1. **Single causal graph**

**Design requirements:**

1. Able to present **large causal graphs**, nodes and directed edges—computational efficiency;
2. Show how a factor affects an outcome, **quantitatively** **estimate** the influence of each dimension;
3. Show the **uncertainty** (by computing the value of OIN/OCF (d), mentioned in step 3 below) of the detected causal relations (computed in step 2) [refer to doi: [10.1109/TVCG.2021.3114779](https://doi.org/10.1109/TVCG.2021.3114779) ] to support identification of **spurious causalities**;
4. Incorporate **human knowledge** in the causal model refinement;
5. Provide **diagnostic measures on model quality** [refer to 10.1109/TVCG.2020.3030465 ];
6. Support **real-time graph update**.

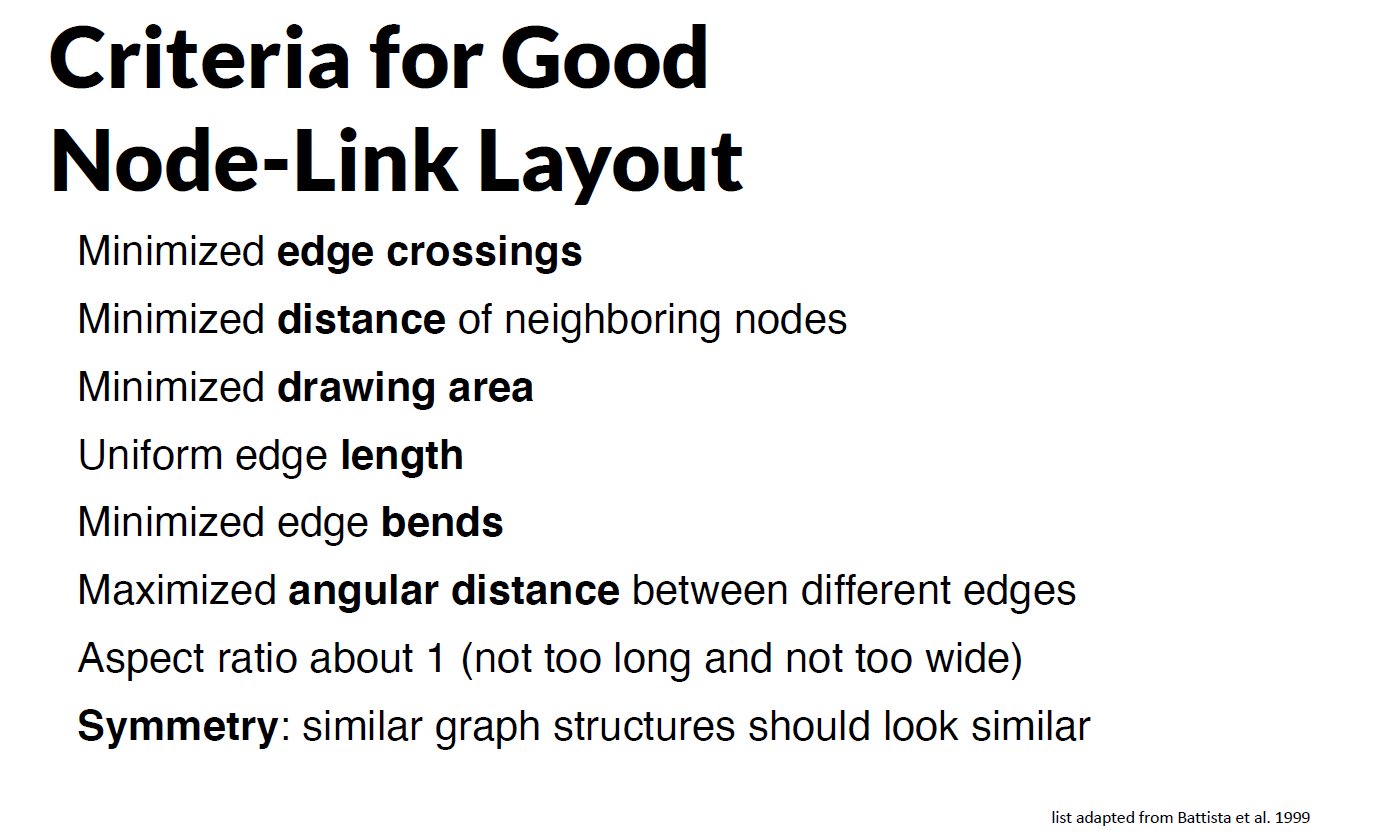
**1. Measure how strongly a feature is associated with the chosen outcome**

* Both numerical: Pearson Correlation Coefficient
* Categorical and numerical: multiple regression R2
* Both categorical: Cramer’s V

Select the top n highly relative features and show the distributions of the selected features.

