Self-Healing Distributed Networks

DAFNI at Durham

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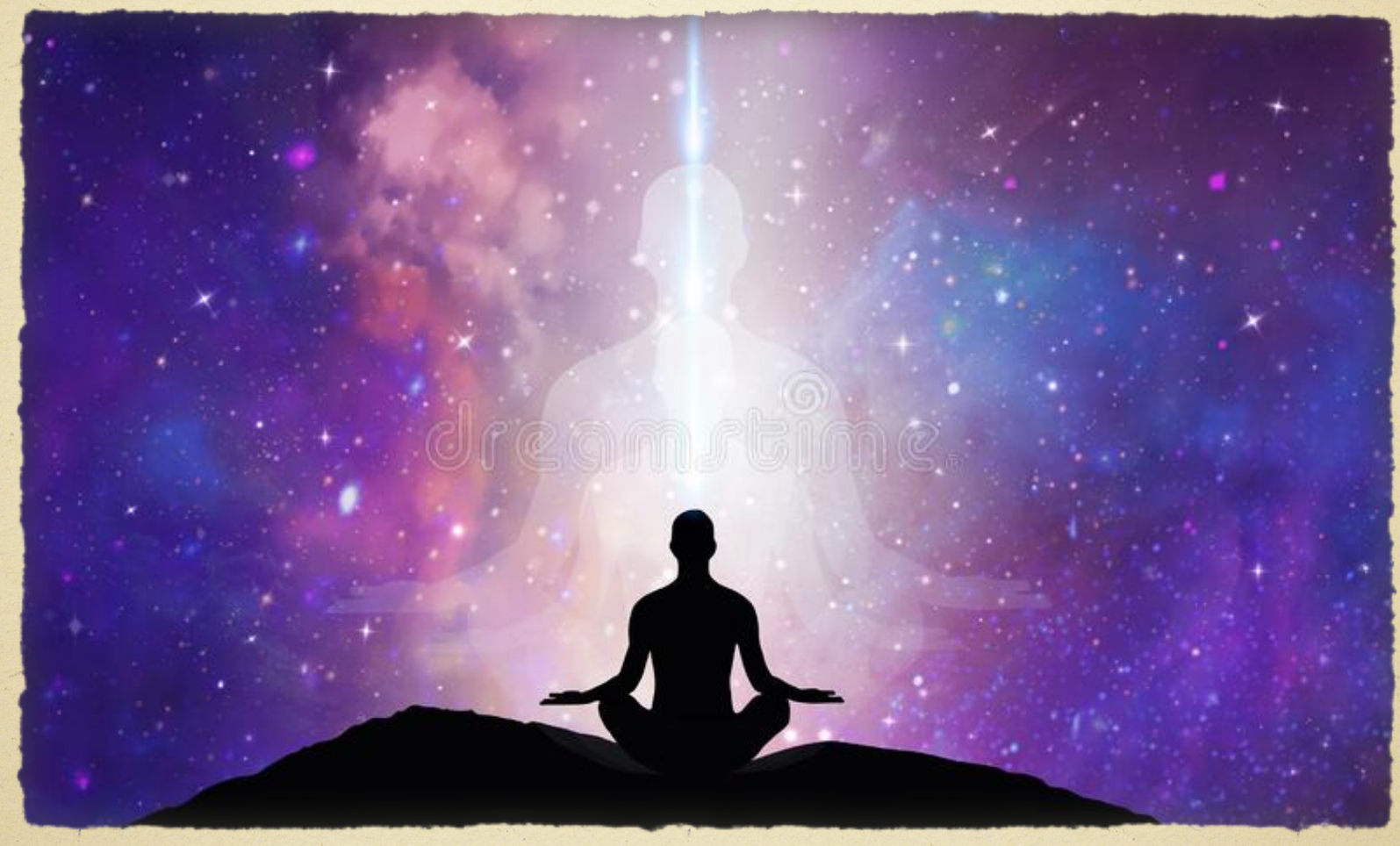
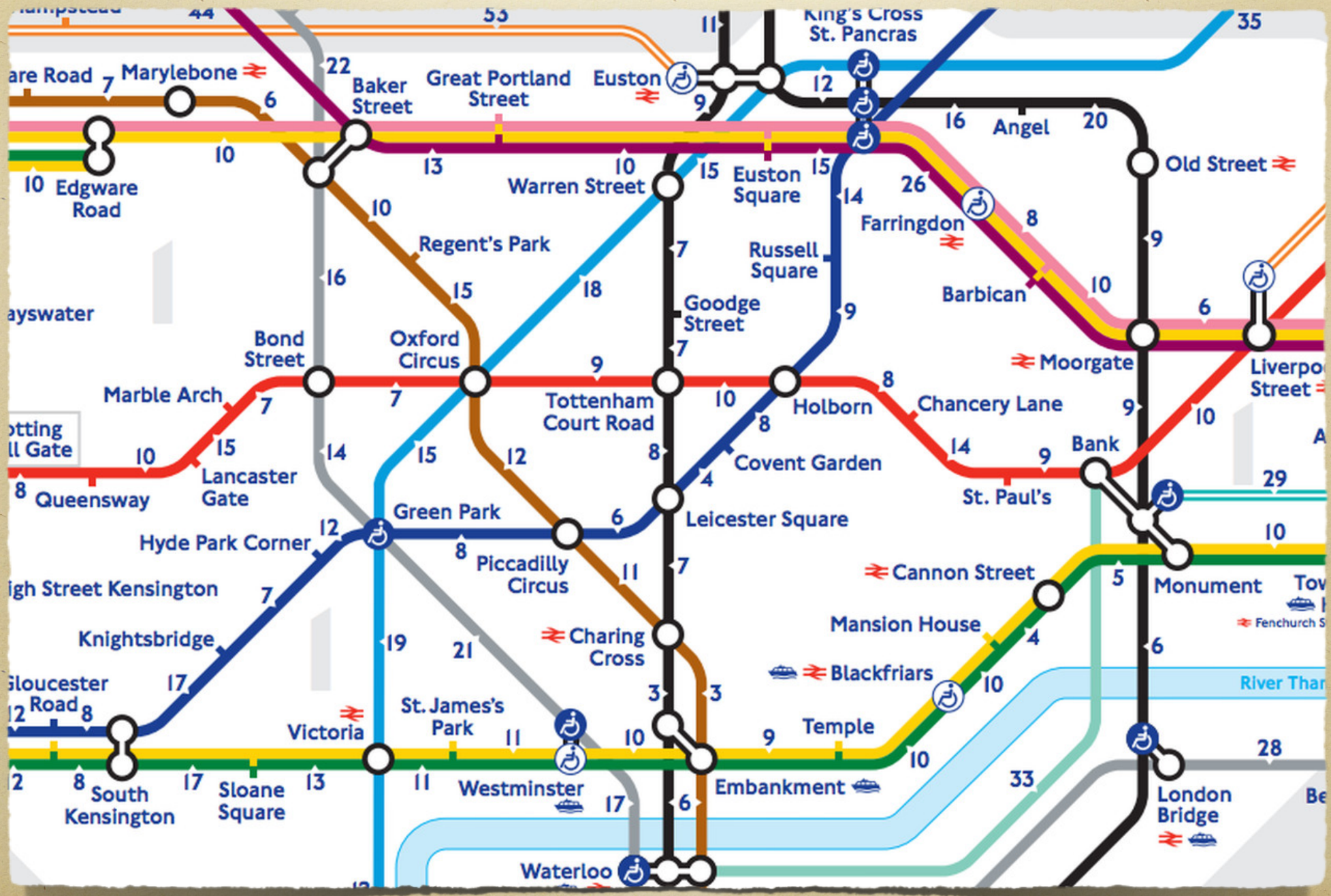
Healing!



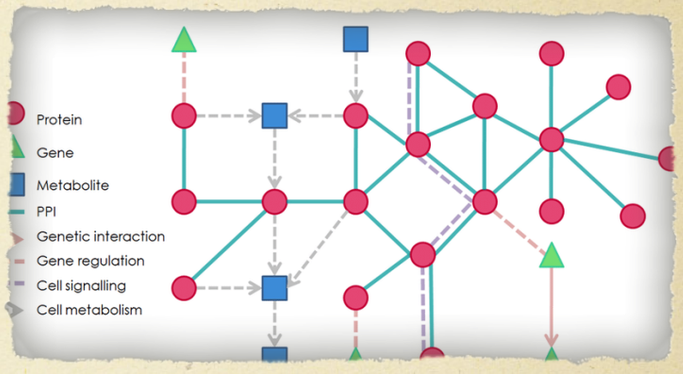
Courtesy: https://www.dreamstime.com (royalty free)

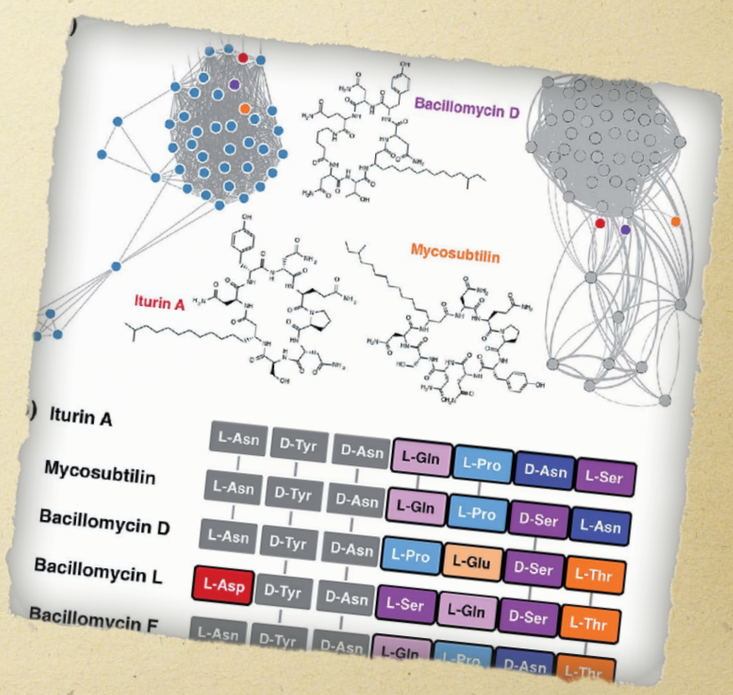
Networks …


King's Cross St. Pancras
Marylebone
Baker Street
Great Portland Street
Euston
Edgware Road
Warren Street
Euston Square
Angel
Old Street
Regent's Park
Farringdon
Russell Square
Barbican
Goodge Street
Bond Street
Oxford Circus
Moorgate
Marble Arch
Tottenham Court Road
Holborn
Chancery Lane
Queensway
Lancaster Gate
Covent Garden
Bank
St. Paul's
Green Park
Hyde Park Corner
Leicester Square
Piccadilly Circus
Cannon Street
Monument
Knightsbridge
Charing Cross
Mansion House
Blackfriars
Victoria
St. James's Park
Temple
South Kensington
Sloane Square
Westminster
Embankment
London Bridge
Waterloo

Networks …are everywhere

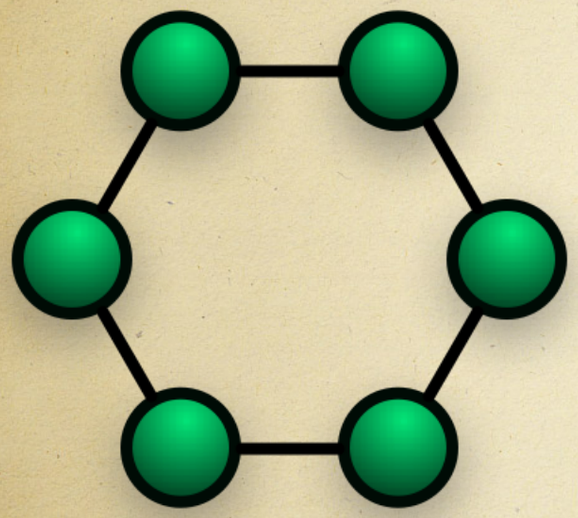
- Transport
- Nature
- Biology
- Ecology
- Society
- Chemistry
- Etc etc …



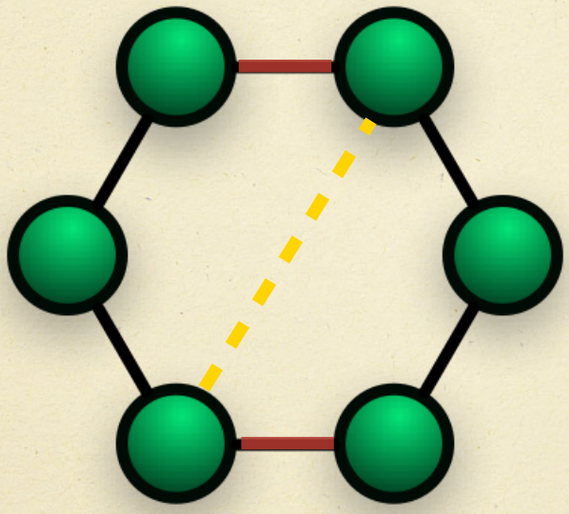


- Combinatorics ~ almost anything which has objects relating to each other!

