Unsteady Flow Visualization via Physics based Pathline Exploration – Supplemental Document

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Abstract

In this supplemental document, we provide the comparison between our proposed EDM with Euclidean and Pearson distance metrics. We also describe the modified edge bundling visualization and the new 2D stacked plots for the visualization of the TAC clustering results.

1 EDM vs Traditional Distance Metrics

Figure 1 (left column of (a) and (b)) illustrates the limitations of Euclidean distance and Pearson correlation coefficient in characterizing the difference in a number of representative TACs. The Euclidean distance separates TACs based on their magnitude differences and the Pearson correlation concentrates on the trends. As EDM takes both the temporal trends and magnitude of TACs into account, it can differentiates the behavior of TACs more accurately (i.e. rigth column of (a) and (b)).

2 Modified Edge Bundling

Traditionally, visualizing clusters is achieved by assigning each cluster a specific color. However, showing all TACs with colors assigned based on their cluster IDs will result in clutter, making it difficult to recognize the behavior encoded in TACs as demonstrated in Figure 2(a). To address this issue, we adapt the edge bundling technique for parallel coordinate plot (PCP) visualization developed by Palmas, et al [1]. Given a cluster of TACs, the average (cyan curve) and boundary TACs (dotted red curves) are first derived (Figure 2(b)). Then we offset the two boundaries towards the centroid. The offset operation does not change the overall behavior of the TACs in the cluster, while the range of the cluster, i.e., the coverage of the attribute values at the two ends of TACs t_s and t_e is changed. To preserve the coverage information of the cluster, we create a head and a tail for the edge-bundling by keeping the maximum and minimum of the attribute values at the two ends (Figure 2(c)). After we apply the edge-bundling method, the clusters in Figure 2(a) are shown as Figure 2(d), which greatly reduces the clutter.

To ensure the color consistency for the temporal clustering visualization of TACs, we assign a color to a cluster C_p based on its *main source cluster*, i.e., the cluster from which most TACs in C_p originate in the previous time interval. For example, in Figure 3(a), cluster C_1 in T_1 is the main source of cluster C_2 in T_2. Thus, the color of C_2 in T_2 will be set in a manner consistent with C_1 in T_1 (Figure 3(b)).

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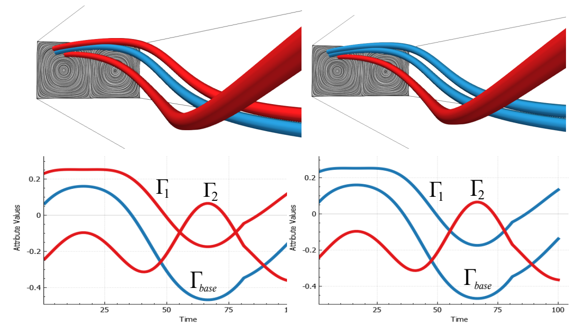
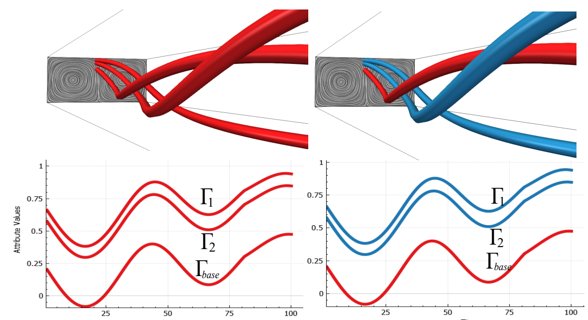


(a) Euclidean (left) vs EDM (right)



(b) Pearson correlation (left) vs EDM (right)

Figure 1: Comparison of EDM and (a) Euclidean and (b) Pearson correlation, respectively. The TACs are computed based on the λ_2 attribute on the Double Gyre simulation. Colors represent clusters. In both cases, the difference of TACs cannot be accurately measured by Euclidean distance or Pearson correlation (left column). (a) $D_e(\Gamma_{base},\Gamma_1) = 42.32 > D_e(\Gamma_{base},\Gamma_2) = 38.87$, using the Euclidean distance. (b) $D_p(\Gamma_1,\Gamma_2) = D_p(\Gamma_2,\Gamma_{base}) = 1$ using Pearson correlation, resulting in all of them belonging to the same group. EDM can differentiate the behavior of TACs more accurately in both cases (right column): (a) $D_{edm}(\Gamma_{base},\Gamma_1) = 62.32 < D_{edm}(\Gamma_{base},\Gamma_2) = 77.74$ (b) $D_{edm}(\Gamma_1,\Gamma_2) = 25.32 < D_{edm}(\Gamma_2,\Gamma_{base}) = 52.64$.

