CIS 4930/6930-002
DATA VISUALIZATION

Force Directed Layouts

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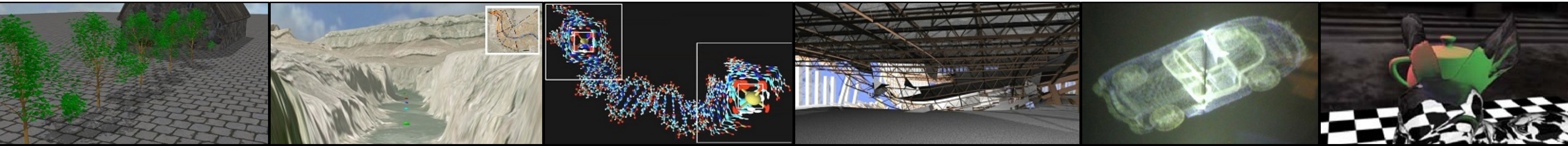
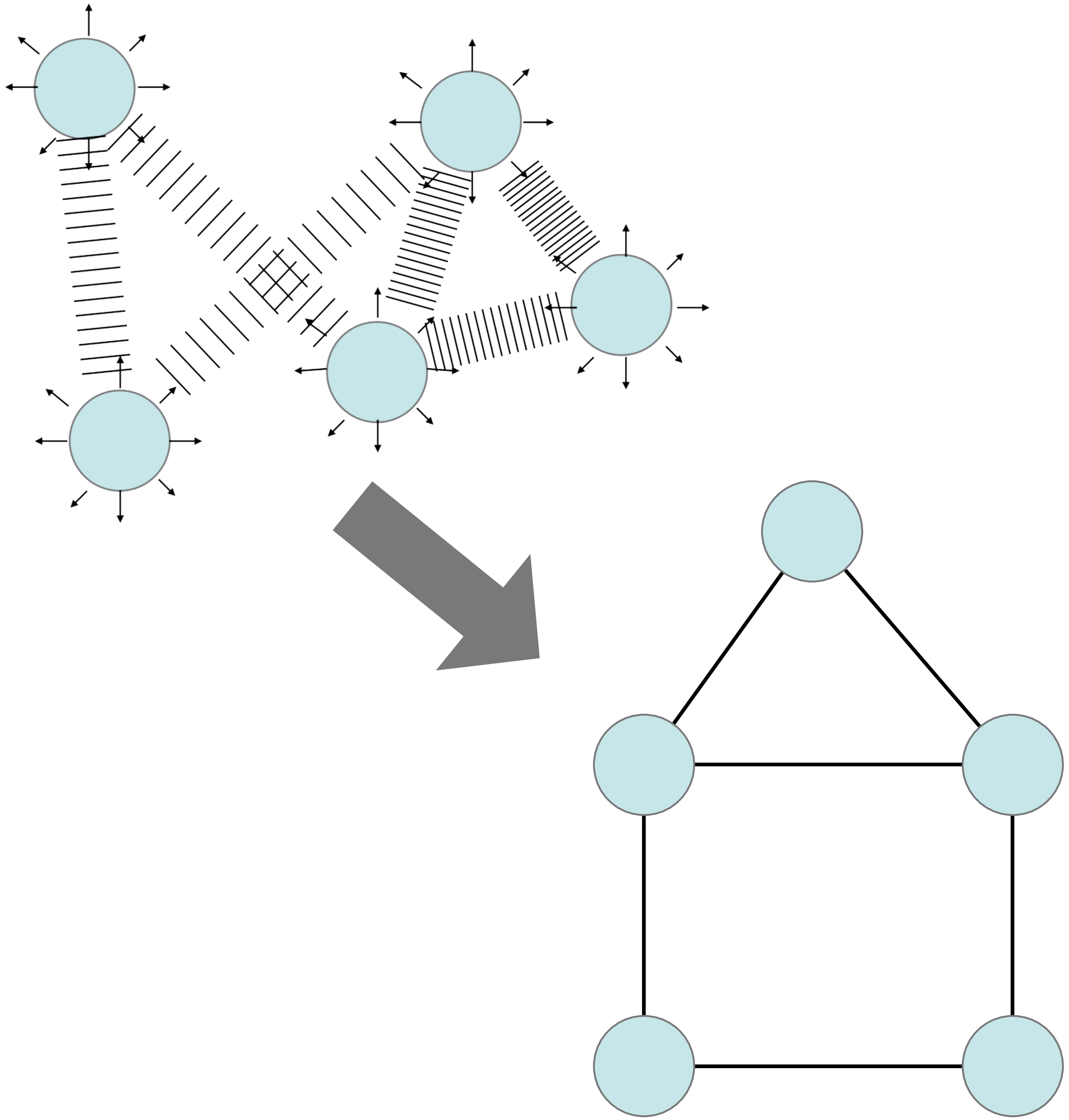


