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# Correlation Clustering with Fairness Constraints

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Green-Aware AI 2025





# Introduction

- Machine Learning (ML) systems achieved **decision-making power** in our lives (shall we **entrust** them?)
- Input data is often (intrinsically) **biased**
- ML algorithms must **avoid amplifying** input data bias
- **Disparate impact** [1] must be removed
  - no group of individuals should (even indirectly) be discriminated by a decision-making system

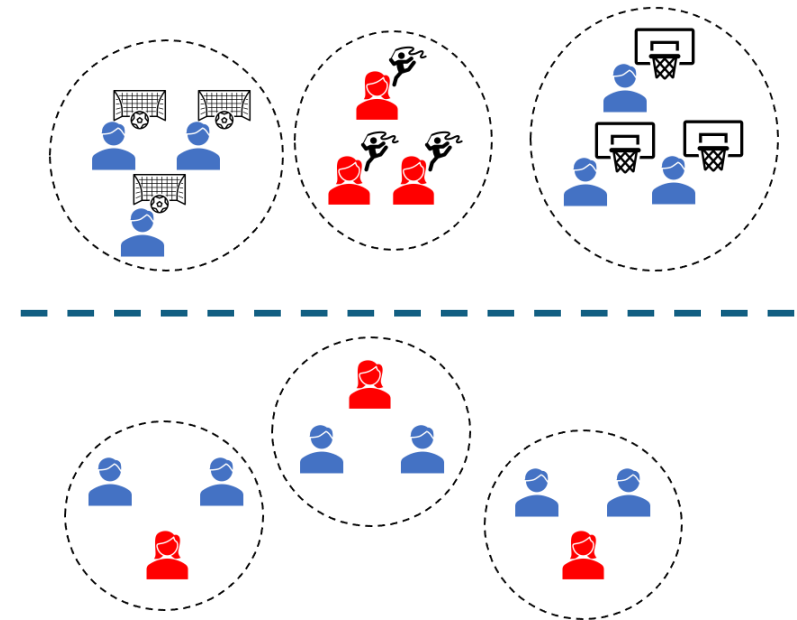
[1] Feldman, M., Friedler, S.A., Moeller, J., Scheidegger, C., Venkatasubramanian, S.: Certifying and removing disparate impact. In: Proc. ACM KDD Conf. pp. 259–268 (2015)



# The Fair Clustering Problem

Clustering a set of data objects s.t.:

- Similar objects are assigned to the same cluster, whereas dissimilar objects are assigned to different clusters
- Clusters should **not be dominated** by a specific type of **sensitive** data class (e.g., people having the same sex)



Can we tackle this problem through a *correlation clustering* framework?



## Min-Disagreement Correlation Clustering (Min-CC)

Given an undirected graph  $G = \langle V, E \rangle$  with vertex set  $V$  and edge set  $E \subseteq V \times V$ , and weights  $w_{uv}^+, w_{uv}^- \in \mathbf{R}_0^+$ , for all edges  $(u, v) \in E$ , find a clustering  $\mathcal{C}: V \rightarrow \mathbf{N}^+$  that minimizes:

$$\sum_{(u,v) \in E, \mathcal{C}(u) = \mathcal{C}(v)} w_{uv}^- + \sum_{(u,v) \in E, \mathcal{C}(u) \neq \mathcal{C}(v)} w_{uv}^+$$

where  $w_{uv}^+$ , resp.  $w_{uv}^-$ , denote the benefit of clustering  $u$  and  $v$  together, resp. separately.



## Fair Clustering - Input

Let  $\mathcal{X} = \{X_1, \dots, X_n\}$  be a set of  $n$  objects defined over a set of attributes  $\mathcal{A}$  divided into two sets:

- $\mathcal{A}^F$  containing *fairness-aware* (or *sensitive*) attributes (e.g., those identifying sex, race, religion, relationship status in a citizen database);
- $\mathcal{A}^{\neg F}$  containing *non-sensitive* attributes (e.g., user preferences).

