

Network: relationships between objects

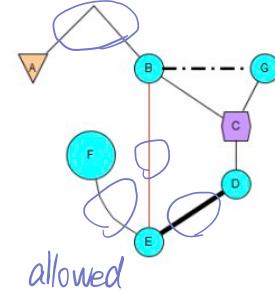
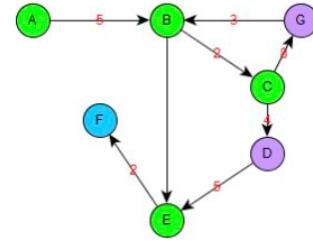
Graph: edges between nodes

structure

directed
undirected
bi-directed 双向

- Graph have **nodes** (vertices) and **edges**
- Edges can be **directed** or **undirected**
- The **degree** of a node: number of connecting edges
- For directed graphs (or 'digraphs')
 - **in-degree**: number of incoming edges
 - **out-degree**: number of outgoing edges
- Directed graphs can have **cycles**
- Edges can have **attributes** (particularly numerical **weights**)
- Nodes can have **attributes**
- **Trees** are graphs with a hierarchical structure
分层
- **Graph drawing**: placing the nodes on the plane
- **Graph visualisation**: providing interactive features for exploring the graph
- **Graph visual encoding**:
 - nodes: shape, colour, size
 - edges: straight/curved/polyline, colour, thickness, texture

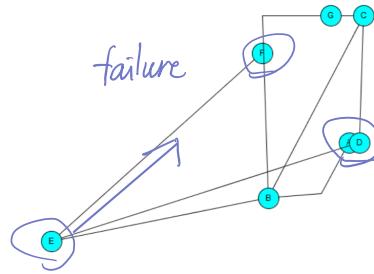
many approaches, just choose the best



Graph drawing aesthetics/ principles

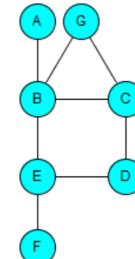
- **Reduce**

- node overlap
- node/edge overlap
- edge crossings
- total area
- edge lengths: maximum, variance, total
- edge bends: number

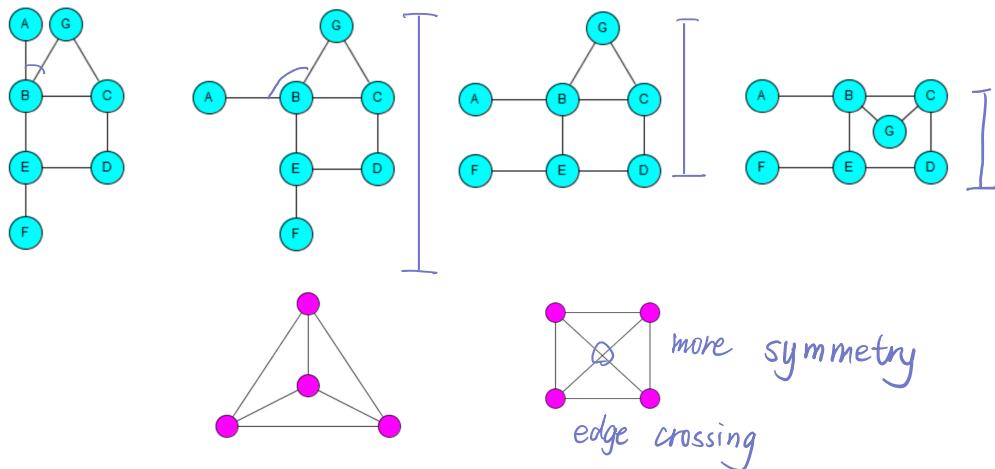


- **Increase**

- depiction of symmetry
- minimum angle at nodes



Aesthetic conflicts



Conforming to aesthetic criteria can also be computationally expensive
Thus: aesthetics can only be *heuristic guidelines*, not mandatory requirements