FORCE-DIRECTED

many variations, but usually physical analogy of repulsion and attraction



Generally…

edges = springs

nodes = repulsive particles

Requires an iterative calculation, should be updated each time the draw loop is called

Physics Review

$$F = ma$$

(Force = mass * acceleration)

$$\Delta v = a\,\Delta t$$

(change in velocity = acceleration * time step)

$$p' = p + v\,\Delta t$$

(new position = old position + velocity * time step)

Physics Review

$$a = \frac{F}{m}$$

(acceleration = Force / mass)

$$v' = v + a\,\Delta t$$

(new velocity = old velocity + acceleration * time step)

$$p' = p + v'\Delta t$$

(new position = old position + velocity * time step)

FOR A GIVEN NODE i

$$\overrightarrow{v_i'} = \overrightarrow{v_i} + \frac{\overrightarrow{F_i}}{m_i}\Delta t$$

(new velocity = old velocity + Force / mass * time step)

$$\dot{p}_i' = \dot{p}_i + \overrightarrow{v_i'}\Delta t$$

(new position = old position + new velocity * time step)

What values do we set for…

time step Δt ?

initial position p_i ?

initial velocity v_i ?

mass m_i ?

Force F_i ?

What values do we set for…

time step Δt ?

Fixed timestep, time since last frame was drawn, …

initial position p_i ?

Start with a random position

initial velocity v_i ?

Zero

mass m_i ?

Depends, however, the heavier it is, the slower it moves

Force F_i ?

That is what we still need to calculate…

FORCE MODEL: REPULSIVE FORCES

$$f_R(d) = \frac{c_R\, m_1\, m_2}{d^2}$$

C_R is a strength constant

$m_1,\ m_2$ are node masses

d is a distance between nodes

FORCE MODEL: ATTRACTIVE FORCES

$$f_A(d) = \mathrm{C_A}(\mathrm{d} - \mathrm{L})$$

C_A is a strength constant

d is a distance between nodes

L is the rest length of the spring (i.e. Hooke's Law)

FORCE MODEL

Every node feels repulsion to every other node

FORCE MODEL

Only **connected** nodes feel attracted

WHAT VALUES FOR…

Repulsive constant C_R ?

Attractive constant C_A ?

Rest length of the spring L ?

What values for…

Repulsive constant C_R ?

Start with something small (weaker force)

Attractive constant C_A ?

Start with something small (weaker force)

Rest length of the spring L ?

Closest you would *like* 2 nodes to be together (they will be closer) – 10-20 pixels is a good start

FORCE MODEL

Repulsive force:

$$\overrightarrow{F_R}(\dot{P}) \ = \sum_{all\ nodes\ :\dot{Q}} f_R(\|\dot{P} - \dot{Q}\|) \frac{(\dot{P}-\dot{Q})}{\|\dot{P}-\dot{Q}\|}$$

Attractive force:

$$\overrightarrow{F_A}(\dot{P}) \ = \sum_{connected\ neighbors\ :\dot{Q}} f_A(\|\dot{Q} - \dot{P}\|) \frac{(\dot{Q}-\dot{P})}{\|\dot{Q}-\dot{P}\|}$$