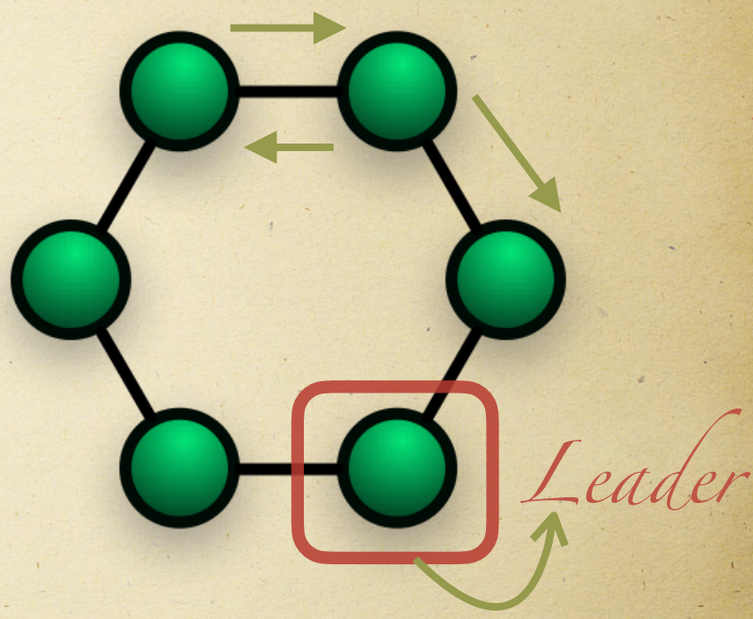
Different scenarios of computing



Static

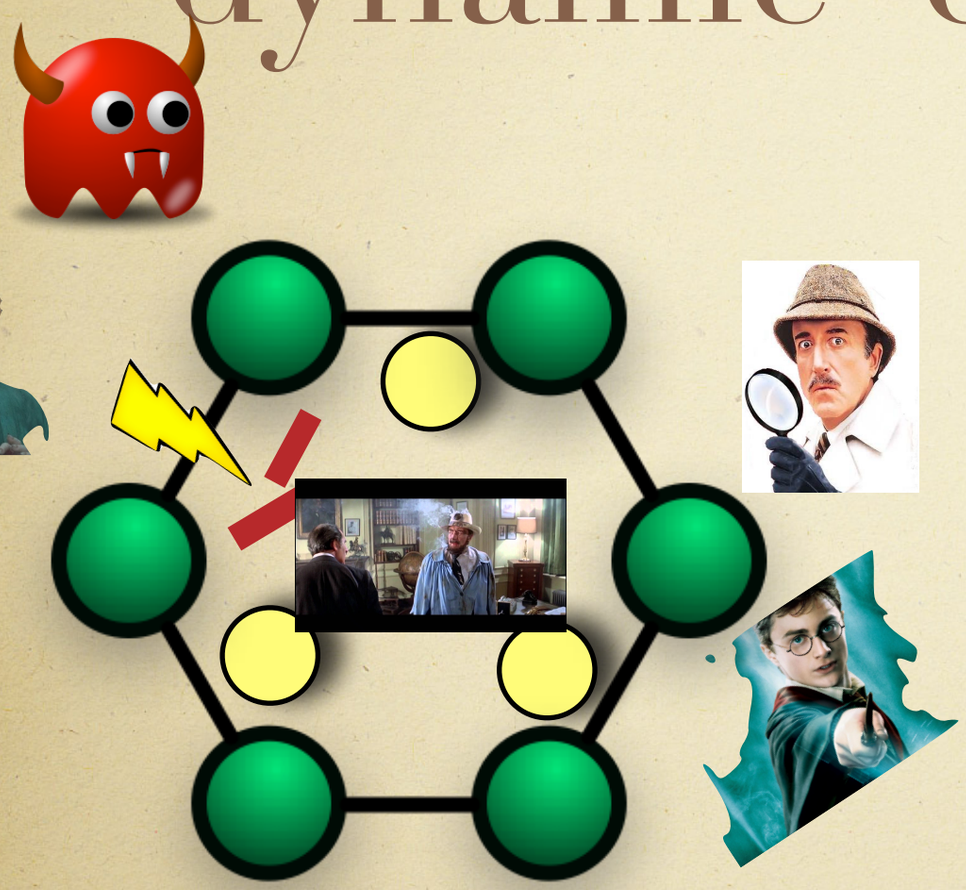


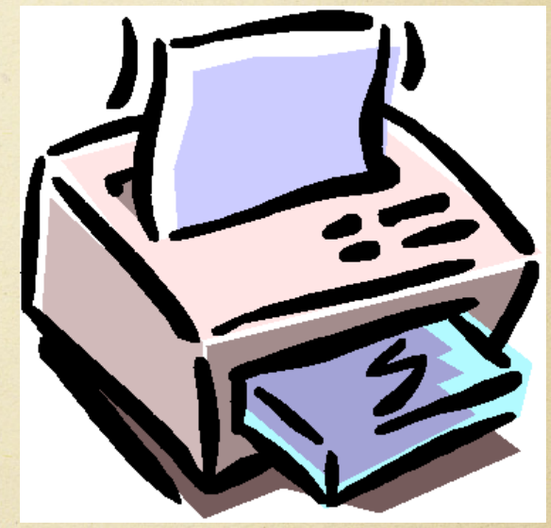
Temporal/Dynamic



- **Centralised Algorithms**: Single computer with the whole problem instance/data available
- **Distributed Algorithms**: `Network' of computers with each having only local view

Distributed in a `faulty/ dynamic' environment





- Fault-tolerant/Dynamic Algorithms: Faulty/ Dynamic environments

Q: Which one of us will get the printer despite failures or changes
(e.g. in a self-healing manner)

The(A) *Distributed* Matrix….

Architecture	Message Passing (Point-to-Point, Broadcast…)	Sensor, Wireless, Reconfigurable, Overlay, Cloud…	Shared Memory
Timing	Synchronous	Partial ..	Asynchronous
Identity	Anonymous	ID	
Knowledge	Local (Own + neighbour IDs), + size, dia estimates?	Restricted	Global
Local Memory	Unlimited	SuperLinear, Linear, Logarithmic	Constant
Bandwidth	*LOCAL* (Unlimited)	*CONGEST* (polylog)	?
Failure	Crash (node)	Edge, Memory, Transient …	Byzantine
Behaviour	Obedient!	Selfish (Game Theory)	Byzantine

Self-healing

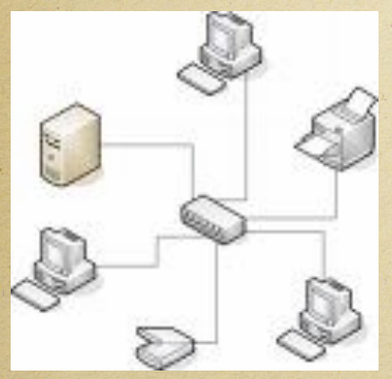
- A self-healing system, starting from a correct state, under attack from an adversary, goes only temporarily out of a correct state.
- Under attack, maintain certain properties within acceptable bounds.

Main self-healing themes

- Resilient Distributed Architectures by Self-healing (~P2P topology maintenance)
- Low Memory devices: Compact Routing over Compact Self-healing Networks ~ Internet of Things
- Under Investigation: Self-Healing Software Defined Networks, Social resilience (e.g. Terror networks) etc…

How to self-heal?

Brain: component fails, brain rewires and does without it



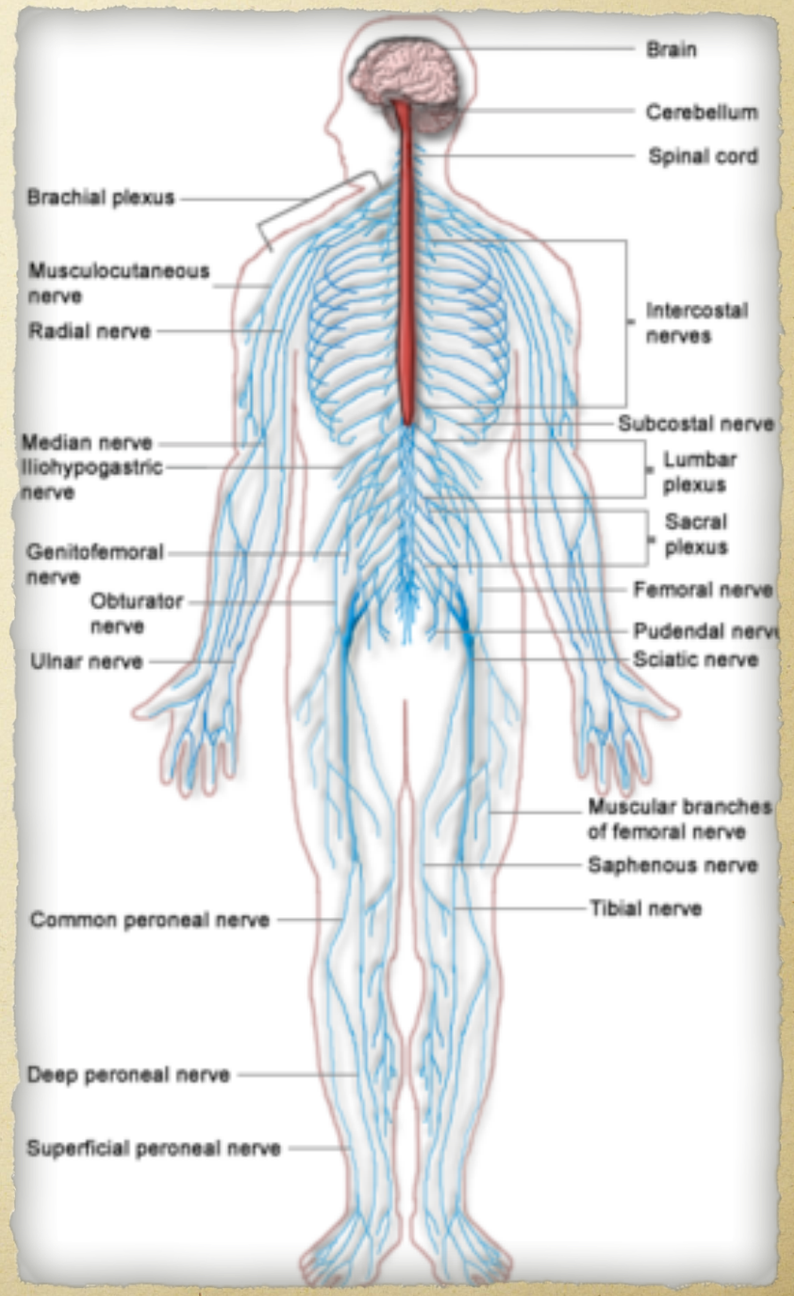
Computer networks: components fail, network fails until components fixed.

Autonomic Computing

- IBM's autonomic computing initiative
- Nature and Bio-inspired
- Self-CHOP

An autonomic system

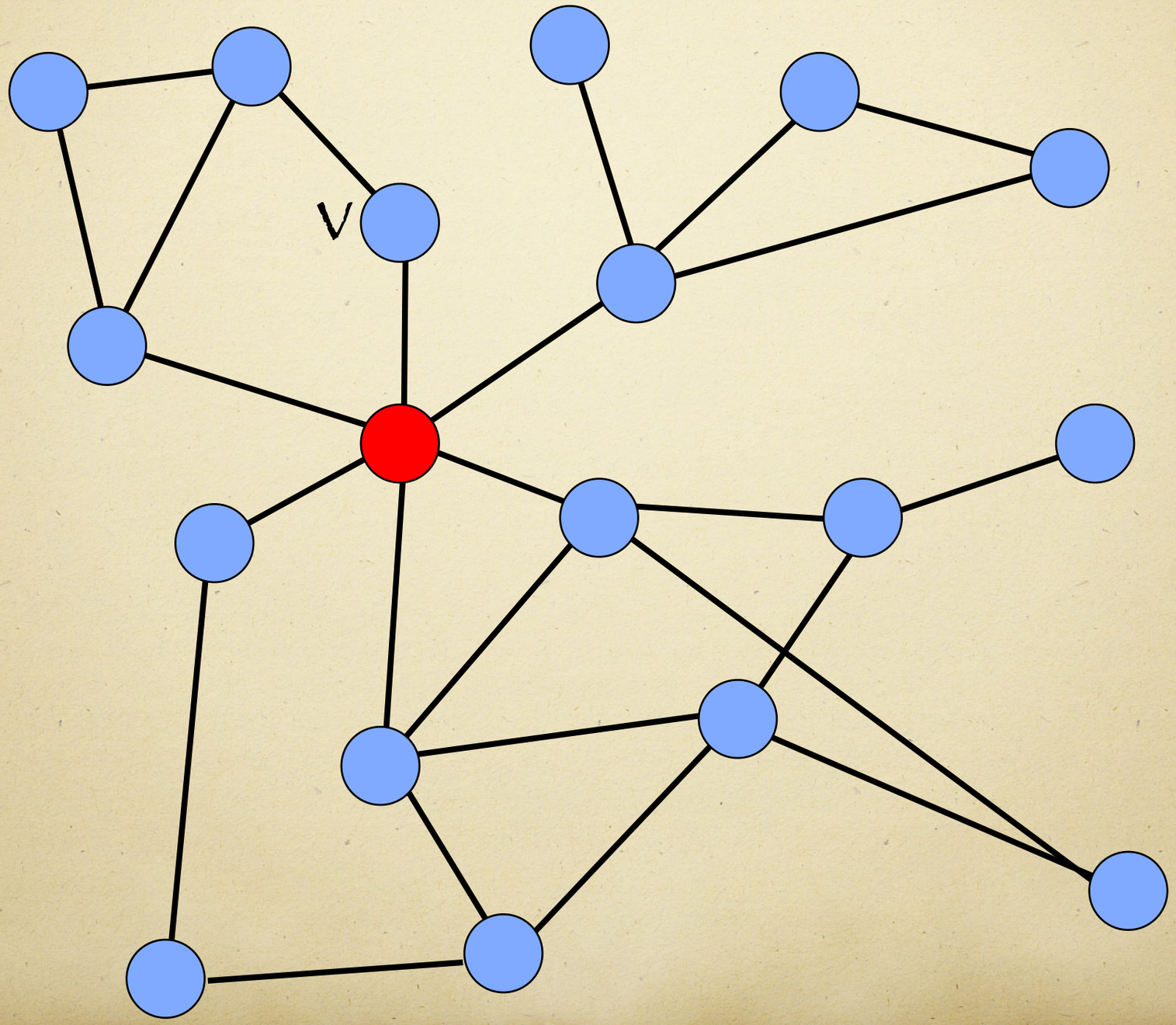
- Self-managing:
  - Self-configuring
  - Self-healing
  - Self-optimizing
  - Self-protecting



Self-healing model (a game on graphs!)