Both can include numerical ( $N$ ) and categorical ( $C$ ) attributes:

$$\mathcal{A}^F = \mathcal{A}_N^F \cup \mathcal{A}_C^F \quad , \mathcal{A}^{\neg F} = \mathcal{A}_N^{\neg F} \cup \mathcal{A}_C^{\neg F}$$



## Problem Statement - Fair-CC

Given a set of objects  $\mathcal{X}$ , two sets of attributes  $\mathcal{A}^F$  and  $\mathcal{A}^{\neg F}$ , and an **object similarity function**  $sim_S(\cdot)$  defined over the subspace  $S$  of the attribute set, find a clustering  $\mathcal{C}^*$  to minimize:

$$\sum_{u,v \in \mathcal{X}, \mathcal{C}(u)=\mathcal{C}(v)} sim_{\mathcal{A}^F}(u,v) + \sum_{u,v \in \mathcal{X}, \mathcal{C}(u) \neq \mathcal{C}(v)} sim_{\mathcal{A}^{\neg F}}(u,v)$$

This corresponds to **solving a complete Min-CC instance**:

- The set of vertices corresponds to the objects in  $\mathcal{X}$  and,
- For each pair of vertices  $u$  and  $v$ , the positive-type (resp. negative-type) correlation-clustering weight corresponds to the similarity score between the two vertices according to the non-sensitive (resp. sensitive) attributes.





## Similarity Computation

$$sim_{\mathcal{A}^{\neg F}}(u, v) := \psi^+(\alpha_N^{\neg F} \cdot sim_{\mathcal{A}_N^{\neg F}}(u, v) + (1 - \alpha_N^{\neg F}) \cdot sim_{\mathcal{A}_C^{\neg F}}(u, v))$$

$$sim_{\mathcal{A}^F}(u, v) := \psi^-(\alpha_N^F \cdot sim_{\mathcal{A}_N^F}(u, v) + (1 - \alpha_N^F) \cdot sim_{\mathcal{A}_C^F}(u, v))$$

*Similarity according to  
the set of non-sensitive  
and sensitive attributes*

$$\alpha_N^F = |\mathcal{A}_N^F| / (|\mathcal{A}_N^F| + |\mathcal{A}_C^F|)$$

$$\alpha_N^{\neg F} = |\mathcal{A}_N^{\neg F}| / (|\mathcal{A}_N^{\neg F}| + |\mathcal{A}_C^{\neg F}|)$$

*Weight similarities  
proportionally to the number  
of involved attributes*

$$\psi^+ = \exp(|\mathcal{A}^F| / (|\mathcal{A}^F| + |\mathcal{A}^{\neg F}|) - 1)$$

$$\psi^- = \exp(|\mathcal{A}^{\neg F}| / (|\mathcal{A}^F| + |\mathcal{A}^{\neg F}|) - 1)$$

*Smoothing factors to penalize  
weights that are computed on  
a small number of attributes*



# The CC-Bound Algorithm

**Input:** Set of objects  $\mathcal{X}$ , sensitive attributes  $\mathcal{A}^F$ , non-sensitive attributes  $\mathcal{A}^{\neg F}$ , Min-CC algorithm A

**Output:** Clustering  $\mathcal{C}$  of  $\mathcal{X}$

1. Compute  $sim_{\mathcal{A}^{\neg F}}(u, v)$ ,  $sim_{\mathcal{A}^F}(u, v) \forall u, v \in \mathcal{X}$
2. Build the instance  $I = \langle G = (\mathcal{X}, \mathcal{X} \times \mathcal{X}), sim_{\mathcal{A}^{\neg F}}(u, v), sim_{\mathcal{A}^F}(u, v)_{(u, v \in \mathcal{X} \times \mathcal{X})} \rangle$
3.  $\mathcal{C} \leftarrow \text{run A on } I$

[2] Mandaglio, D., Tagarelli, A., Gullo, F.: Correlation clustering with global weight bounds. In: Proc. ECML-PKDD Conf. pp. 499–515 (2021)





## Complexity Remarks

Let  $T_A(\mathcal{X})$  the running time of the algorithm A on the set of data objects  $\mathcal{X}$ :