For a Given Node i

$$\overrightarrow{v_i'} = \overrightarrow{v_i} + \frac{\overrightarrow{F_R}(\dot{P_i}) + \overrightarrow{F_A}(\dot{P_i})}{m_i} \Delta t$$

(new velocity = old velocity + Force / mass * time step)

$$\dot{p_i'} = \dot{p_i} + \overrightarrow{v_i}' \Delta t$$

(new position = old position + velocity * time step)

ALGORITHM

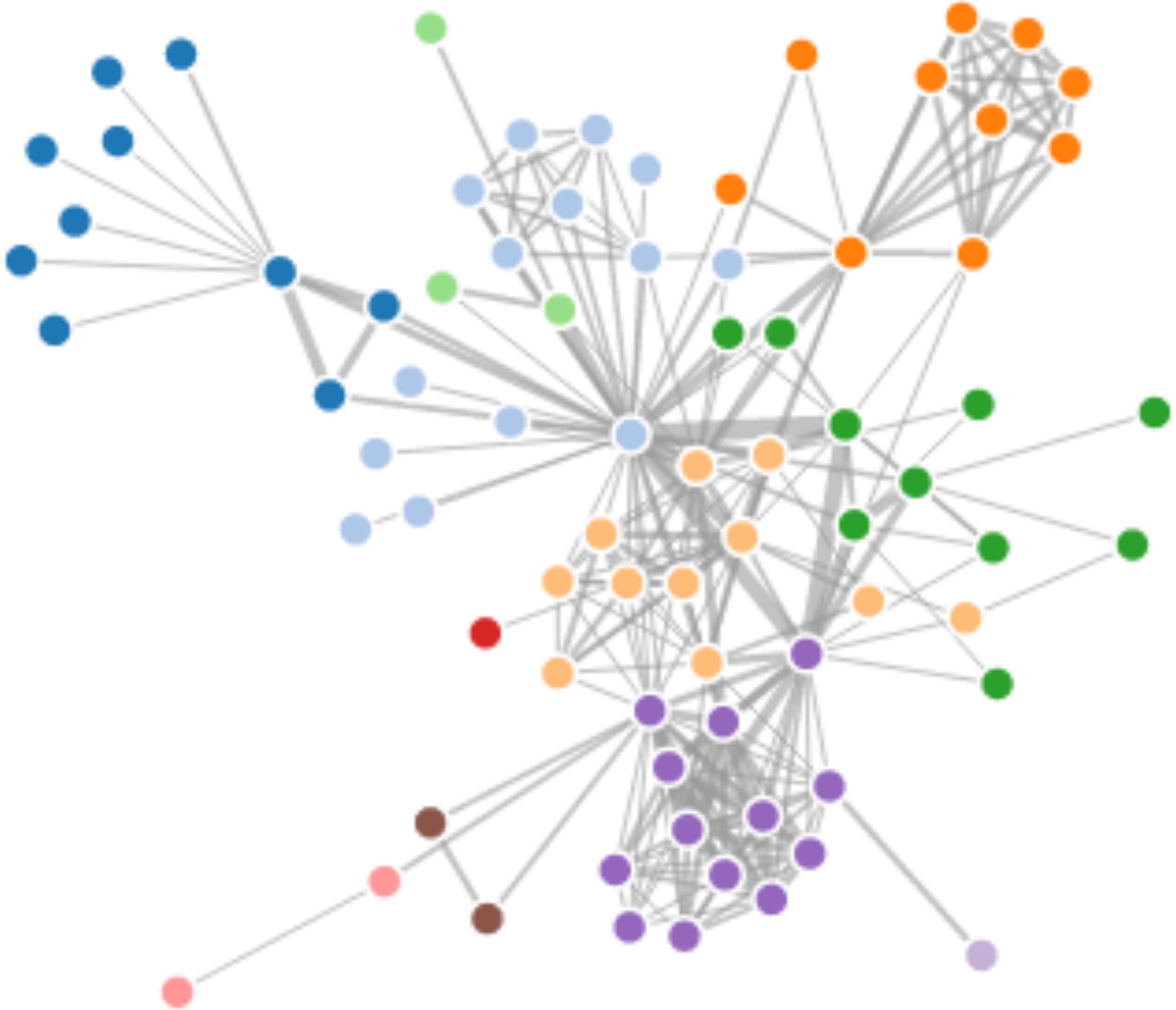
start from random layout

(global) loop:

Calculate a new velocity for every point

Calculate a new position for every point

stop when layout is ‘good enough’



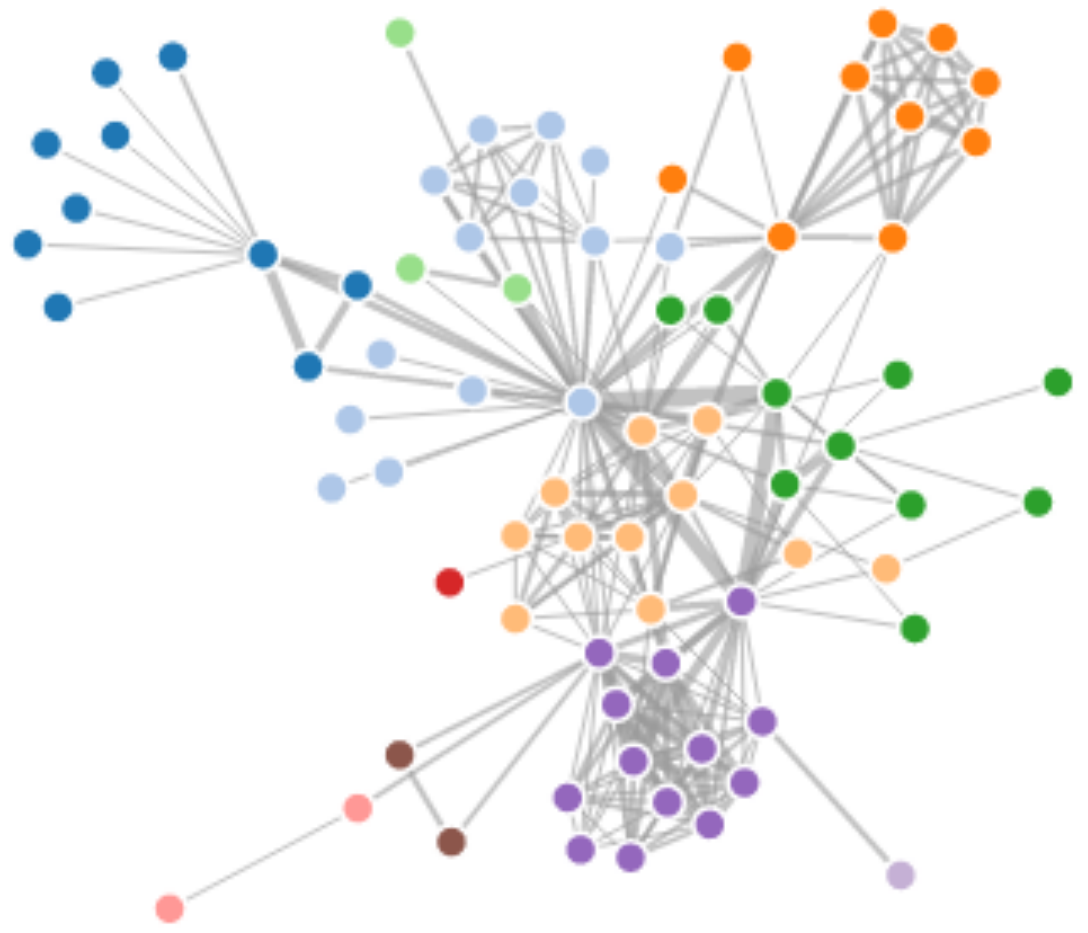
[HTTP://BL.OCKS.ORG/MBOSTOCK/4062045](http://bl.ocks.org/mbostock/4062045)