**2. Causal discovery algorithm (PC or F-GES) to draw a graph**

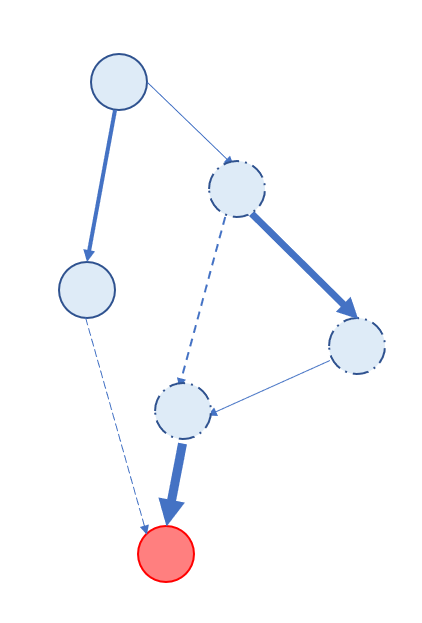
**2.1 Graph layout**



We adapt existing layered **graph layouts** [4] and techniques for reducing edge-crossings [19] to the causal graph visualization. 【X. Xie, F. Du and Y. Wu, "A Visual Analytics Approach for Exploratory Causal Analysis: Exploration, Validation, and Applications," in IEEE Transactions on Visualization and Computer Graphics, vol. 27, no. 2, pp. 1448-1458, Feb. 2021, doi: 10.1109/TVCG.2020.3028957.】

**2.2 Map:**

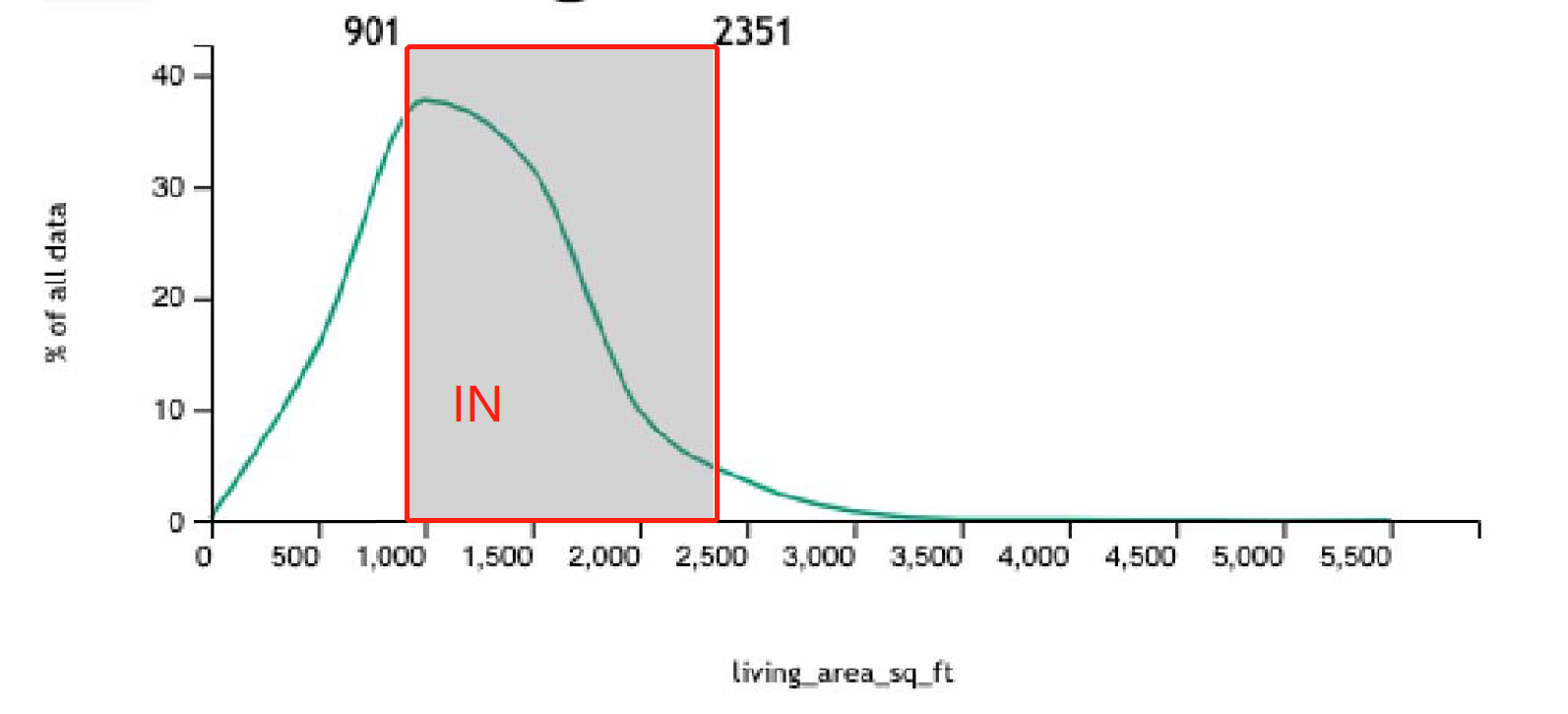
1. variable + label: node
   1. variable type: solid node (numerical), dashed node (categorical)
2. causal direction: direction of edge arrow
3. causal effect size（**only counts those with edges**）: edge weight
   1. positive effect size: solid edge
   2. negative effect size: dashed edge
4. Outcome is highlighted.