Visual overlapping persists at two ends of edge bundle as shown in Figure 3(c). To address this limitation, we offset proportionally to clusters' size, whose heads or tails are overlapping. As illustrated by the red arrow in Figure 3(d), the minimum value of C_2 at the tail end is increased and the maximum value of C_3 at the tail end is decreased, eliminating the overlapping between C_2 and C_3 while preserving the relative range size simultaneously. Removing overlapping at the tail of T_{k-1} makes the boundaries of source clusters clear. To fully resolve the connections among time intervals, we visualize both main and minor sources at the head of a cluster. From Figure 3(d), we can easily ascertain the transition of clusters between two time intervals.

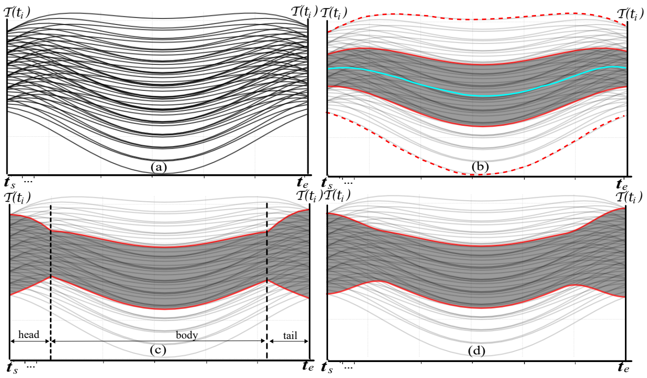


Figure 2: Illustration of edge-bundling method for TACs cluster visualization. (a) individual TACs, (b) edge-bundling rendering of a group of TACs by thinning toward the representative TAC, (c) preservation of the range of a group of TACs by adding head and tail segments, (d) the final result.

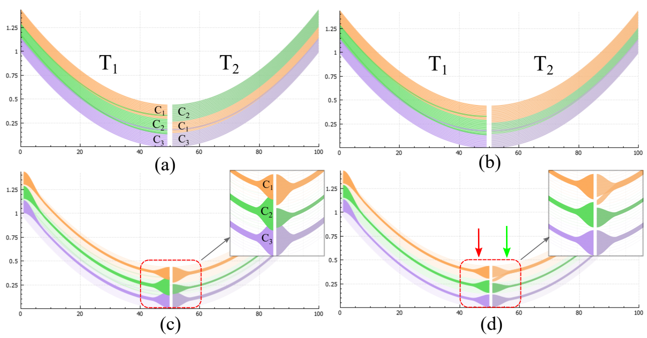


Figure 3: Visualization of transition between time intervals. Results before (a) and after (b) cluster ID adjustment, respectively. (c) edge-bundling visualization of the result. (d) modified edge-bundling visualization. Magnified views show the transition between two time intervals.

2.1 2D Stacked Plot for Visualizing TAC Clusters

Although edge-bundling visualization is an effective way to provide an overview about a group of TACs , the detailed behavior of individual TACs and the difference between TACs in the group is not conveyed effectively (see the cyan TAC cluster shown in Figure 4(b)). To address this, we visualize each TAC using a 1D bar, whose colors are determined by attribute values of the TAC over time. We then stack these 1D color plots to form a 2D color plot (Figure 4(c)). Note that TACs belonging to the same cluster are rendered next to each other. With this condense representation, one can easily assess the clustering quality. That is, if the color in this 2D plot is smooth, it means that the neighboring TACs have similar characteristics, indicating a good clustering result. The distance between two neighboring TACs is also converted to the 1D color bar to create the gradient plot. If neighboring TACs have similar patterns, the gradient between them is small, then the plot exhibits mostly uniform color.

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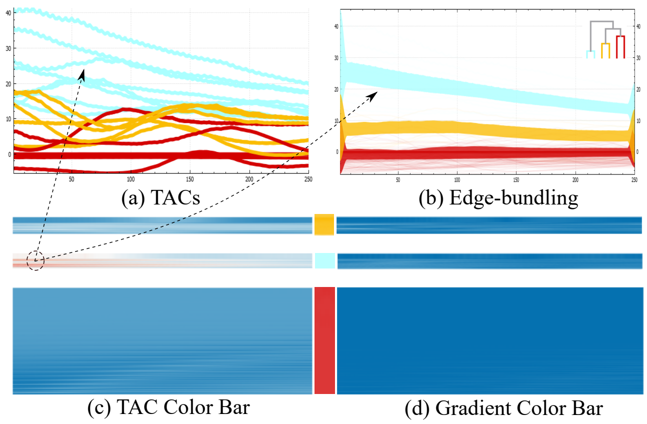

Figure 4: The visual comparison of edge-bundling with 1D TAC color plot. (a) Actual TACs exhibit occlusion. (b) Edge-bundling visualization provides an overview of each group of TACs. (c) The smooth 1D stacked color plot means that the TACs are grouped effectively. (d) The uniform blue color in the gradient color plot indicates the similarity among neighboring TACs in each cluster.

REFERENCES

[1] G. Palmas, M. Bachynskyi, A. Oulasvirta, H. P. Seidel, and T. Weinkauf. An edge-bundling layout for interactive parallel coordinates. In *Visualization Symposium (PacificVis), 2014 IEEE Pacific*, pp. 57–64. IEEE, 2014.