscale combinatorial grouping for image segmentation and object proposal generation. IEEE PAMI. 2015.
[AMFM, 2011] P. Arbelaez, M. Maire, C. Fowlkes and J. Malik. Contour detection and hierarchical image segmentation. IEEE PAMI. 2011.

- 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
- Next, we want to learn how to combine hierarchies

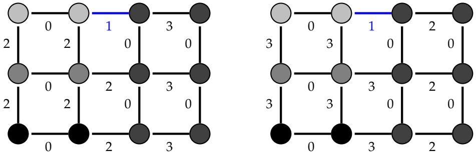
Combinations that are not watershed-cut hierarchies



Graph G



$\Phi(\mathcal{H}_1)$ and $\Phi(\mathcal{H}_2)$
(Watershed-cut hierarchies of G)



Saliency maps of average and suppremum of $\mathcal{H}_1$ and $\mathcal{H}_2$. They are not watershed-cut hierarchies of G because A and D can never be the first merging.

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

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

Combining n-weight functions

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

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

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 $(\mathcal{H}_1, \ldots, \mathcal{H}_n)$ and threshold values $\Theta = (\lambda_1, \ldots, \lambda_{n-1})$, *the concatenation of* $(\mathcal{H}_1, \ldots, \mathcal{H}_n)$ *with parameter* Θ is $\mathcal{H}_{\uplus_\Theta}(\mathcal{H}_1, \ldots, \mathcal{H}_n)$.

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.