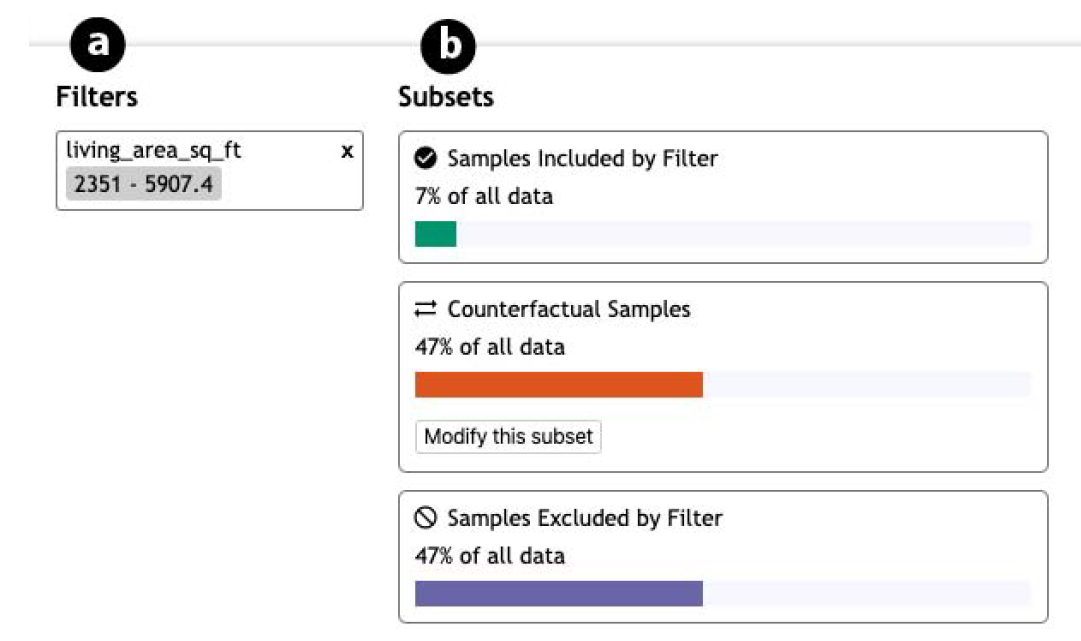


**3. counterfactual approach to identify potential confounding**

***[ S. Kaul, D. Borland, N. Cao and D. Gotz, "Improving Visualization Interpretation Using Counterfactuals," in*IEEE Transactions on Visualization and Computer Graphics*, vol. 28, no. 1, pp. 998-1008, Jan. 2022, doi: 10.1109/TVCG.2021.3114779.]***