- Start: a distributed network G
- Attack action: An adversary inserts or deletes one node per round
- Healing action: After each adversary action, we *add and/or drop some edges* between pairs of nearby nodes, to "heal" the network

Illustration



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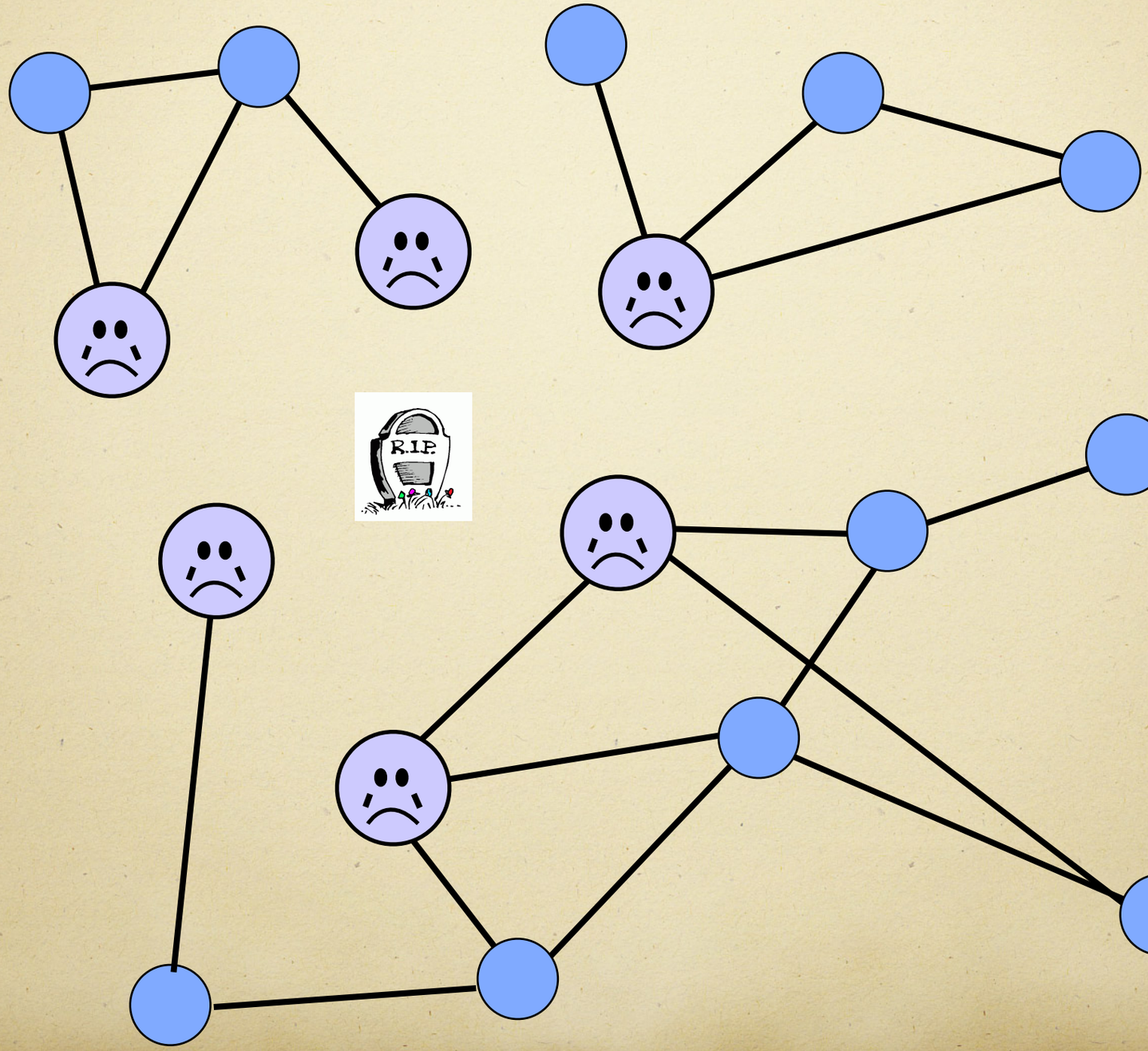

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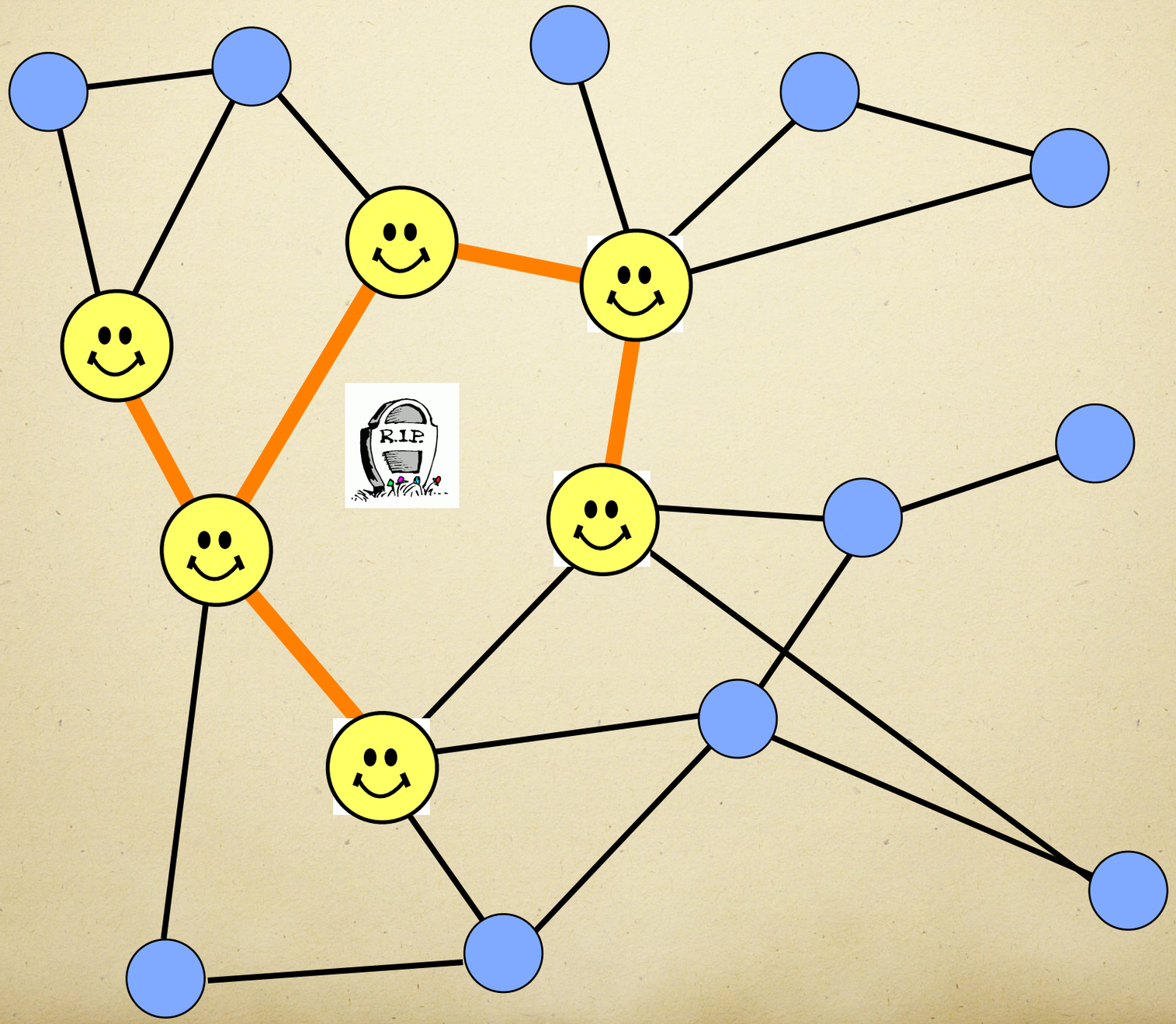

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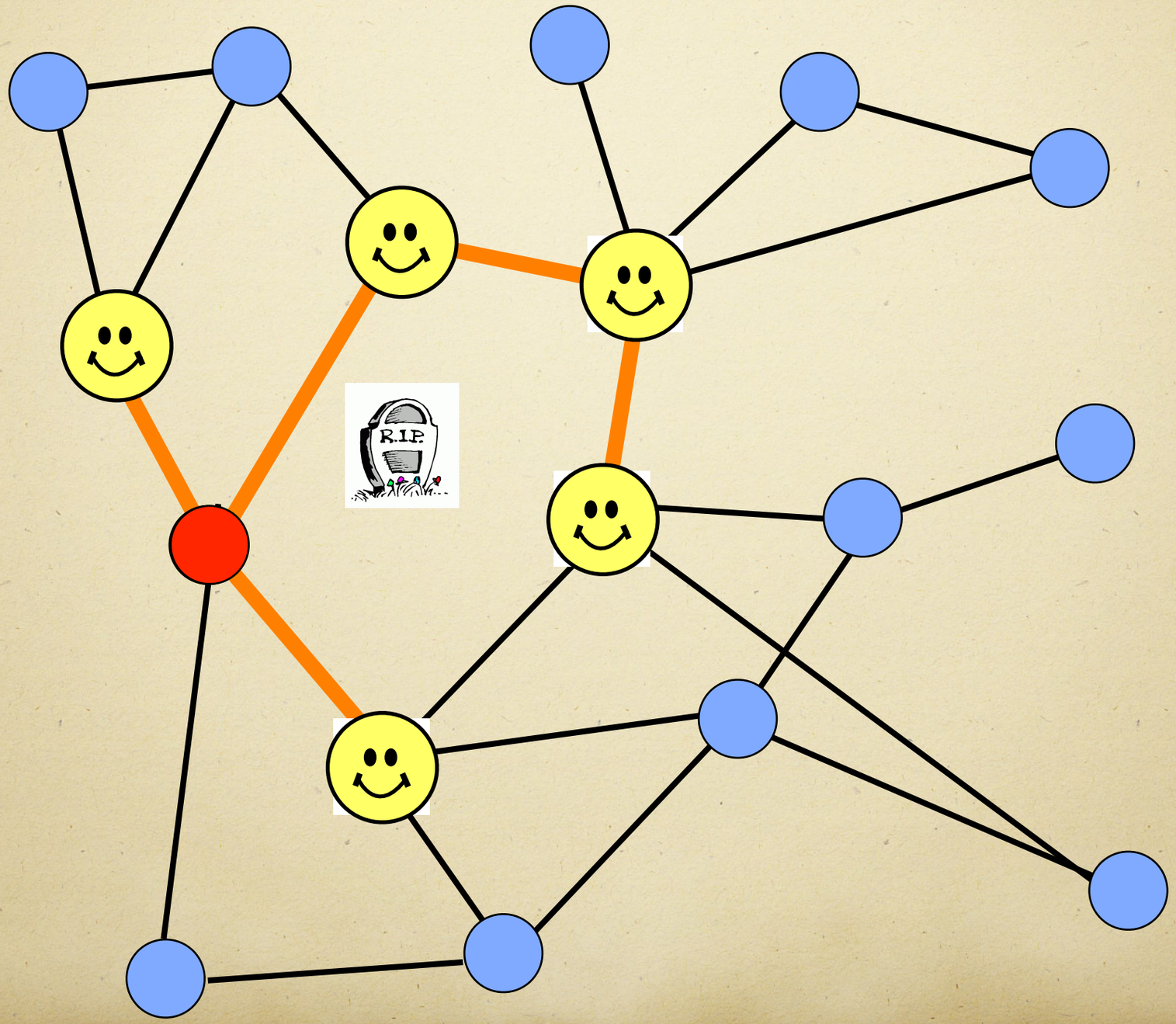

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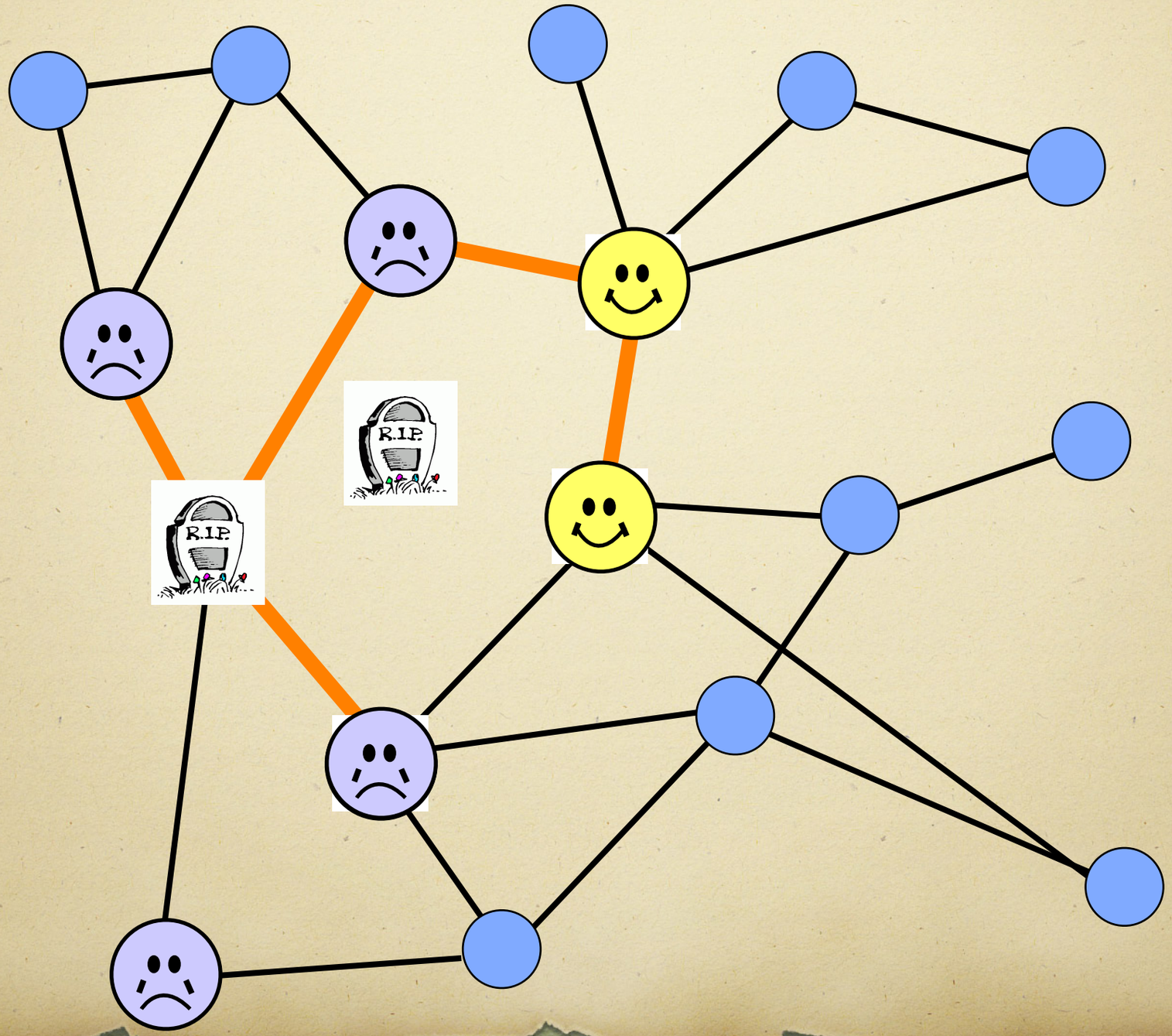