- The time complexity of CCBounds is  $\mathcal{O}(|\mathcal{X}|^2|\mathcal{A}| + T_A(\mathcal{X}))$ 
  - Compute similarities over  $\mathcal{A}$  attributes, for each pair of objects in  $\mathcal{X}$ , then solve the resulting Min-CC instance through A
- The space complexity of CC-Bounds is  $\mathcal{O}(|\mathcal{X}|^2)$ 
  - In-memory similarity storing

The Min-CC algorithm A used in CC-Bounds is the one proposed in [3], as it proposes **constant-factor approximation guarantees** (under certain conditions), s.t.  $T_A(\mathcal{X}) = \mathcal{O}(|\mathcal{X}|^2)$ .

✓ The time complexity of CCBounds become  $\mathcal{O}(|\mathcal{X}|^2|\mathcal{A}|)$ .

[3] Ailon, N., Charikar, M., Newman, A.: Aggregating inconsistent information: ranking and clustering. In: Proc. ACM STOC Symp. pp. 684–693 (2005)



# Approximation Guarantees

**Theorem [2].** If the global condition

$$\sum_{u,v \in \mathcal{X}} \binom{|\mathcal{X}|}{2}^{-1} (sim_{\mathcal{A}^{\neg F}}(u, v) + sim_{\mathcal{A}^F}(u, v)) \geq \max_{u,v \in \mathcal{X}} |sim_{\mathcal{A}^{\neg F}}(u, v) - sim_{\mathcal{A}^F}(u, v)|$$

holds on the similarity scores and the **oracle  $A$**  is an  **$\alpha$ -approximation** algorithm ( **$\alpha \geq 1$** ) for **Min-CC**, **CCBounds** is  **$\alpha$ -approximation** algorithm for **Fair-CC**.

[2] Mandaglio, D., Tagarelli, A., Gullo, F.: Correlation clustering with global weight bounds. In: Proc. ECML-PKDD Conf. pp. 499–515 (2021)



## Datasets

- Publicly available real-world relational datasets
- Focus on a smaller subset of the original attributes

	#objs.	<i>sensitive</i> attribute	<i>non-sensitive</i> attributes
<i>Adult</i>	48 842	sex	age, fnlgwt, education_num, capital_gain, hours_per_week
<i>Bank</i>	40 004	marital	age, balance, duration
<i>CreditCard</i>	10 127	sex	customer_age, dependent_count, avg_utilization_ratio, total_relationship_count
<i>Diabetes</i>	101 763	sex	age, time_in_hospital
<i>Student</i>	649	sex	age, study_time, absences



## Evaluation Criteria - Fairness

Focus on *algorithm-independent* evaluation metrics following a *group-level* approach under the *disparate impact* doctrine [4]

$$\text{balance}(\mathcal{C}) \stackrel{[5, 6]}{=} \min_{C \in \mathcal{C}, b \in [m]} \min\{R_{C,b}, \frac{1}{R_{C,b}}\} \in [0,1]$$

$$\text{AE}_A(\mathcal{C}) \stackrel{[7]}{=} \frac{\sum_{C \in \mathcal{C}} |C| \times \text{ED}(C_A, \mathcal{X}_A)}{\sum_{C \in \mathcal{C}} |C|}$$

[4] Feldman, M., Friedler, S.A., Moeller, J., Scheidegger, C., Venkatasubramanian, S.: Certifying and removing disparate impact. In: Proc. ACM KDD Conf. pp. 259–268 (2015)

[5] Chierichetti, F., Kumar, R., Lattanzi, S., Vassilvitskii, S.: Fair clustering through fairlets. In: Proc. NIPS Conf. pp. 5029–5037 (2017)

[6] Bera, S.K., Chakrabarty, D., Flores, N., Negahbani, M.: Fair algorithms for clustering. In: Proc. NIPS Conf. pp. 4955–4966 (2019)

[7] Abraham, S.S., P, D., Sundaram, S.S.: Fairness in clustering with multiple sensitive attributes. In: Proc. EDBT Conf. pp. 287–298 (2020)