* Applying a filter constraint (f) based on one of the features selected in step 1 and create three subsets----the included subset (IN)、counterfactual subset (CF)、excluded subset (EX)





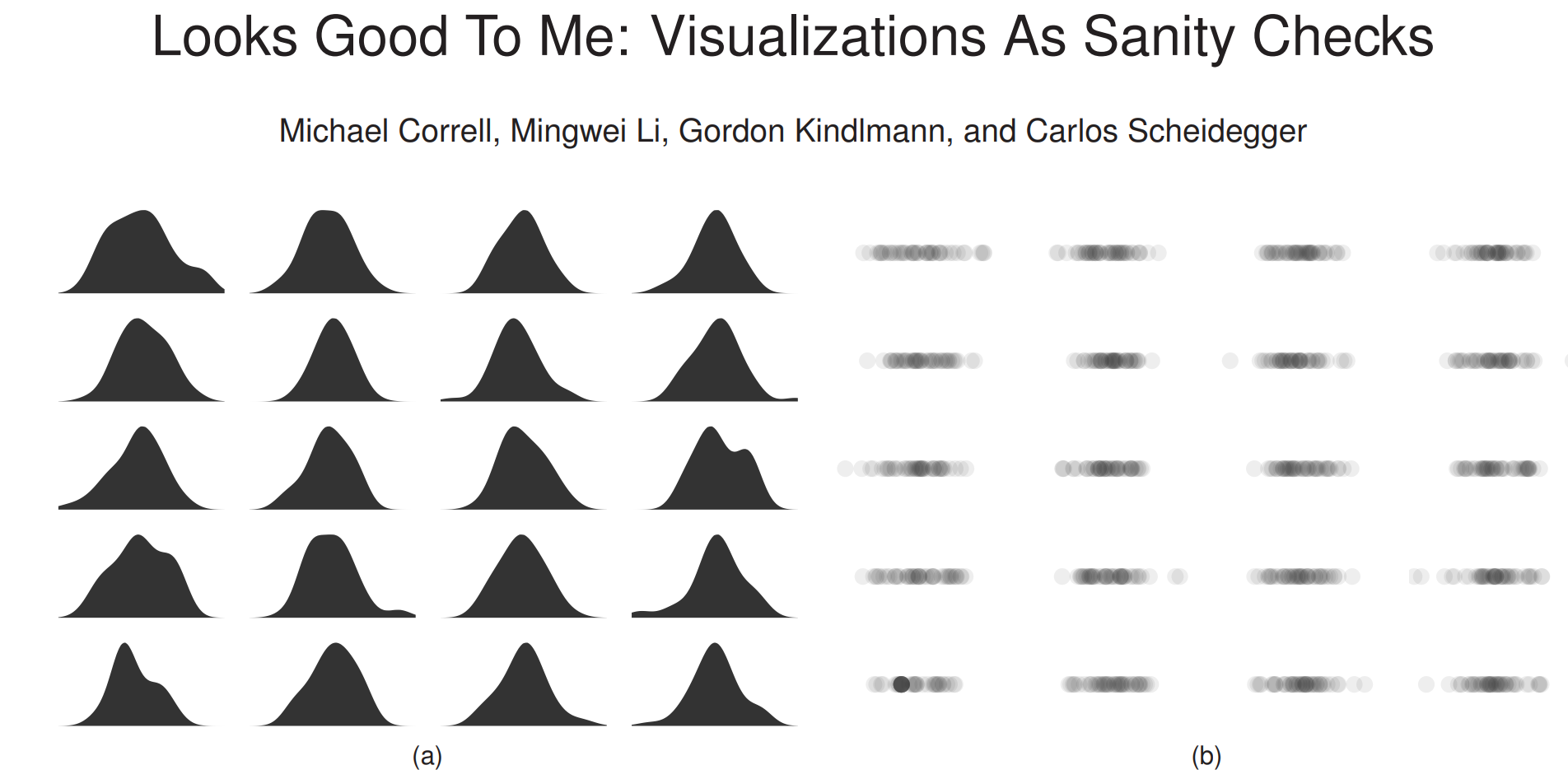
* Observe impact on the **target node** distributions of the IN, CF, and EX subsets of the **start node** ---- OIN, OCF, OEX