启发

强制

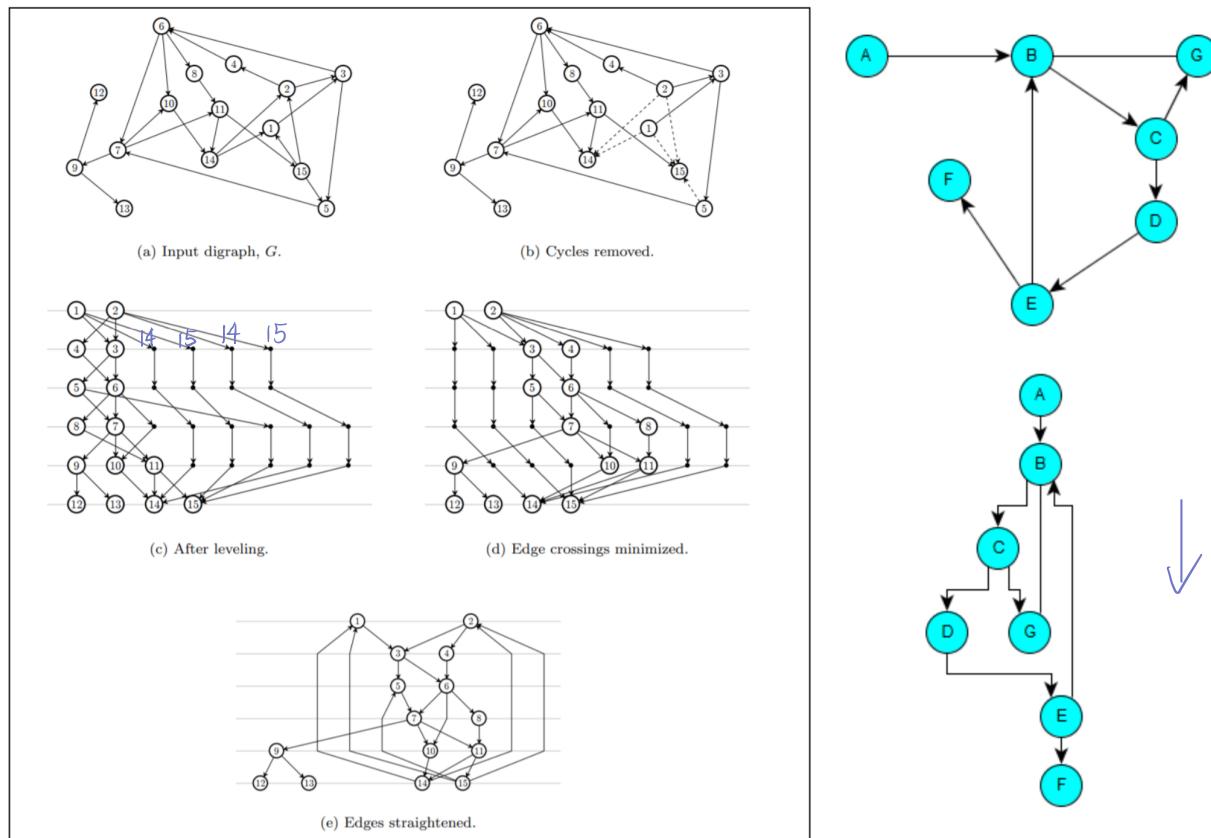
Types of graph

- **Directed Acyclic:** directed edges, no cycles
- **Planar:** can be drawn with no edge crossings
- **General graphs:** no assumptions
- **Trees:** strict hierarchy

Directed Acyclic graphs

K. Sugiyama, S. Tagawa and M. Toda, Methods for Visual Understanding of Hierarchical System Structures, in IEEE Transactions on Systems, Man, and Cybernetics, 11(2):109-125, Feb. 1981.

1. If the graph has cycles, reverse the direction so that the cycles are removed
 - (remember which ones; you will need to re-reverse the direction at the end)
2. Assign nodes to vertical layers
 - create dummy nodes so that each edge only traverses one layer
 - directed edges go from one layer to the next
3. Order the nodes horizontally within each layer to minimise crossings
4. Move the nodes horizontally within each layer to straighten edges
5. Re-reverse the direction of the edges changed in step 1



Planar graphs

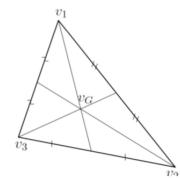
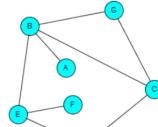
most popular

Tutte, W. T. (1963), *How to Draw a Graph*. Proceedings of the London Mathematical Society, s3-13: 743–767