## Evaluation Criteria - Similarity

$$inter(\mathcal{A}^{\neg F}) = \frac{1}{|\Theta|} \sum_{u,v \in \Theta} sim_{\mathcal{A}^{\neg F}}(u, v) \quad \Downarrow$$

$$inter(\mathcal{A}^F) = \frac{1}{|\Theta|} \sum_{u,v \in \Theta} sim_{\mathcal{A}^F}(u, v) \quad \Uparrow$$

$$intra(\mathcal{A}^{\neg F}) = \frac{1}{|\Omega|} \sum_{u,v \in \Omega} sim_{\mathcal{A}^{\neg F}}(u, v) \quad \Uparrow$$

$$intra(\mathcal{A}^F) = \frac{1}{|\Omega|} \sum_{u,v \in \Omega} sim_{\mathcal{A}^F}(u, v) \quad \Downarrow$$

$$\Omega = \{u, v \in \mathcal{X} | \mathcal{C}(u) = \mathcal{C}(v)\}, \quad \Theta = \{u, v \in \mathcal{X} | \mathcal{C}(u) \neq \mathcal{C}(v)\}$$



## Competing methods

- Fair Clustering through Fairlets [5] (FAIRLETS, in short)
- HST-based Fair Clustering [8] (HST-FC)
- Fair Correlation Clustering [9] (SIGNED)

Based on [fairlets decomposition](#) (direct or via correlation clustering)

The first two can just handle [a single sensitive attribute](#)

[5] Chierichetti, F., Kumar, R., Lattanzi, S., Vassilvitskii, S.: Fair clustering through fairlets. In: Proc. NIPS Conf. pp. 5029–5037 (2017)

[8] Backurs, A., Indyk, P., Onak, K., Schieber, B., Vakilian, A., Wagner, T.: Scalable fair clustering. In: Proc. ICML Conf. pp. 405–413 (2019)

[9] Ahmadian, S., Epasto, A., Kumar, R., Mahdian, M.: Fair correlation clustering. In: Proc. AISTATS Conf. pp. 4195–4205 (2020)





## Experimental Setting

- Random sampling of the original data: 1k/10k tuples which preserve some desired **ratio** between the protected classes
- Specification of **p** and **q** parameters for FAIRLETS and HST-FC methods:  $p/q$  represents the minimum balance required by each cluster
- Minimum shared requirements, e.g., single and binary sensitive attribute
- Number of clusters **k** as the (rounded) avg. number of clusters returned by CCBounds in ten iterations

	$p, q$	split ratio	$k_{avg}$	$k$
<i>Adult-1k</i>	1,2	650/350	3.12	3
<i>Bank-1k</i>	1,2	650/350	3.48	3
<i>Credit-Card-1k</i>	1,6	800/200	5.6	6
<i>Diabetes-1k</i>	1,2	540/460	5.2	5
<i>Student-1k</i>	1,2	266/383	3.88	4
<i>Adult-10k</i>	1,2	6 500/3 500	2.96	3
<i>Bank-10k</i>	1,2	6 500/3 500	3.28	3
<i>Credit-Card-10k</i>	1,6	4 769/5 358	6.32	6
<i>Diabetes-10k</i>	1,2	5 400/4 600	6.44	6
<i>Adult-Full</i>	2,5	32 650/16 192	3.64	4
<i>Bank-Full</i>	2,5	12 790/27 214	3.64	4
<i>Diabetes-Full</i>	1,2	47 055/54 708	OOM	6