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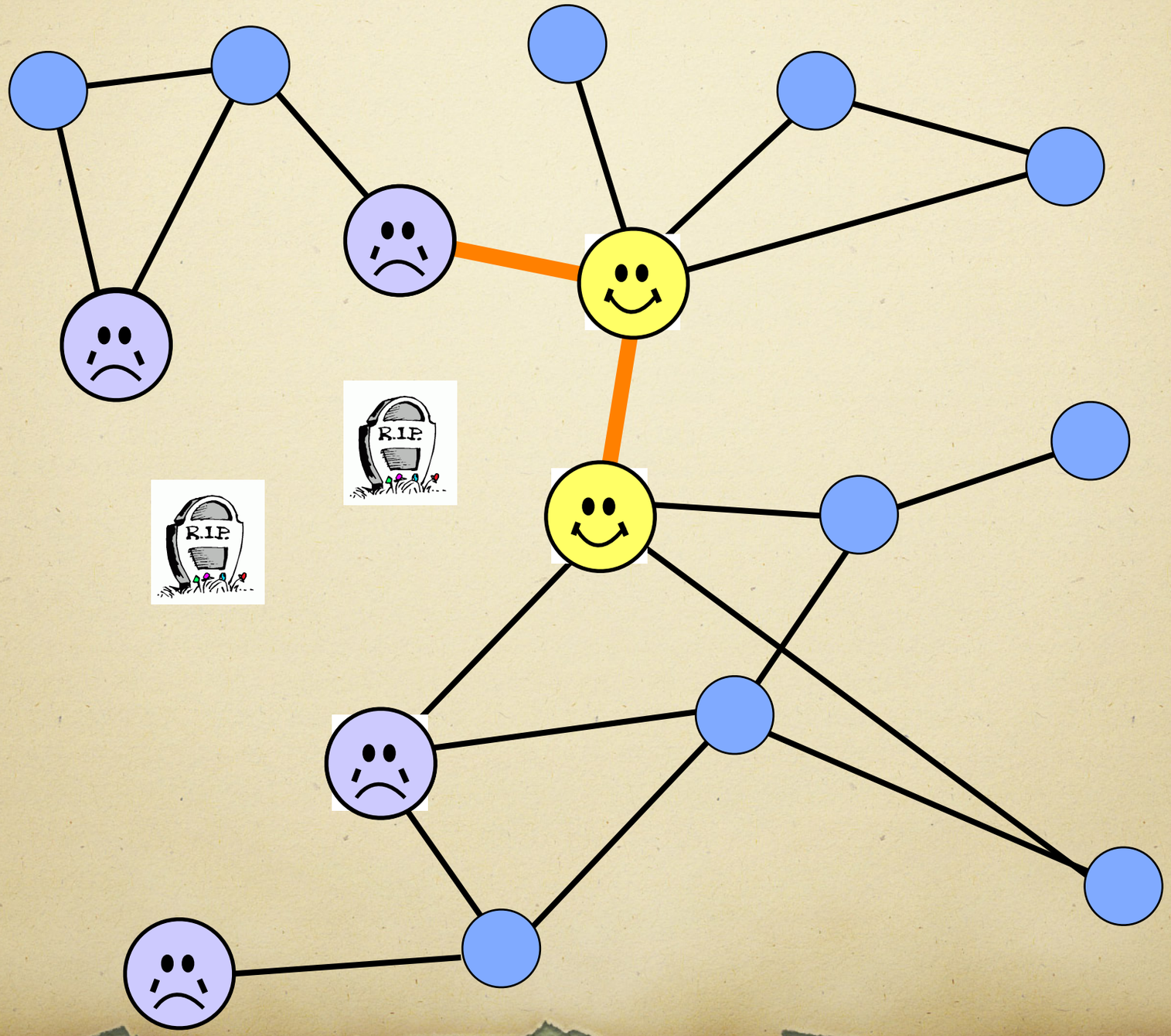

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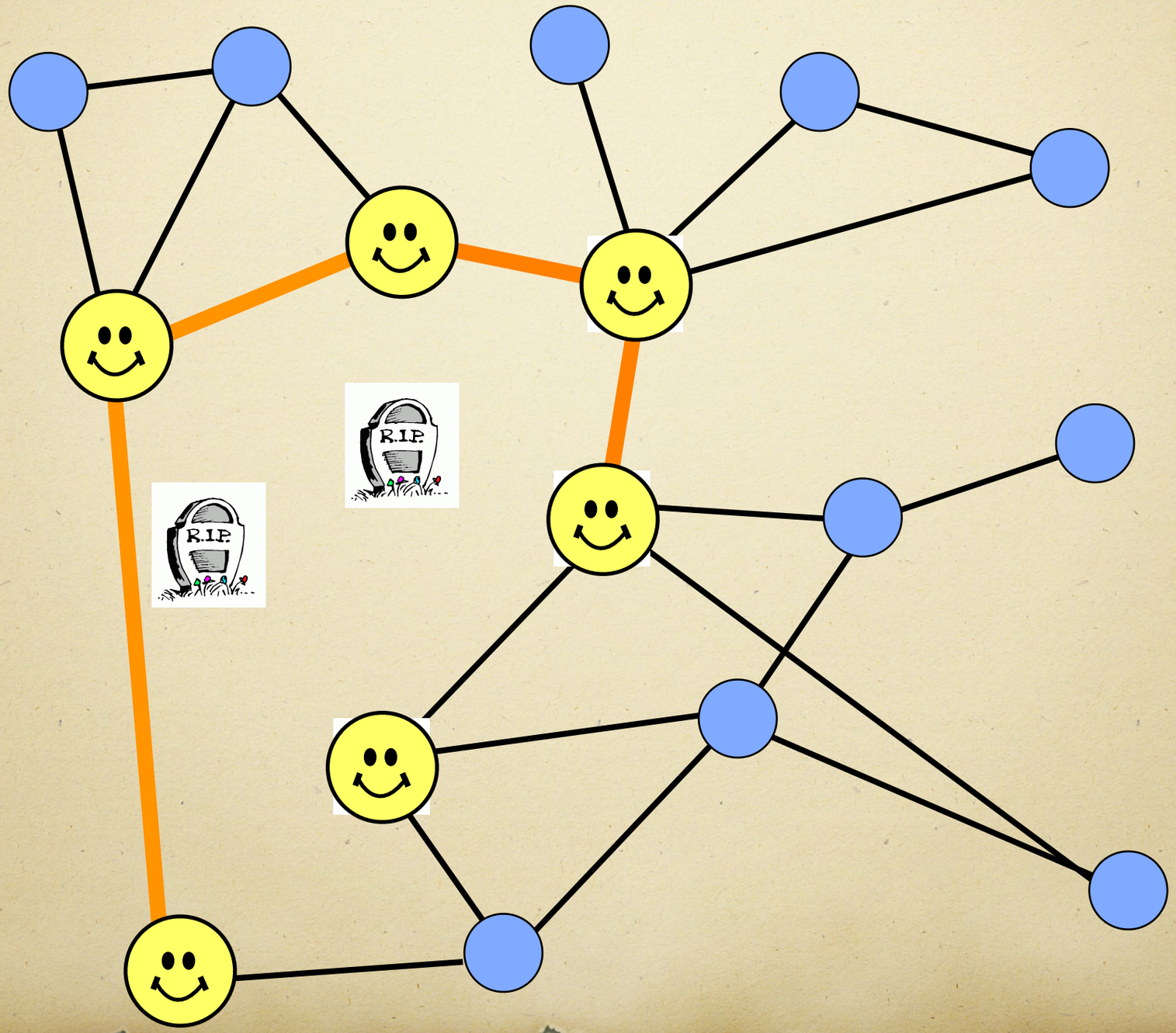
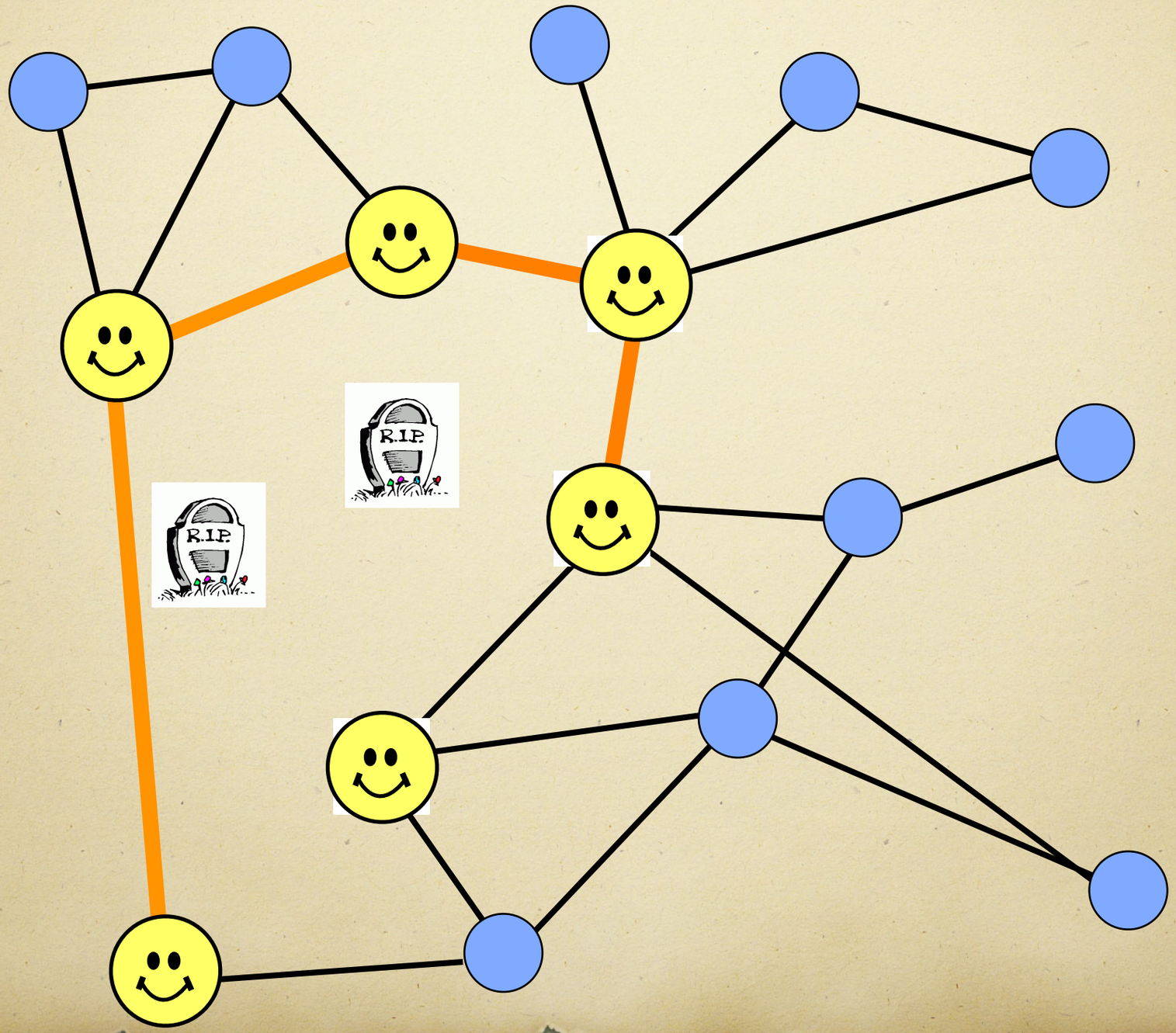


Naive?