FORCE DIRECTED

+ very flexible, aesthetic layouts on many types of graphs

+ can add custom forces

+ relatively easy to implement



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FORCE DIRECTED

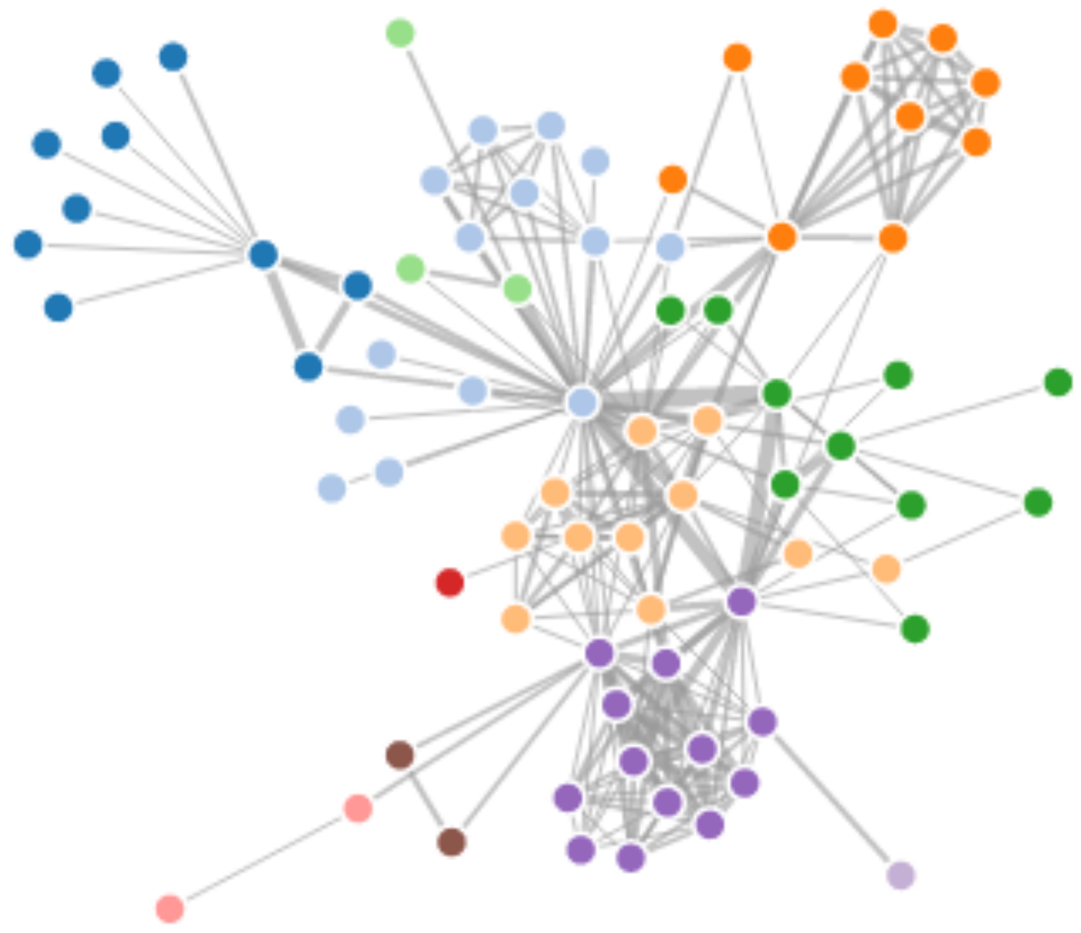
- repulsion loop is $O(n^2)$ per iteration

can speed up to O(n log n) using quadtree or k-d tree

- prone to local minima

can use simulated annealing

- doesn't work well on highly connected (low diameter) graphs



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IDEAS TO MAKE IT BETTER

Add extra forces, such as repulsion from the boundary or attraction to the center of the screen.

Allow overriding node positions using the mouse (dragging vertices)

Allow fixing the position of certain nodes

Other ideas?