## Results - Balance

		#clust.	balance $\uparrow$	AE $\downarrow$	$\text{intra}(\mathcal{A}^{-F}) \uparrow$	$\text{intra}(\mathcal{A}^F) \downarrow$	$\text{inter}(\mathcal{A}^{-F}) \downarrow$	$\text{inter}(\mathcal{A}^F) \uparrow$	time (s) $\downarrow$
Adult-1k	CCBounds	3.12	0.565	<b>0.007</b>	<b>0.685</b>	0.524	<b>0.415</b>	<b>0.334</b>	< 1
	FAIRLETS	3	0.805	<b>0.004</b>	0.585	<b>0.319</b>	0.596	<b>0.335</b>	< 1
	HST-FC	3	<b>0.971</b>	0.01	0.616	0.335	0.599	<b>0.336</b>	< 1
	SIGNED	41	0.66	0.03	0.59	<b>0.32</b>	0.60	<b>0.33</b>	240
Adult-10k	CCBounds	2.96	0.52	0.03	<b>0.65</b>	0.43	<b>0.43</b>	<b>0.33</b>	3.86
	FAIRLETS	3	0.82	<b>0.003</b>	0.60	<b>0.32</b>	0.615	<b>0.33</b>	< 1
	HST-FC	3	<b>0.98</b>	<b>0.006</b>	0.626	0.336	0.618	<b>0.336</b>	3.03
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Adult-Full	CCBounds	3.64	0.56	<b>0.003</b>	<b>0.69</b>	0.47	<b>0.42</b>	0.24	75.5
	FAIRLETS	4	0.66	0.02	0.59	<b>0.32</b>	0.62	<b>0.34</b>	<b>6.5</b>
	HST-FC	4	<b>0.96</b>	<b>0.008</b>	0.63	0.34	0.62	<b>0.34</b>	72.86
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Bank-1k	CCBounds	3.48	0.565	<b>0.006</b>	<b>0.727</b>	0.587	<b>0.441</b>	<b>0.369</b>	< 1
	FAIRLETS	3	0.828	<b>0.002</b>	0.606	<b>0.354</b>	0.613	<b>0.364</b>	< 1
	HST-FC	3	<b>0.968</b>	<b>0.007</b>	0.621	0.365	0.617	<b>0.365</b>	< 1
	SIGNED	41	0.7	0.03	0.61	<b>0.35</b>	0.63	<b>0.36</b>	224
Bank-10k	CCBounds	3.28	0.52	<b>0.0007</b>	<b>0.78</b>	0.63	<b>0.45</b>	<b>0.36</b>	4.74
	FAIRLETS	3	0.7	0.001	0.59	<b>0.32</b>	0.63	<b>0.36</b>	< 1
	HST-FC	3	<b>0.969</b>	0.004	0.656	0.365	0.656	<b>0.365</b>	3.07
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Bank-Full	CCBounds	3.64	0.55	<b>0.0004</b>	<b>0.72</b>	0.55	<b>0.45</b>	<b>0.37</b>	51.1
	FAIRLETS	4	0.68	0.001	0.62	<b>0.34</b>	0.65	0.36	<b>5.3</b>
	HST-FC	4	<b>0.94</b>	0.008	0.66	0.37	0.66	<b>0.37</b>	28
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h

- “Fairness-native” methods yield better balance scores
- CCBounds is aligned with its direct competing method in most cases
- On small yet heavily unbalanced datasets (i.e., CreditCard-1k with an 80:20 ratio), CCBounds achieves the second-best score, while other competing methods struggle
- Overall, the balance obtained by CCBounds in all evaluation scenarios ranges from 0.45 to 0.613



