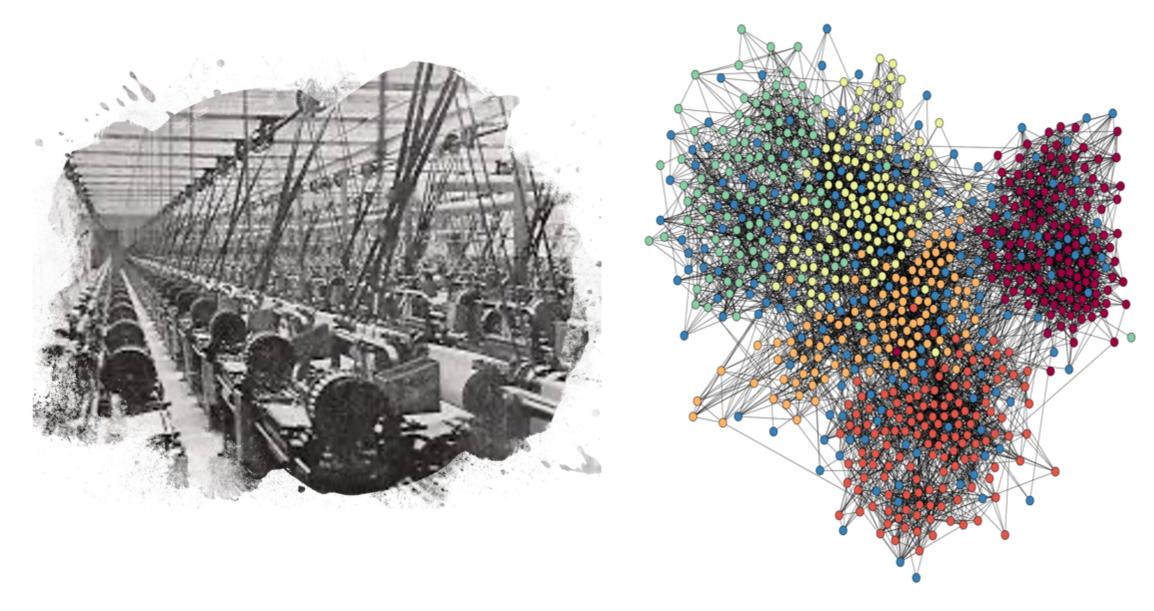
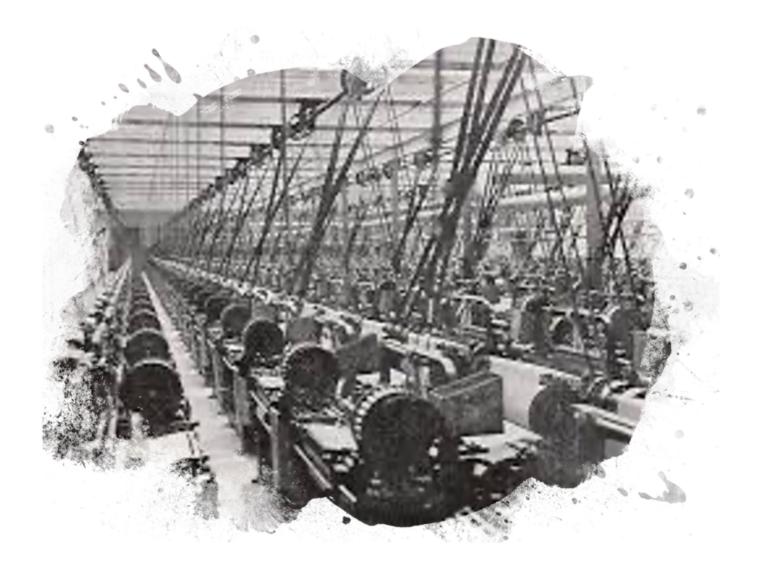
Graphs – A Fundamental shift from Linear to non-linear



Industrial Scientific Foundation

Newtonian Science

Industrial Era Cause -> Effect Linear



A Recent Scientific Evolution

Newtonian Network Science -----> Science Industrial Era Information Era Cause -> Effect Causes -> <sparse matrix> -> Effect Non-linear Linear FLIGHT SOFTWARE **HYDRAULIC FLIGHT CONTROL** CONTROLS DEPENDANCIES ENGIN MAN MACHINE INTERFACE