Drawing a “3-connected” planar graph with no edge crossings

1. Nodes on the **outer face** placed at vertices of a convex polygon
2. Each internal node is placed at the **barycentre average** of its neighbours, solving a set of linear equations

not deal with directed graph



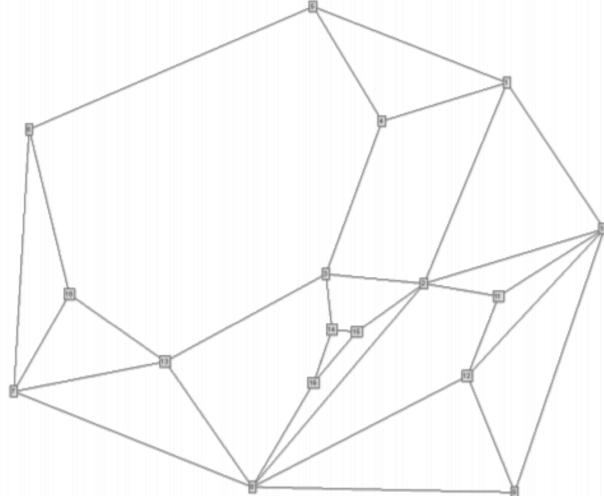
Face: set of nodes connected in a loop

Outer face: connected nodes that are unbounded



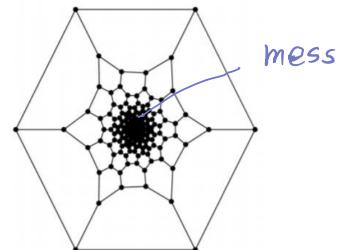
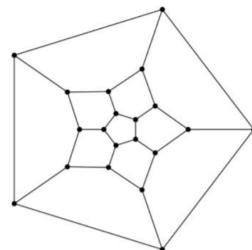
Barycentre: point where three medians of a triangle meet

3-connected: you need to delete at least 3 nodes to disconnect the graph



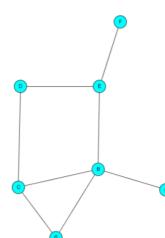
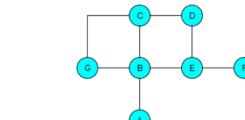
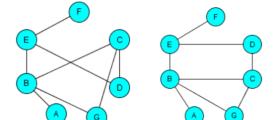
Vismara, Ch 6, Handbook of Graph Drawing and Visualization, 2013
<http://cs.brown.edu/people/rtamassi/gdhandbook/>

good for small graph



General graphs

- No assumptions made
- Typically stochastic approach
 - randomly place nodes
 - improvement by iteration
 - may be non-deterministic
- Different principles
 - Circular
 - Radial
 - Orthogonal
 - Force-directed



General Graphs: force-directed layout

力导向

Peter Eades. A heuristic for graph drawing. Congressus Numerantium, 42:149–160, 1984

Fruchterman, T. M. J.; Reingold, E. M.. Graph Drawing by Force-Directed Placement, Software – Practice & Experience, 21(11): 1129–1164, 1991.

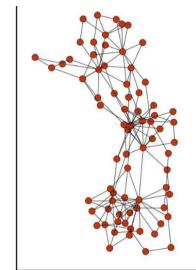
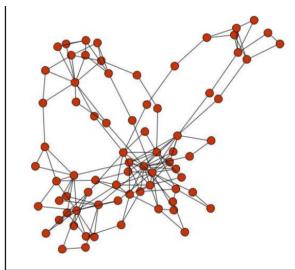
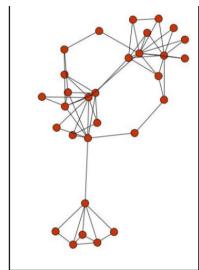
Nodes: steel rings

Edges: springs

Connected nodes: attractive force

Unconnected nodes: repulsive forces

1. Start with random placement of nodes
2. Calculate the energy represented by the attractive and repulsive forces
3. Move nodes until there is minimum energy
4. F&R: “temperature adjustment” - adjustments become smaller as layout improves



There're some
edge crossings.

maximise one of
criterion

focus more on
pushing and spreading
out the graph
and show the
symmetric area