## Results - Balance

		#clust.	balance $\uparrow$	AE $\downarrow$	$\text{intra}(\mathcal{A}^{-F}) \uparrow$	$\text{intra}(\mathcal{A}^F) \downarrow$	$\text{inter}(\mathcal{A}^{-F}) \downarrow$	$\text{inter}(\mathcal{A}^F) \uparrow$	time (s) $\downarrow$
CreditCard-1k	CCBounds	5.6	0.613	0.127	<b>0.6</b>	0.497	<b>0.46</b>	0.362	< 1
	FAIRLETS	6	0.4	0.042	0.485	<b>0.355</b>	0.486	<b>0.375</b>	< 1
	HST-FC	6	<b>0.756</b>	<b>0.026</b>	0.513	0.373	0.481	<b>0.377</b>	< 1
	SIGNED	171	0.56	0.1	0.56	0.41	0.49	<b>0.38</b>	173
CreditCard-10k	CCBounds	6.32	0.496	0.17	<b>0.6</b>	0.46	<b>0.46</b>	0.32	4.1
	FAIRLETS	6	0.94	<b>0.01</b>	0.497	<b>0.34</b>	0.49	<b>0.337</b>	< 1
	HST-FC	6	<b>0.955</b>	<b>0.013</b>	0.52	<b>0.337</b>	0.491	<b>0.337</b>	2.52
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Diabetes-1k	CCBounds	5.2	0.45	0.33	<b>0.622</b>	0.519	<b>0.512</b>	0.352	< 1
	FAIRLETS	5	<b>0.92</b>	<b>0.015</b>	0.537	0.381	0.532	<b>0.385</b>	< 1
	HST-FC	5	0.872	0.05	0.585	0.386	0.529	<b>0.386</b>	< 1
	SIGNED	106	0.85	0.04	0.58	<b>0.36</b>	0.54	<b>0.38</b>	257
Diabetes-10k	CCBounds	6.44	0.48	0.22	<b>0.65</b>	0.54	<b>0.5</b>	0.36	4.72
	FAIRLETS	6	<b>0.92</b>	<b>0.01</b>	0.53	<b>0.38</b>	<b>0.53</b>	<b>0.39</b>	< 1
	HST-FC	6	0.799	0.065	0.59	<b>0.388</b>	<b>0.53</b>	<b>0.386</b>	2.84
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Diabetes-Full	CCBounds	OOM	OOM	OOM	OOM	OOM	OOM	OOM	OOM
	FAIRLETS	6	<b>0.93</b>	<b>0.01</b>	OOM	OOM	OOM	OOM	<b>22.2</b>
	HST-FC	6	0.81	0.06	OOM	OOM	OOM	OOM	761.2
	SIGNED	OOM	OOM	OOM	OOM	OOM	OOM	OOM	OOM
Student-1k	CCBounds	3.88	0.51	0.10	<b>0.625</b>	0.463	<b>0.471</b>	0.224	< 1
	FAIRLETS	4	0.82	<b>0.013</b>	0.528	<b>0.339</b>	0.543	<b>0.357</b>	< 1
	HST-FC	4	<b>0.93</b>	0.024	0.563	0.357	0.541	<b>0.358</b>	< 1
	SIGNED	55	0.82	0.04	0.57	<b>0.34</b>	0.55	<b>0.36</b>	71

- “Fairness-native” methods yield better balance scores
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- Overall, the balance obtained by CCBounds in all evaluation scenarios ranges from 0.45 to 0.613



## Results - Average Euclidean Fairness (AE)

		#clust.	balance ↑	AE ↓	$\text{intra}(\mathcal{A}^{-F}) \uparrow$	$\text{intra}(\mathcal{A}^F) \downarrow$	$\text{inter}(\mathcal{A}^{-F}) \downarrow$	$\text{inter}(\mathcal{A}^F) \uparrow$	time (s) ↓
Adult-1k	CCBounds	3.12	0.565	<b>0.007</b>	<b>0.685</b>	0.524	<b>0.415</b>	<b>0.334</b>	< 1
	FAIRLETS	3	0.805	<b>0.004</b>	0.585	<b>0.319</b>	0.596	<b>0.335</b>	< 1
	HST-FC	3	<b>0.971</b>	0.01	0.616	0.335	0.599	<b>0.336</b>	< 1
	SIGNED	41	0.66	0.03	0.59	<b>0.32</b>	0.60	<b>0.33</b>	240
Adult-10k	CCBounds	2.96	0.52	0.03	<b>0.65</b>	0.43	<b>0.43</b>	<b>0.33</b>	3.86
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	FAIRLETS	3	0.828	<b>0.002</b>	0.606	<b>0.354</b>	0.613	<b>0.364</b>	< 1
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	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h

- CCBounds obtains very good scores under different scenarios
- Among the best-performing approaches for the Adult-1k, Adult-Full and Bank-1k datasets
- Outperforms all the other methods by an order of magnitude on Bank-10k and Bank-Full
- Performances worsen while considering the remaining datasets