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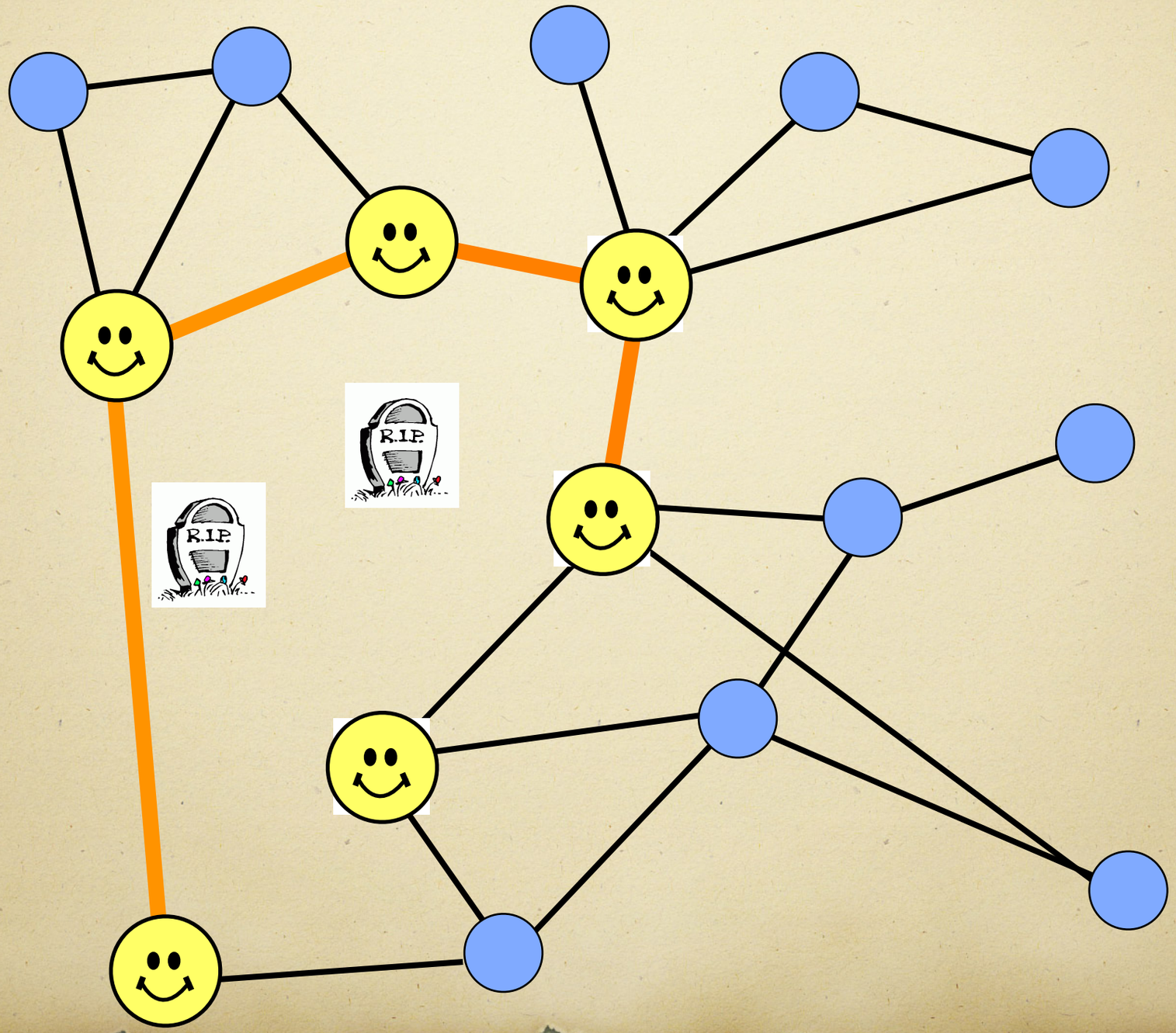

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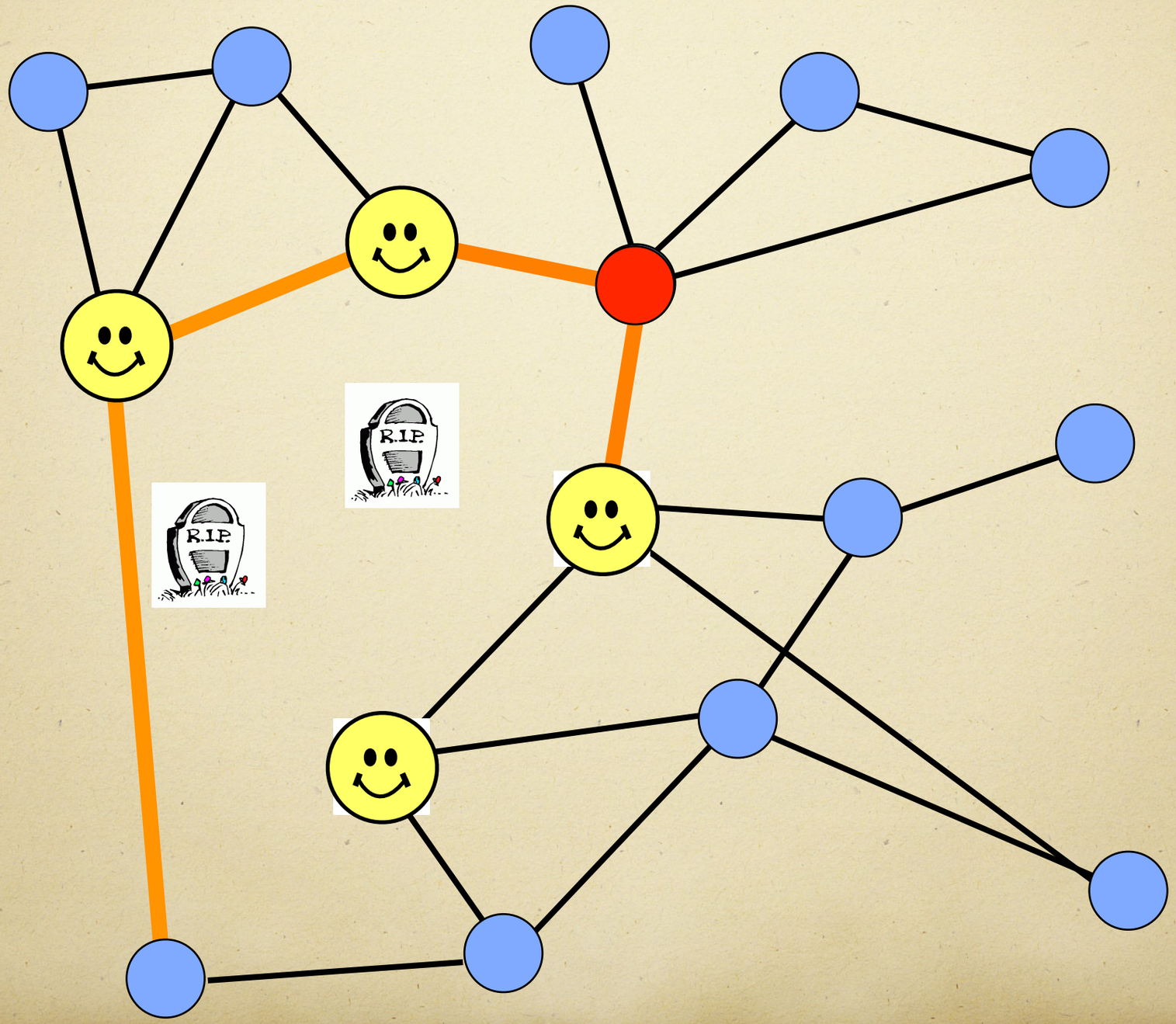

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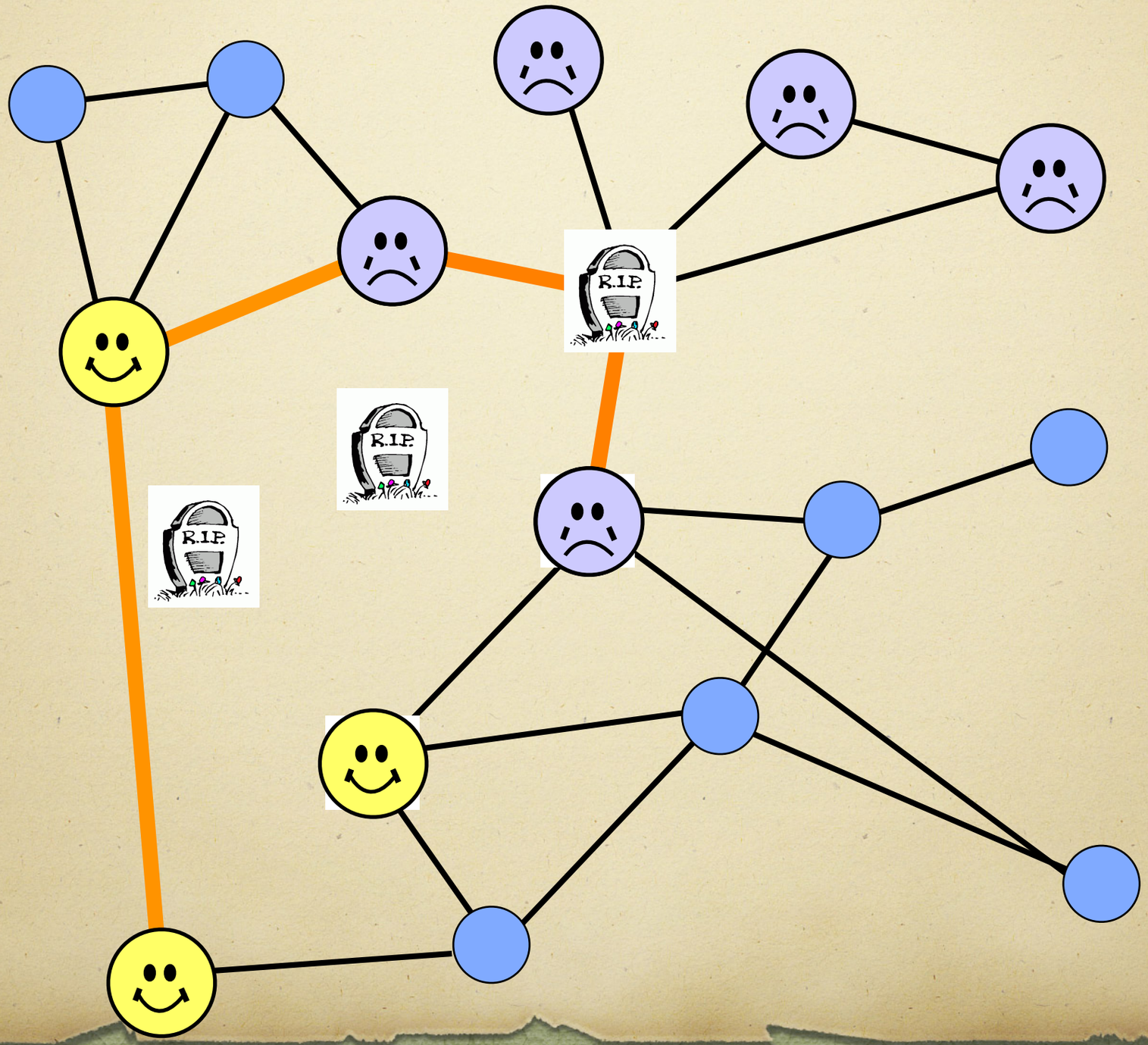

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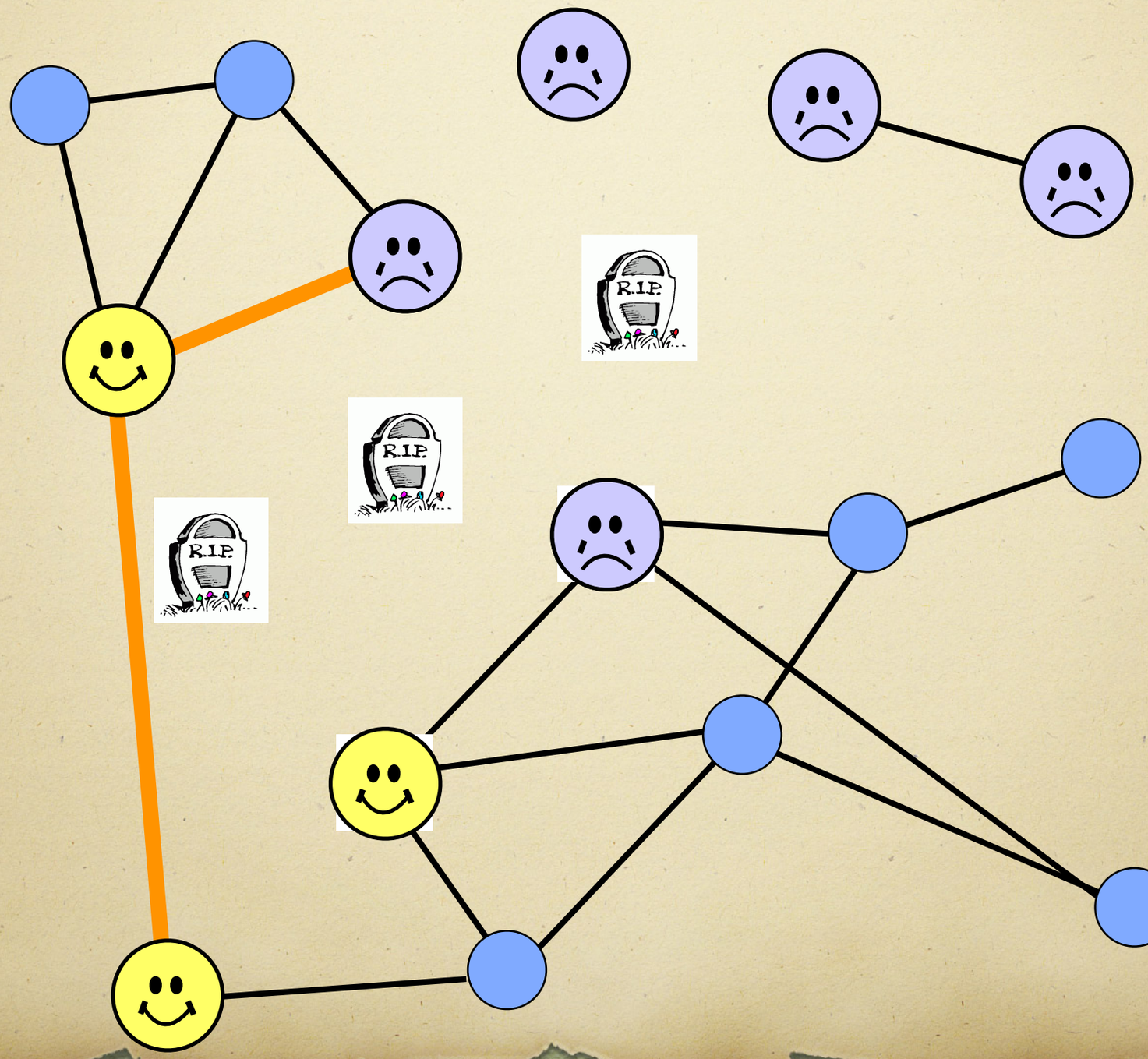