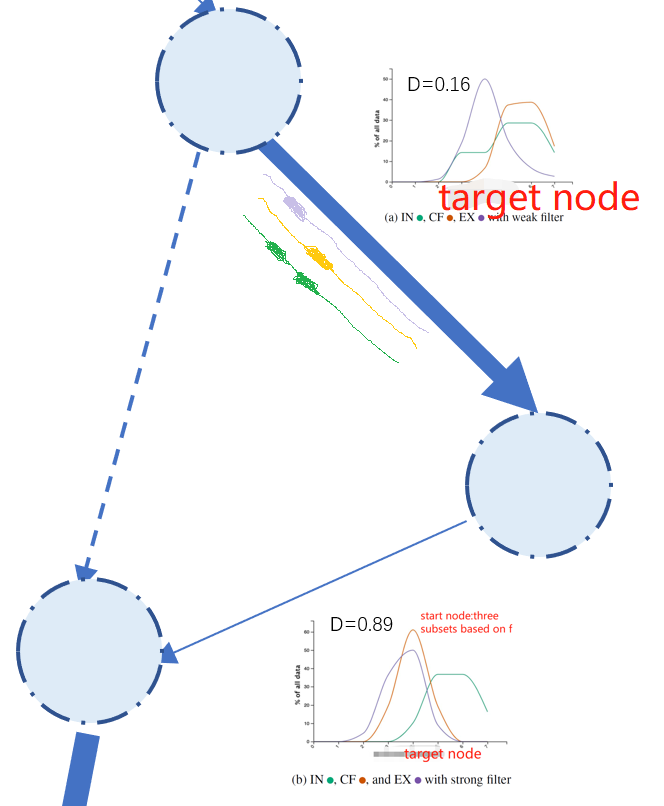
Compute the value of OIN/OCF (d) to measure the difference between OIN and OCF,

the **Hellinger distance** [62] is used for categorical outcomes and the **Kolmogorov-Smirnov test** [45] for numerical outcomes

D ranks between 0-1, **0 corresponds to no impact by f (i.e., OIN = OCF) [likely to be a confounding variable]** and 1 corresponds to a large impact (i.e., a maximal difference between OIN and OCF).

Example lineups refer to 10.1109/TVCG.2018.2864907





For **every edge**, there should be three density lines of all subsets (IN, CF, EX) and a distribution plot containing three subsets, illustrating the end node’s distribution based on the start node’s filter, respectively. Also, a directed weighted line illustrates the causal effect and direction.

**4. manually delete edges based on domain knowledge and potential confounding detected in step 3**

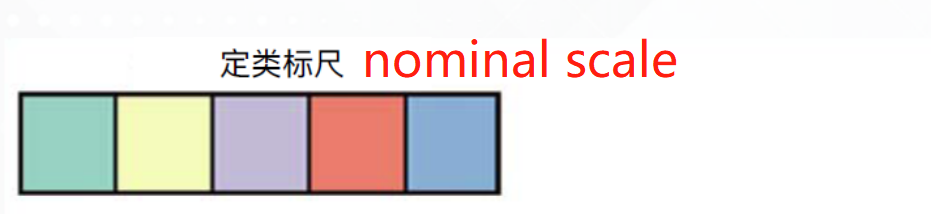
supporting real-time update → save specific single graph to history