## Results - Average Euclidean Fairness (AE)

		#clust.	balance ↑	AE ↓	$\text{intra}(\mathcal{A}^{-F}) \uparrow$	$\text{intra}(\mathcal{A}^F) \downarrow$	$\text{inter}(\mathcal{A}^{-F}) \downarrow$	$\text{inter}(\mathcal{A}^F) \uparrow$	time (s) ↓
CreditCard-1k	CCBounds	5.6	0.613	0.127	<b>0.6</b>	0.497	<b>0.46</b>	0.362	< 1
	FAIRLETS	6	0.4	0.042	0.485	<b>0.355</b>	0.486	<b>0.375</b>	< 1
	HST-FC	6	<b>0.756</b>	<b>0.026</b>	0.513	0.373	0.481	<b>0.377</b>	< 1
	SIGNED	171	0.56	0.1	0.56	0.41	0.49	<b>0.38</b>	173
CreditCard-10k	CCBounds	6.32	0.496	0.17	<b>0.6</b>	0.46	<b>0.46</b>	0.32	4.1
	FAIRLETS	6	0.94	<b>0.01</b>	0.497	<b>0.34</b>	0.49	<b>0.337</b>	< 1
	HST-FC	6	<b>0.955</b>	<b>0.013</b>	0.52	<b>0.337</b>	0.491	<b>0.337</b>	2.52
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Diabetes-1k	CCBounds	5.2	0.45	0.33	<b>0.622</b>	0.519	<b>0.512</b>	0.352	< 1
	FAIRLETS	5	<b>0.92</b>	<b>0.015</b>	0.537	0.381	0.532	<b>0.385</b>	< 1
	HST-FC	5	0.872	0.05	0.585	0.386	0.529	<b>0.386</b>	< 1
	SIGNED	106	0.85	0.04	0.58	<b>0.36</b>	0.54	<b>0.38</b>	257
Diabetes-10k	CCBounds	6.44	0.48	0.22	<b>0.65</b>	0.54	<b>0.5</b>	0.36	4.72
	FAIRLETS	6	<b>0.92</b>	<b>0.01</b>	0.53	<b>0.38</b>	<b>0.53</b>	<b>0.39</b>	< 1
	HST-FC	6	0.799	0.065	0.59	<b>0.388</b>	<b>0.53</b>	<b>0.386</b>	2.84
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Diabetes-Full	CCBounds	OOM	OOM	OOM	OOM	OOM	OOM	OOM	OOM
	FAIRLETS	6	<b>0.93</b>	<b>0.01</b>	OOM	OOM	OOM	OOM	<b>22.2</b>
	HST-FC	6	0.81	0.06	OOM	OOM	OOM	OOM	761.2
	SIGNED	OOM	OOM	OOM	OOM	OOM	OOM	OOM	OOM
Student-1k	CCBounds	3.88	0.51	0.10	<b>0.625</b>	0.463	<b>0.471</b>	0.224	< 1
	FAIRLETS	4	0.82	<b>0.013</b>	0.528	<b>0.339</b>	0.543	<b>0.357</b>	< 1
	HST-FC	4	<b>0.93</b>	0.024	0.563	0.357	0.541	<b>0.358</b>	< 1
	SIGNED	55	0.82	0.04	0.57	<b>0.34</b>	0.55	<b>0.36</b>	71

- CCBounds obtains very good scores under different scenarios
- Among the best-performing approaches for the Adult-1k, Adult-Full and Bank-1k datasets
- Outperforms all the other methods by an order of magnitude on Bank-10k and Bank-Full
- Performances worsen while considering the remaining datasets