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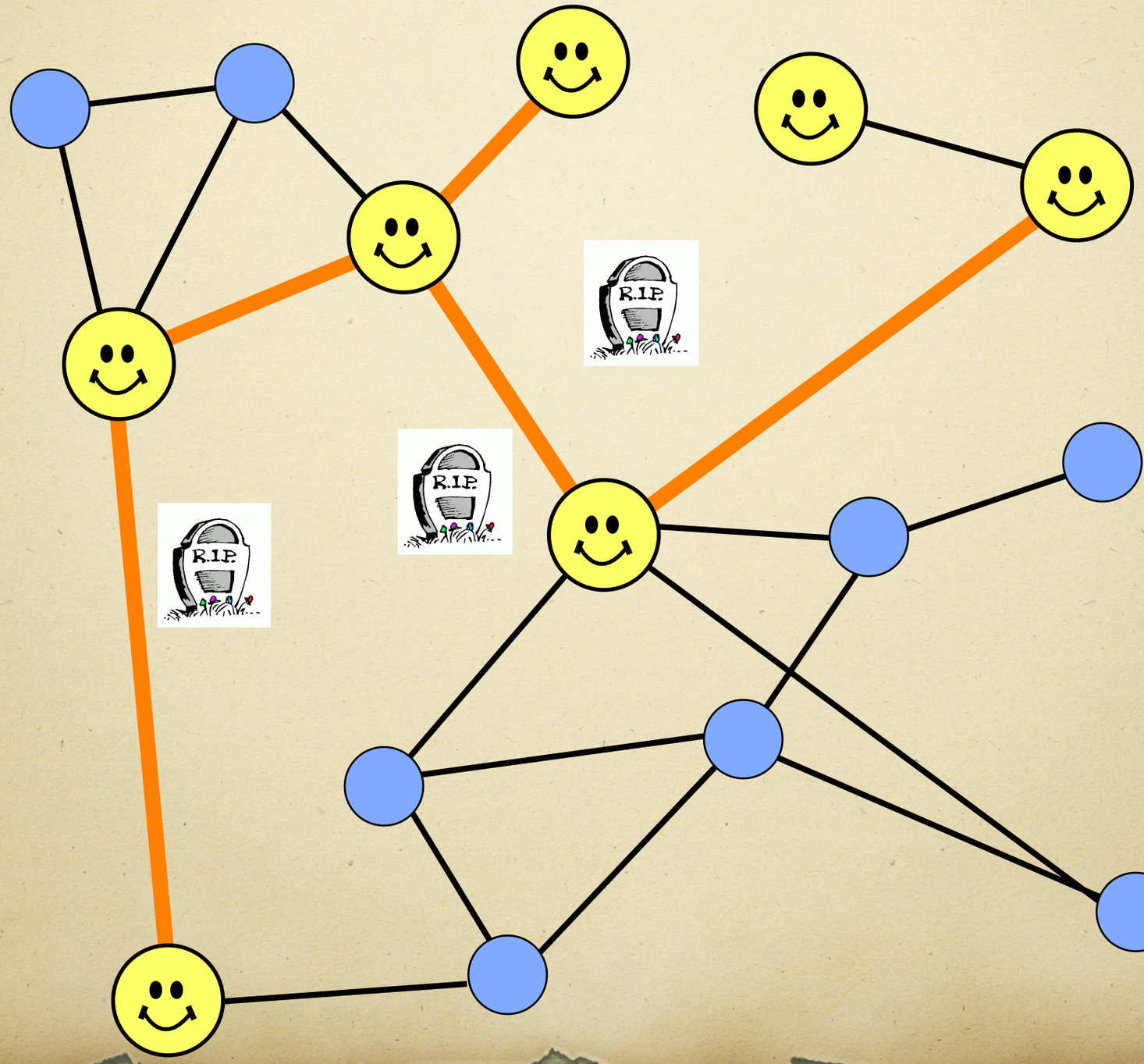

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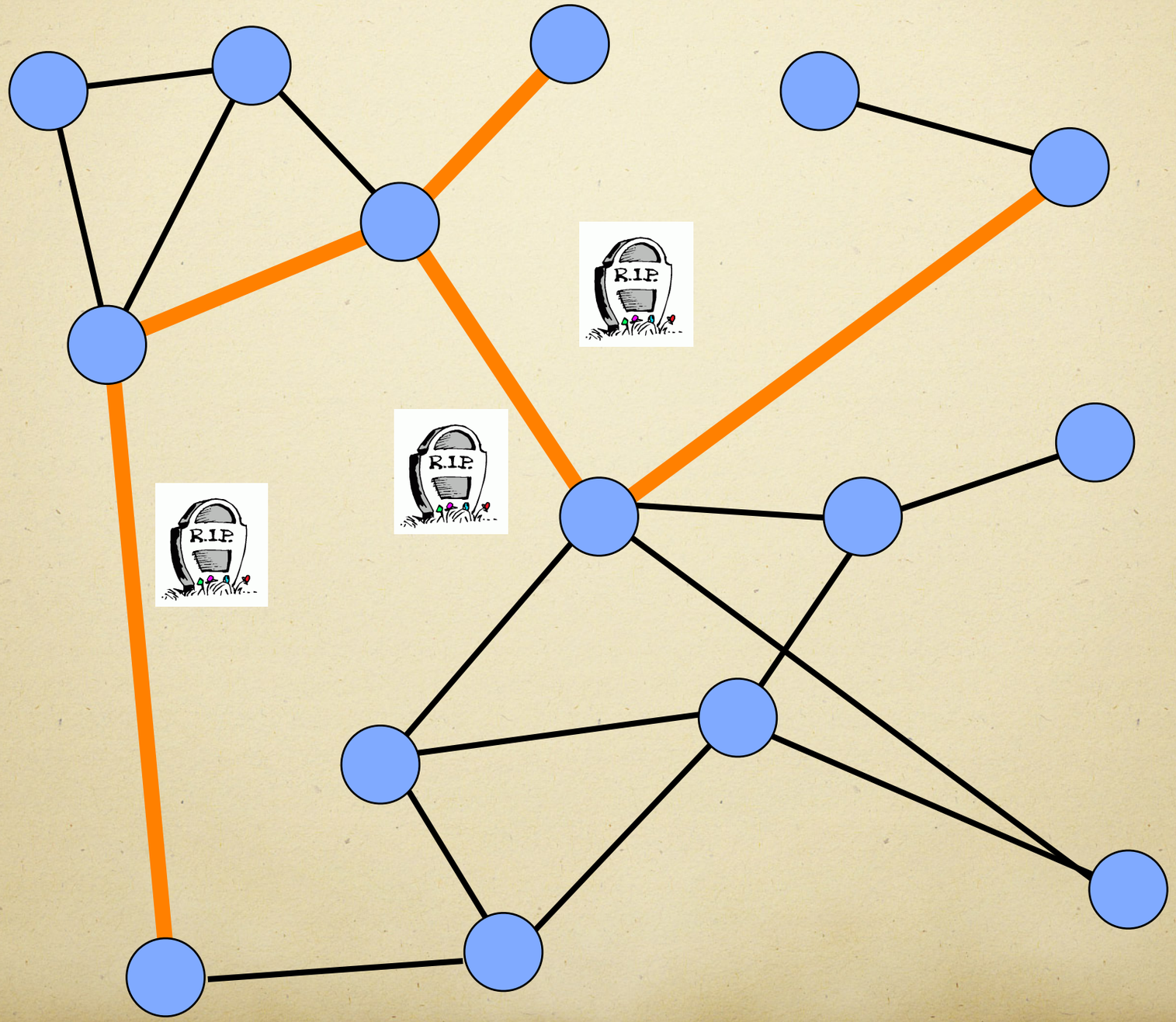

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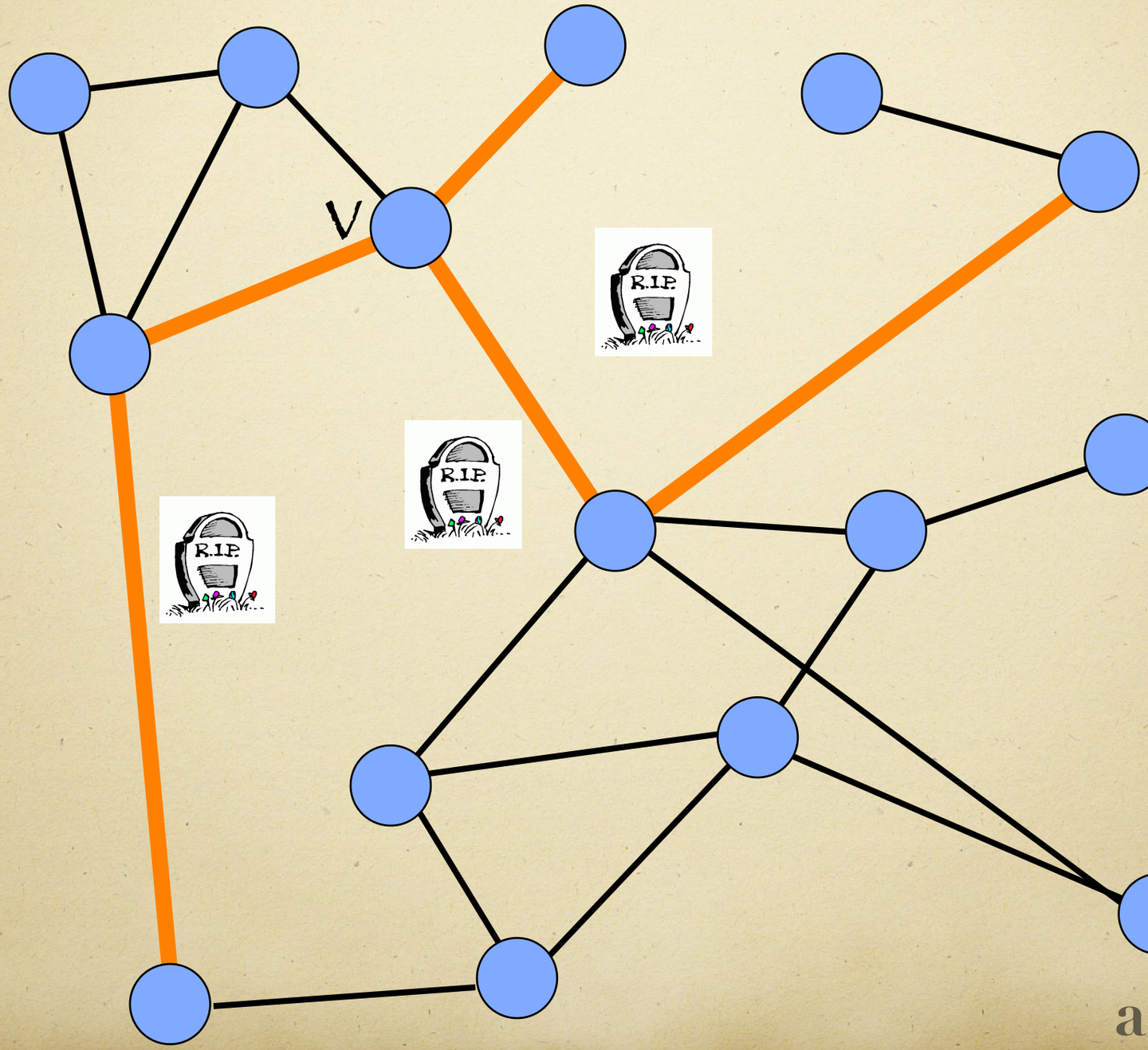
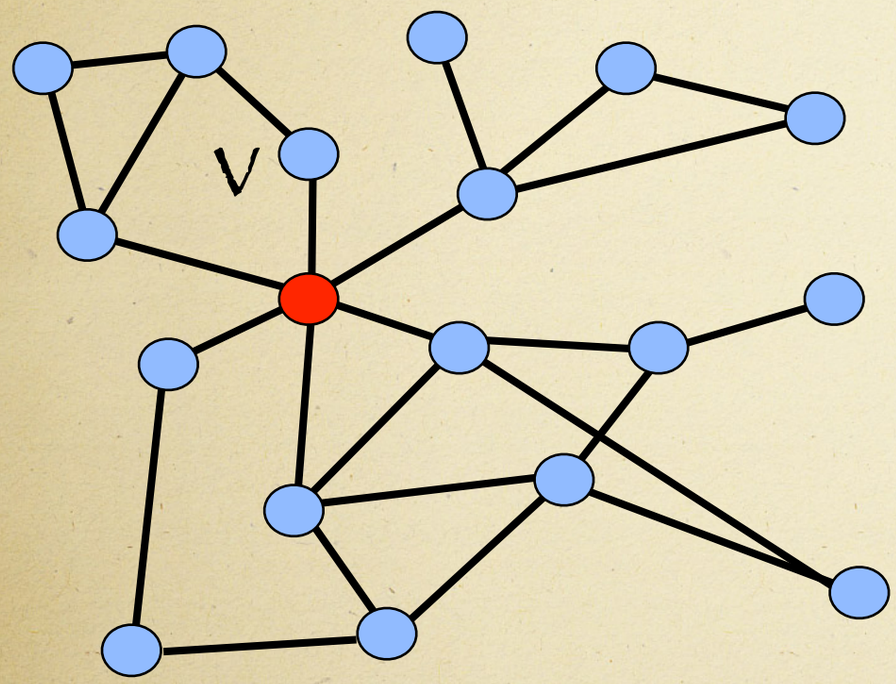