GROUND HANDLING

WEAPON MANAGEMENT

LOGISTICS

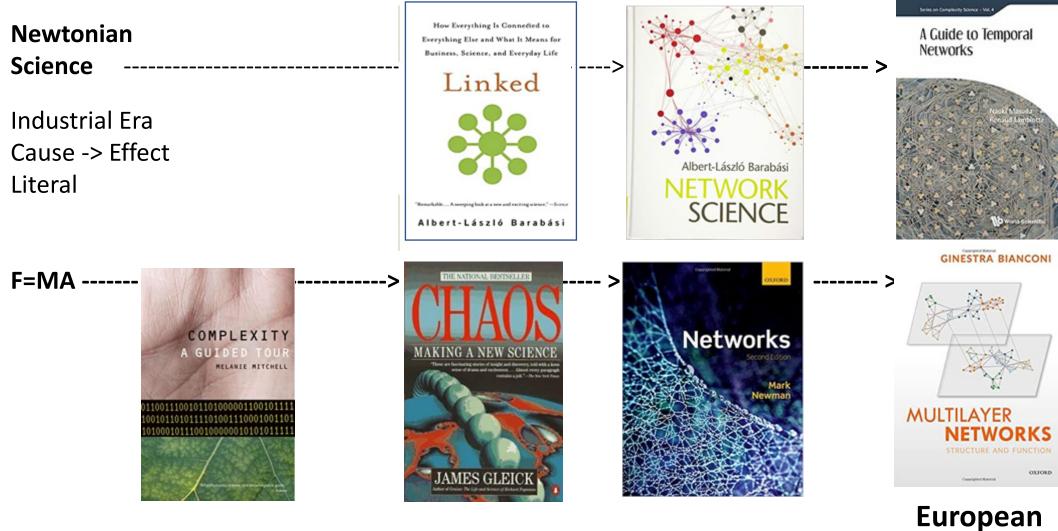
A Recent Scientific Evolution

Newtonian Science		Network > Science
Industrial Era Cause -> Effect Linear		Information Era Causes -> <sparse matrix=""> -> Effect Non-linear</sparse>
F=MA >Complexity	> Chaos>	Network

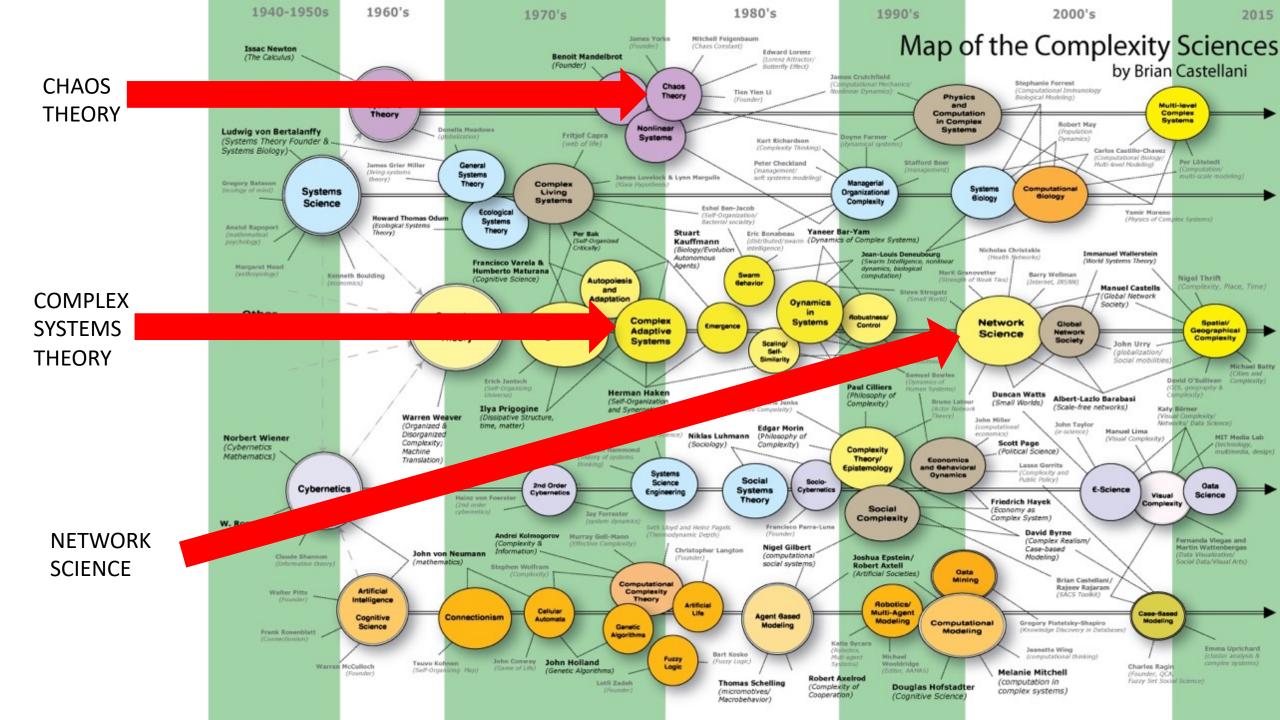
F=IVIA >Complexity	> Chaos	> Network
Theory	Theory	Science
Diversity	Fractals	Data Relationships
Emergence	Tipping-	Metrics for understanding-
Self-	Points	relationships
Organization		Network ubiquity across