## Results – Similarity Scores

		#clust.	balance ↑	AE ↓	$\text{intra}(\mathcal{A}^{-F}) \uparrow$	$\text{intra}(\mathcal{A}^F) \downarrow$	$\text{inter}(\mathcal{A}^{-F}) \downarrow$	$\text{inter}(\mathcal{A}^F) \uparrow$	time (s) ↓
Adult-1k	CCBounds	3.12	0.565	<b>0.007</b>	<b>0.685</b>	0.524	<b>0.415</b>	<b>0.334</b>	< 1
	FAIRLETS	3	0.805	<b>0.004</b>	0.585	<b>0.319</b>	0.596	<b>0.335</b>	< 1
	HST-FC	3	<b>0.971</b>	0.01	0.616	0.335	0.599	<b>0.336</b>	< 1
	SIGNED	41	0.66	0.03	0.59	<b>0.32</b>	0.60	<b>0.33</b>	240
Adult-10k	CCBounds	2.96	0.52	0.03	<b>0.65</b>	0.43	<b>0.43</b>	<b>0.33</b>	3.86
	FAIRLETS	3	0.82	<b>0.003</b>	0.60	<b>0.32</b>	0.615	<b>0.33</b>	< 1
	HST-FC	3	<b>0.98</b>	<b>0.006</b>	0.626	0.336	0.618	<b>0.336</b>	3.03
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Adult-Full	CCBounds	3.64	0.56	<b>0.003</b>	<b>0.69</b>	0.47	<b>0.42</b>	0.24	75.5
	FAIRLETS	4	0.66	0.02	0.59	<b>0.32</b>	0.62	<b>0.34</b>	<b>6.5</b>
	HST-FC	4	<b>0.96</b>	<b>0.008</b>	0.63	0.34	0.62	<b>0.34</b>	72.86
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Bank-1k	CCBounds	3.48	0.565	<b>0.006</b>	<b>0.727</b>	0.587	<b>0.441</b>	<b>0.369</b>	< 1
	FAIRLETS	3	0.828	<b>0.002</b>	0.606	<b>0.354</b>	0.613	<b>0.364</b>	< 1
	HST-FC	3	<b>0.968</b>	<b>0.007</b>	0.621	0.365	0.617	<b>0.365</b>	< 1
	SIGNED	41	0.7	0.03	0.61	<b>0.35</b>	0.63	<b>0.36</b>	224
Bank-10k	CCBounds	3.28	0.52	<b>0.0007</b>	<b>0.78</b>	0.63	<b>0.45</b>	<b>0.36</b>	4.74
	FAIRLETS	3	0.7	0.001	0.59	<b>0.32</b>	0.63	<b>0.36</b>	< 1
	HST-FC	3	<b>0.969</b>	0.004	0.656	0.365	0.656	<b>0.365</b>	3.07
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h
Bank-Full	CCBounds	3.64	0.55	<b>0.0004</b>	<b>0.72</b>	0.55	<b>0.45</b>	<b>0.37</b>	51.1
	FAIRLETS	4	0.68	0.001	0.62	<b>0.34</b>	0.65	0.36	<b>5.3</b>
	HST-FC	4	<b>0.94</b>	0.008	0.66	0.37	0.66	<b>0.37</b>	28
	SIGNED	NA	NA	NA	NA	NA	NA	NA	> 48h

- On the sensitive attributes, CCBounds tends to group a few more objects with the same sensitive attribute value than the other methods
- CCBounds is still able to properly separate the objects into clusters, when accounting for the sensitive attribute
- CCBounds achieves the best performance in all the considered evaluation scenarios when considering non-sensitive attributes





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## Results – Running Times

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- FAIRLETS, HST-FC and CCBounds guarantee reasonable running times
- CCBounds overcomes its direct competing method SIGNED
- Parallelized pairwise similarity computation
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## Results – Running Times

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## Conclusions & Future Work

### Conclusions:

- We assessed how **correlation clustering** can handle **fair clustering**
- **Experimental evidence** that CCBounds may serve as a **good trade-off** between the traditional and fairness-aware clustering settings

### Future Work:

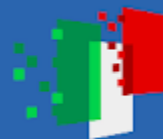
- Alternative definitions of the **similarity functions**
- **Generalization** of CCBounds to
  - Multiple protected values
  - Multiple sensitive attributes with many values



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DI RIPRESA E RESILIENZA



Future  
Artificial  
Intelligence  
Research

# Thank you!

## Questions?



Green-Aware AI 2025