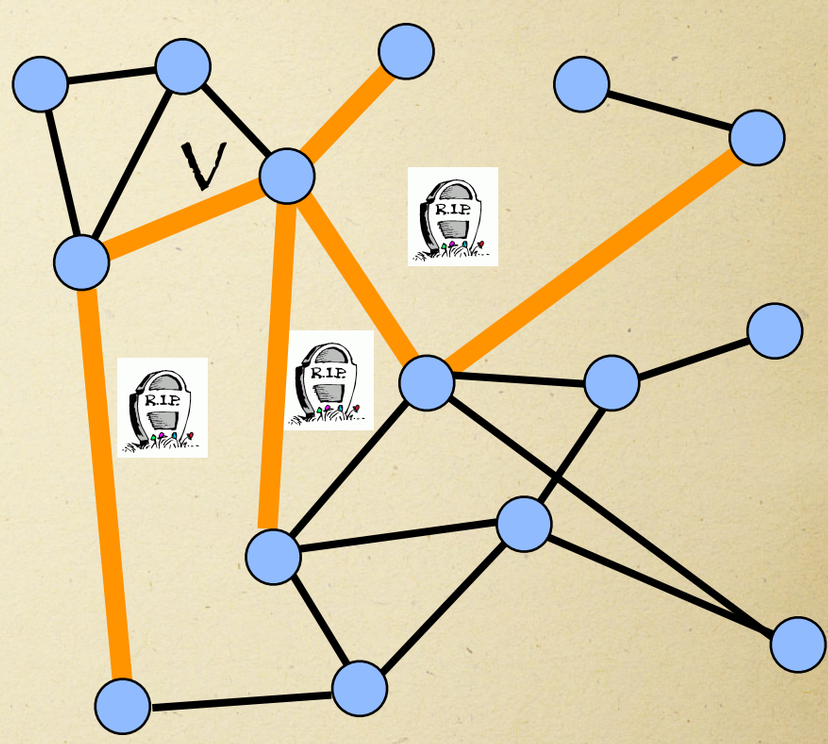
and so on ....

Possible healing topologies:

Line Graph



G_0

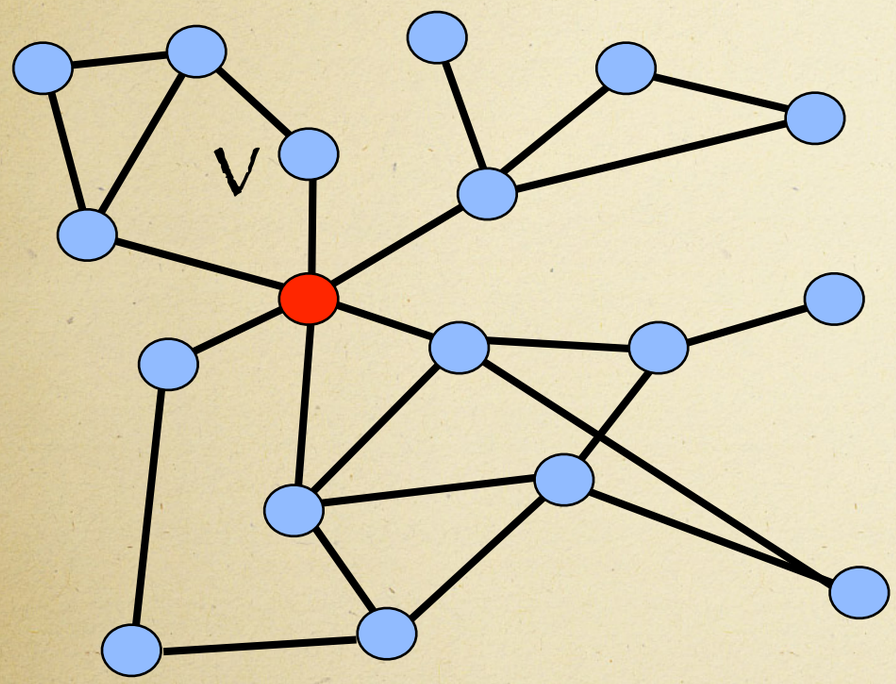


G_3

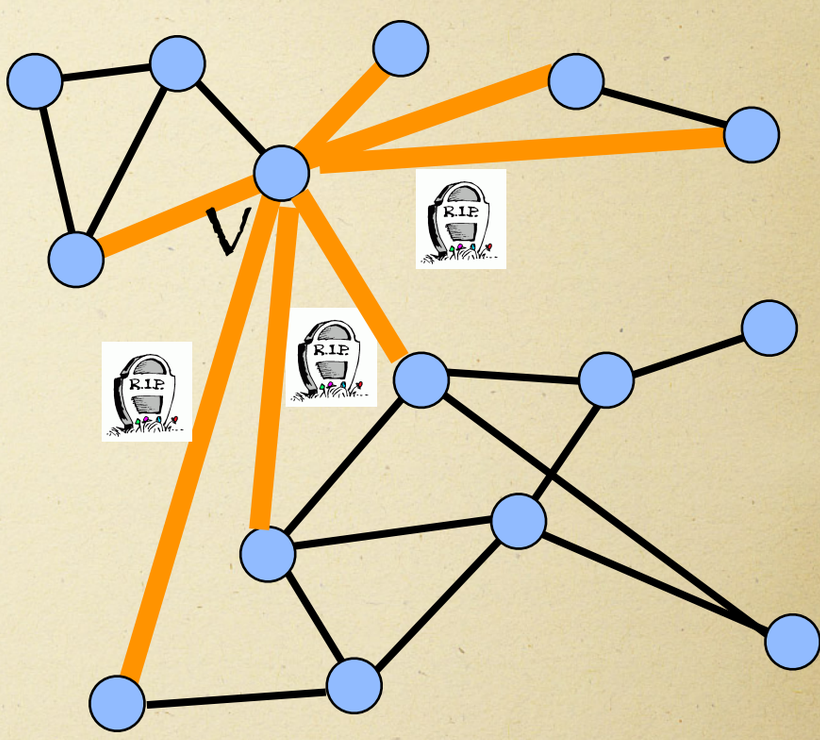
Low degree increase but diameter/ distances blow up

Possible healing topologies:

Star Graph



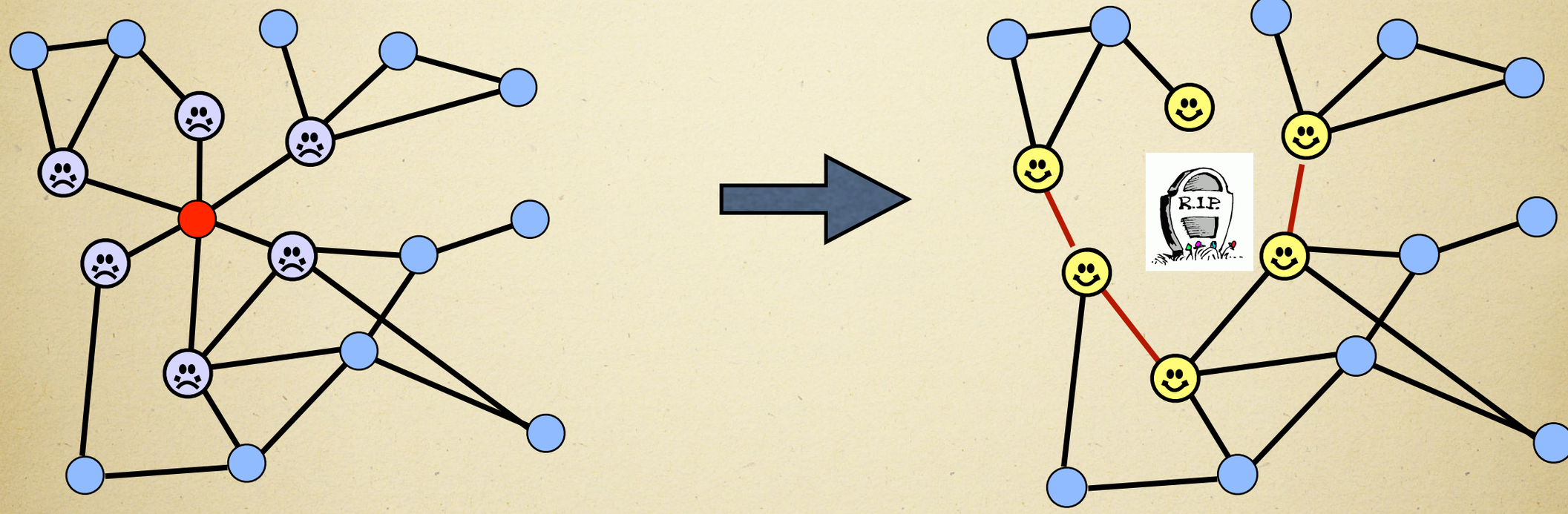
G_0



G_3

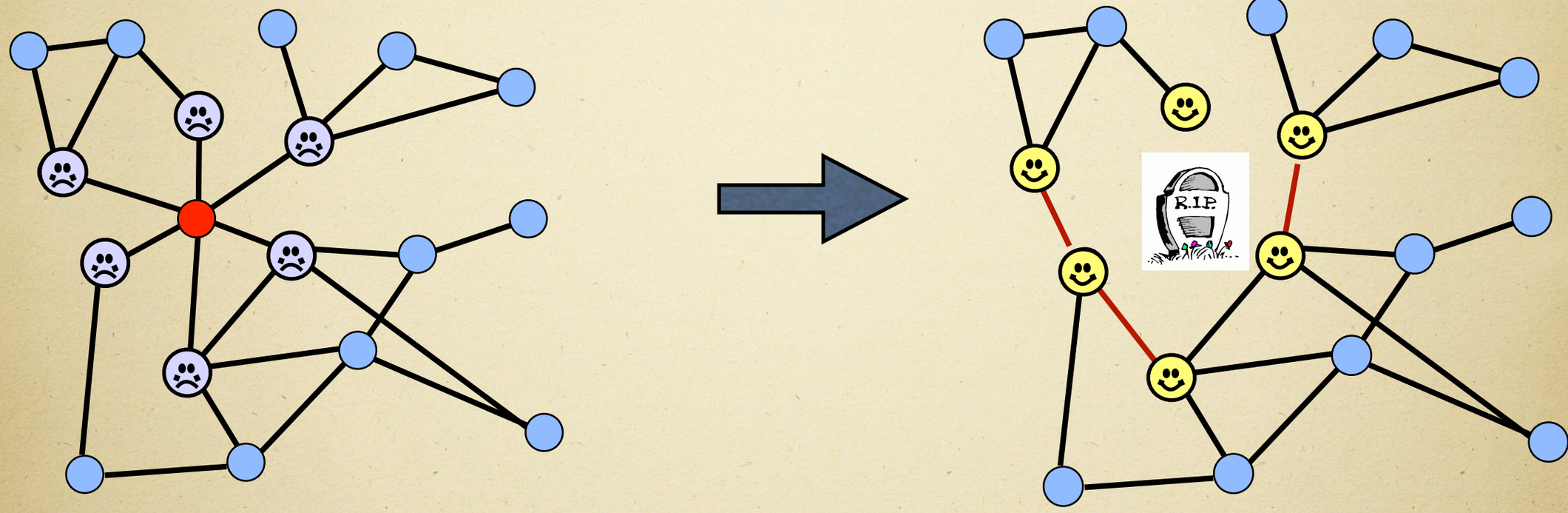
Low distances but degree blows up

Challenge 1: properties conflict



- *Low degree increase => high diameter/stretch/ poorer expansion?*
- *Low diameter => high degree increase?*

Challenge 2: local fixing of global properties

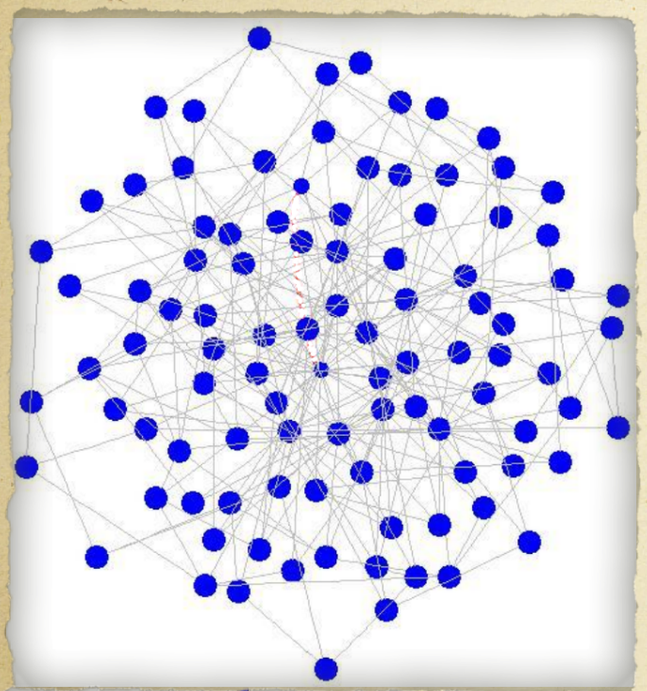


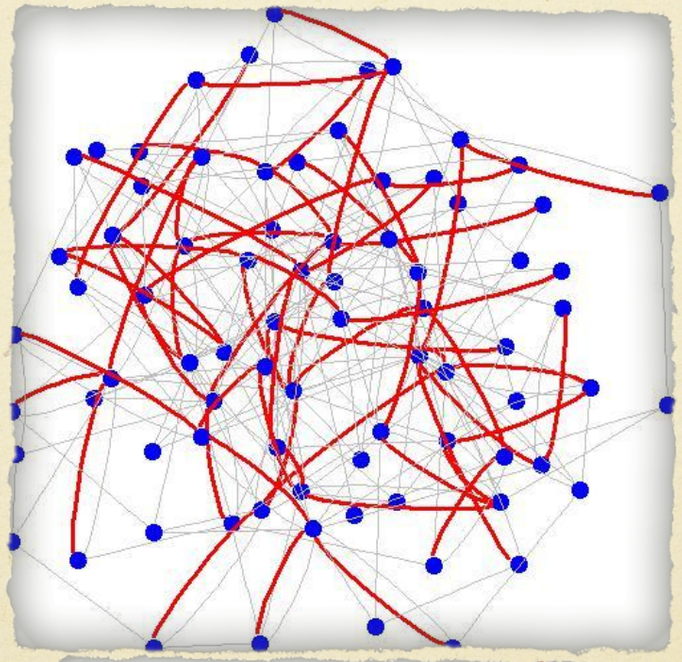
- *Limited global Information with nodes*
- *Limited resources and time constraint*