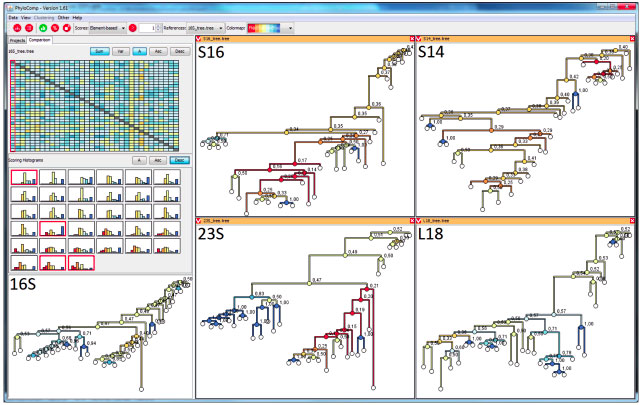
1. **Multiple causal graphs**

**Design requirements:**

Allow **comparison** of causalities for different outcome groups;

Clearly **distinguish between** multiple groups (color);

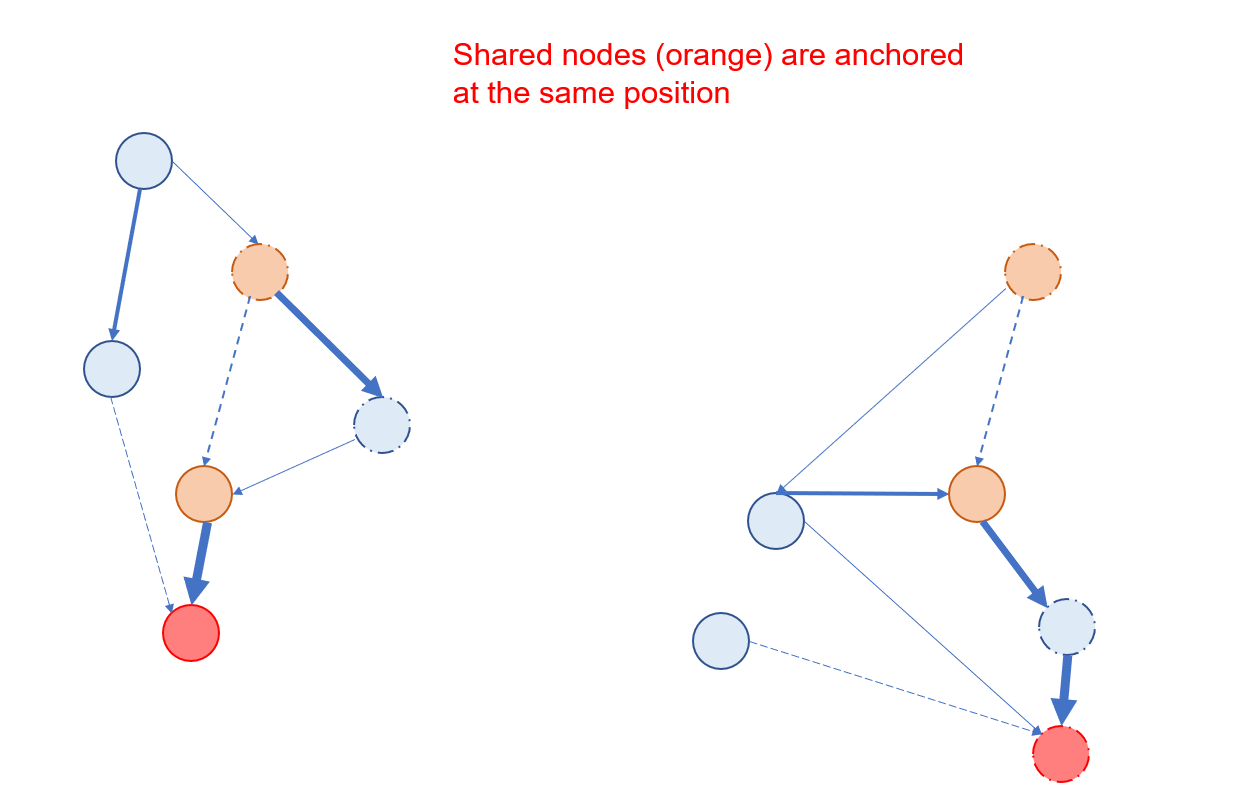




Use the **matrix** as an **overview diagram** to list the similarities between any two graphs, thus helping the user select a portion of the graph for comparison.

**method 1:**

juxtaposition ---- anchor and highlight the same nodes in different groups.



**method 2:** merge same nodes