Adaptability

A Recent Scientific Evolution



Origin



NETWORK SCIENCE – HIGH SCHOOL TO TERMINAL DEGREE

Principals of Network Literacy

Networks

Are everywhere

Describe how things connect and interact .

Reveal patterns.

Cross Disciplines

Can be visualized in many ways.

Permit comparison of a wide variety of systems.

Computer technology allows the study real-world networks. The structure and state of networks interact dynamically

Network PhD Offerings

Indiana University Informatics PhD track in Complex Networks and Systems, established 2005.

Northeastern: PhD Program, established 2014.

Central European University, established 2015.

UCSB Network Science IGERT, established 2014.

<u>Network Biology, University of Maryland, NRT</u>, beginning 2017.

Indiana University NSF-NRT Dual PhD program in Complex Networks and Systems, established 2017.

NETWORKS ARE EVERYWHERE!

<u>Technological</u>

<u>Electronic</u> Internet

> PAN, LAN, WAN, MAN Cloud Virtualization IOT, II, IOE, IOA. 4th IR Software Dependency Infrastructure

> > Gas Electricity (Grid) Water Sewer

Telephone <u>Transportation</u> Road Vehicles Railroad Airplane Maritime

Industry

Distribution/Logistics Supply Chain Military Warfare Architecture Social (Ego-Centered, Affiliation, SNA) Economics (Macro, Micro, Market) Information

WWW (Internet Virtualization) Citation **Academic** Patent Legal Peer to peer Recommendation/Keyword Index **Psychology** (Consciousness, Cognition) Neurology (Human Brain, neurology) Physics (Quantum, String Theory) Chemistry (Organic, Nano) **Biology** Epidemiology **Biochemical**

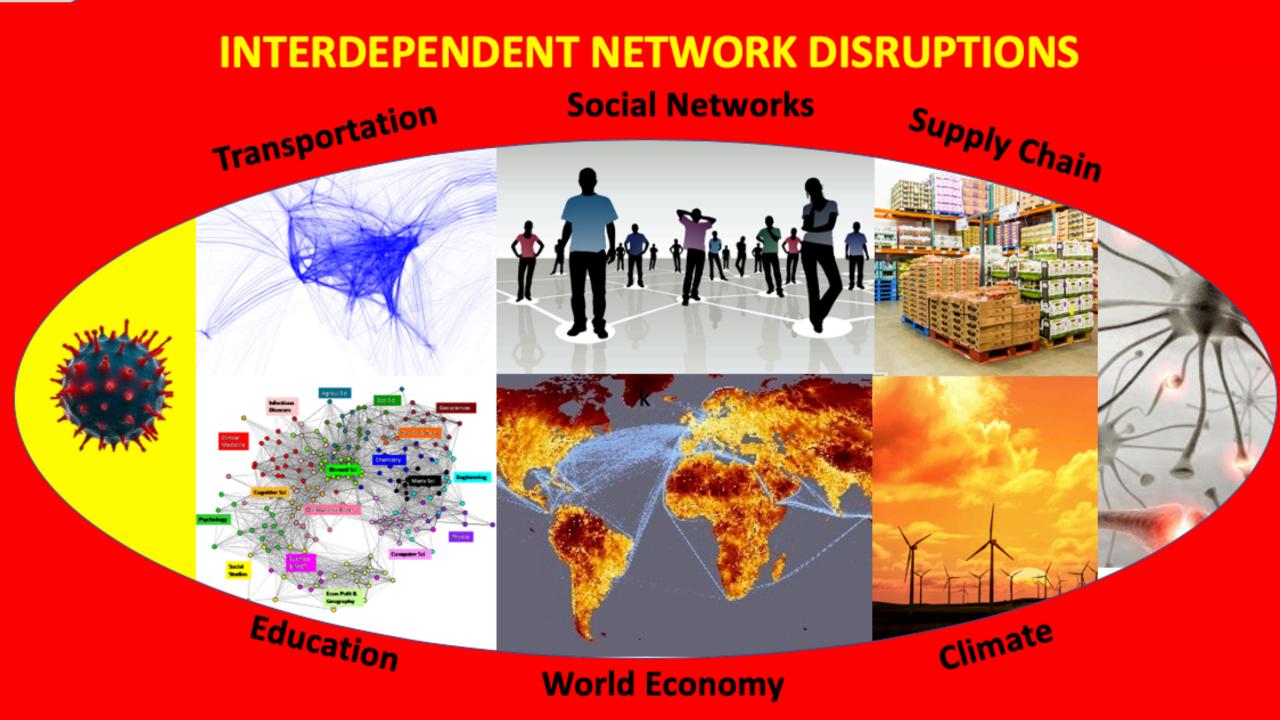
> Metabolic and Molecular Protien-Protien Interaction Genetic Regulation (RNA, DNA)