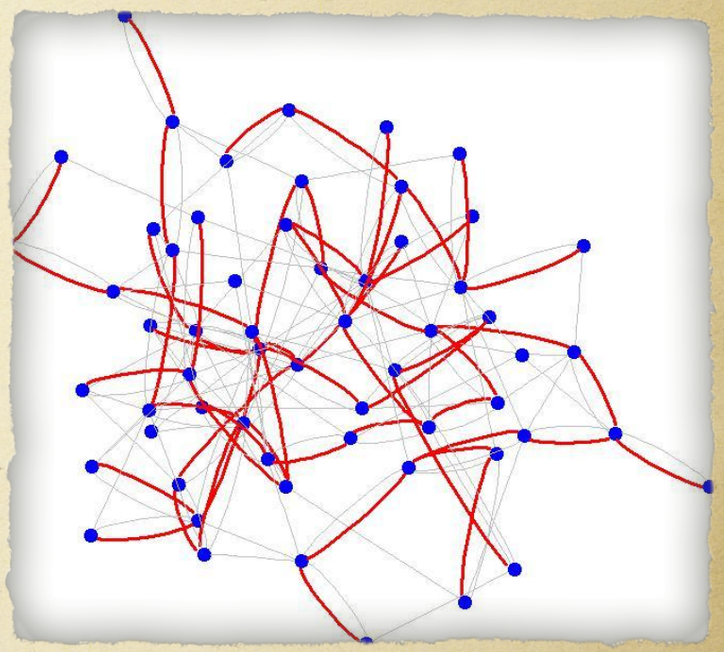
A series of unfortunate events

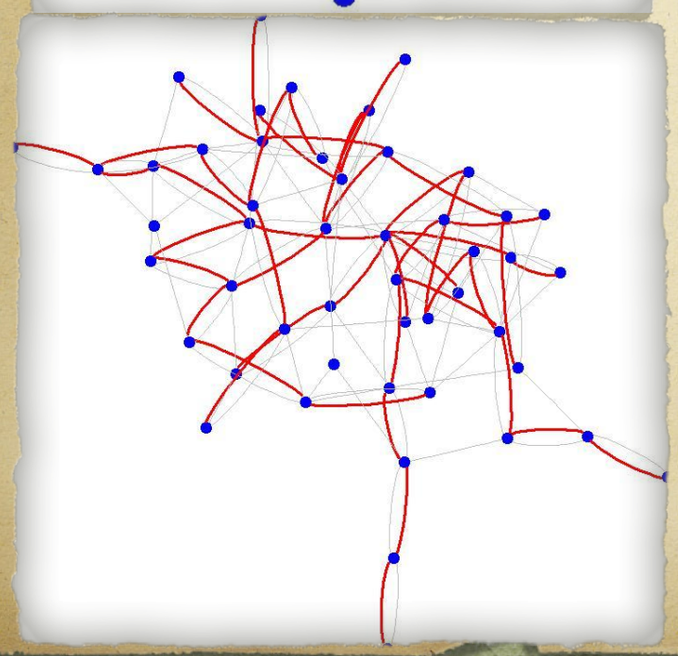
N=100

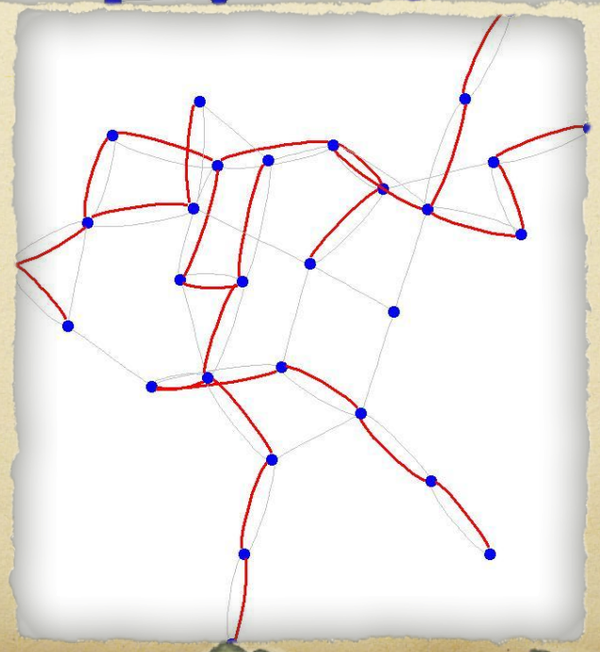
[*DASH*, IPDPS 2008]

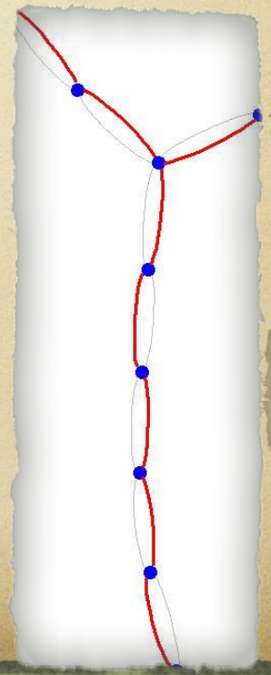












N=10

Self-healing (topological) Goals

- Healing should be fast.
- Certain (topological etc…) properties should be maintained within bounds:
  - Connectivity
  - Degree (quantifies the work done by algorithm)
  - Diameter/ Stretch
  - Expansion/ Spectral properties
  - *<Add your own> ….*
- Cost Metrics: Time, #messages per healing and change in properties (dilation) over lifetime.

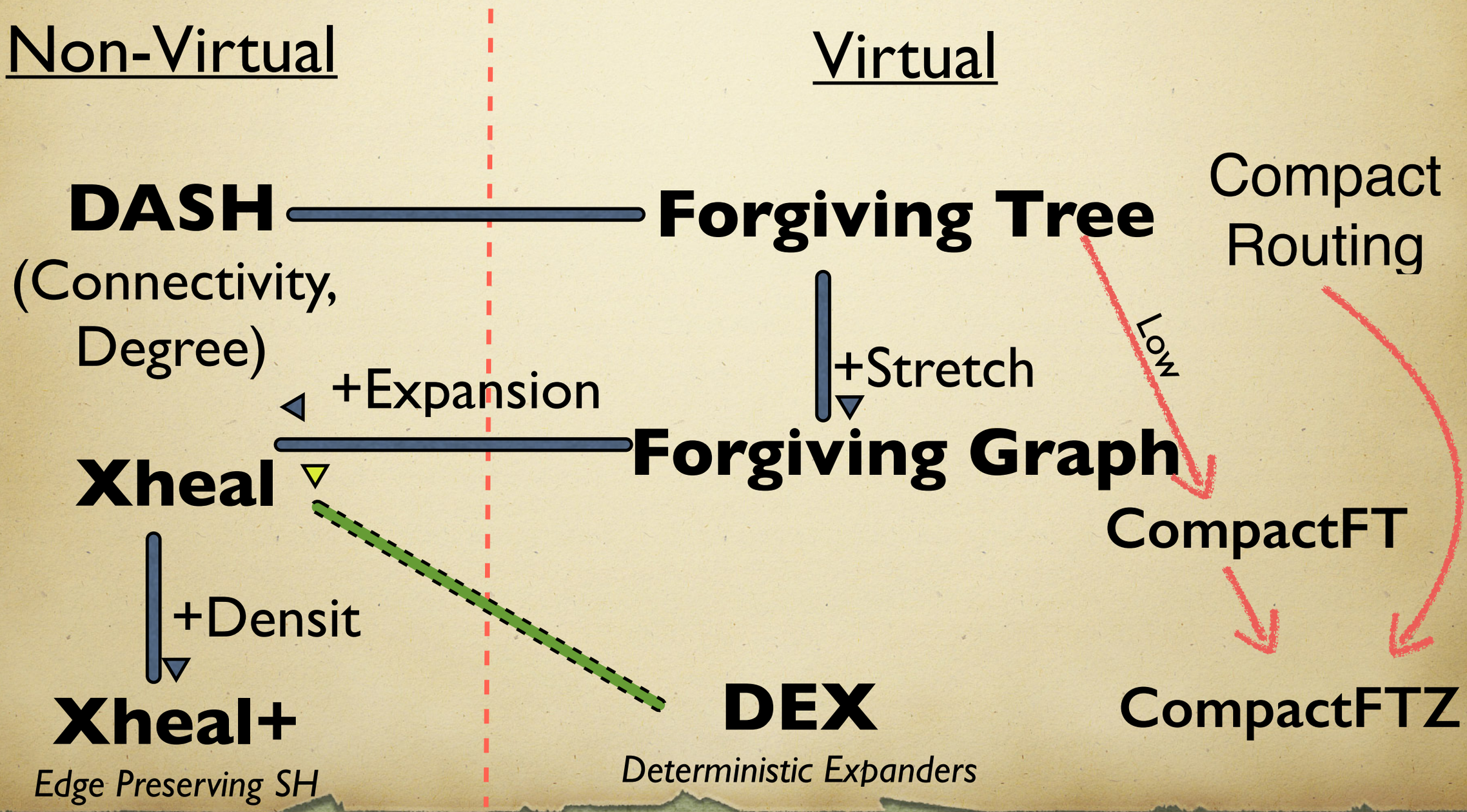
A Self-healing System

- System: a responsive reconfigurable system
- Attack action: An adversary <attacks>
- Healing action: After each adversary action, we <*repair*> locally (and quickly)!

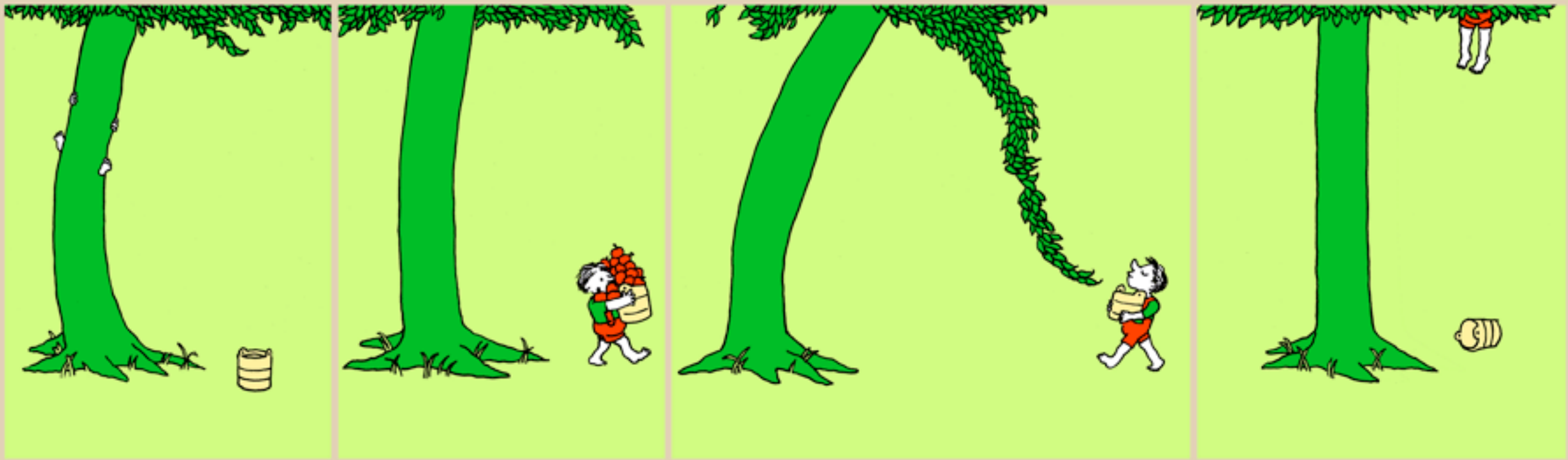
Self-healing Goals

- Healing should be fast.
- Fault Tolerant: Certain properties should be maintained within bounds
  - <List the properties>
- Cost Metrics: Costs per healing and change in properties (dilation) over lifetime.

Our Self-healing Algorithms



pbfcomics.com (apologies, Silverstein)



Thank You

Questions and future work

- Empirical studies: Beyond model assumptions, multiple failures (varying proximities), cascading failures, high churn, restricted rules, topologies
- What is the best way to analyse fully node dynamic algorithms (say, self-healing graphs)?
- Load-balanced self-healing: Chord like structures? Small world models?
- Extend model and algorithms to multiple failures, sensor networks etc.
- `Behavioural' Self-healing
- Can edge dynamic temporal theory help? In some use cases, possibly node dynamic are contained in Edge dynamic!
- Temporal self-healing and memory constrained Processes? - Routing* etc…
- A general theory for dynamicity - routing schemes as compositions/ operators on self-healing networks