Ecological Evolution Mathematical

© STEMCorp

INTERDEPENDENT NETWORK DISRUPTIONS

COVID-19



NEWTONIAN PHYSICS

NETWORKED WORLD

Image: http://alwaysquestionauthority.com/2013/04/14/art-round-hole-square-peg/

PEOPLE TEND TO BE LITERATE

http://intervisivejournal.com/integs while to see and, door as atten as writh with hile. For her, human to an through at long retiring all show and times we do have when we finally moning to be in the same place in the Same time, Init's just helping andrew, this make the works while a schoolly, he lister a little with the spear older teather, only he's much tables and with divides pair. and so, but so, but the could be I guess that mans he doesn't welly take the your writer at all. Company, I was belie her doub to doe attended found that our The behinding in their and Sample rists angent idea to my and you at the term the countripoint Encyclinger const First Body is not of the countries and west contributing extress a second second second second below the Ca of Triangue is her countries how a conder-town the triang of the countries of the thirty below the Ca The line There is a street during that the webback-the neural with the directs sent in +7 section were still be diving and a king for direction & Under that security in the agreed resigned on the or I I don't know but and a king for direction & Under that security is a great resigned on the or I

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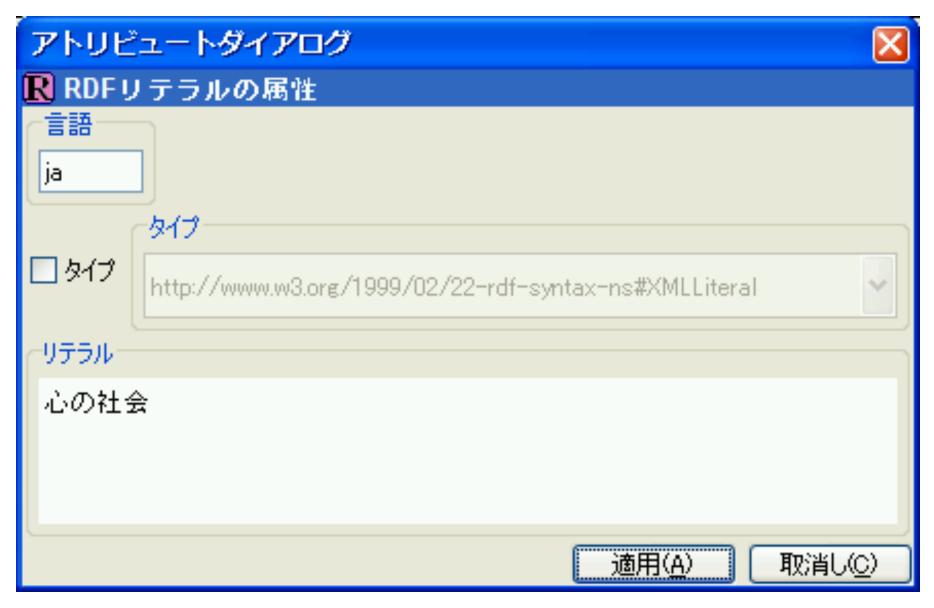
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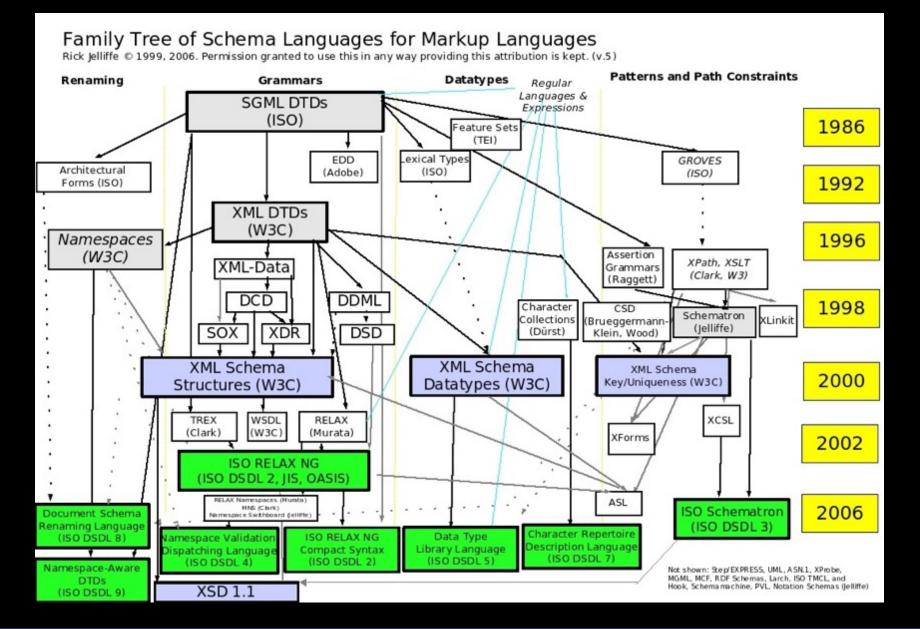
LITERACY BREEDS KNOWLEDGE



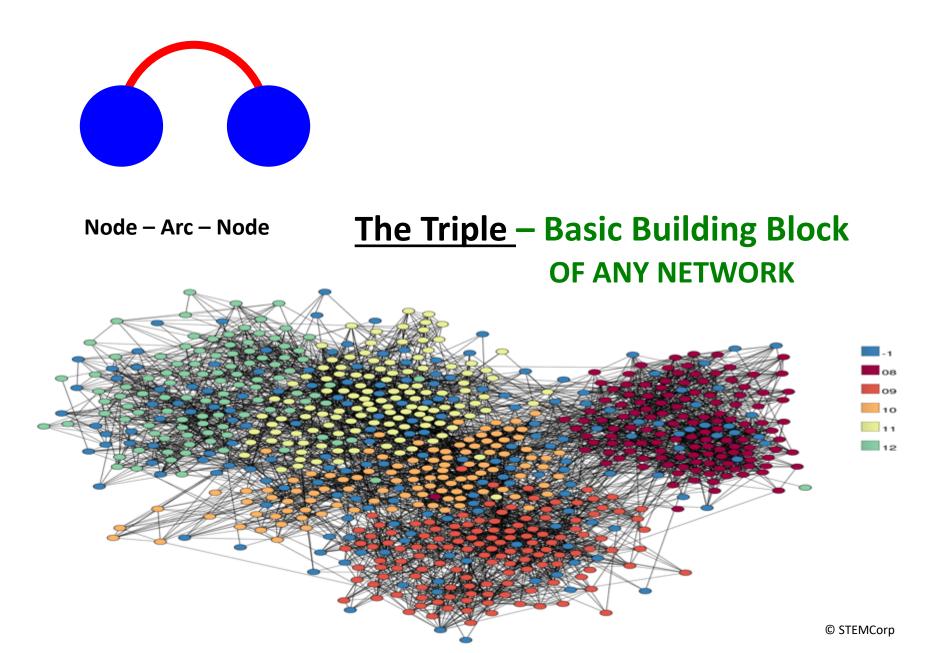
COMPUTERS ARE LITERAL



LITERAL BREEDS MORE LITERAL



FUNDAMENTAL GRAPH REASONING



Coloring algorithm Hopcroft–Karp algorithm

Hungarian algorithm

GRAPH ALGORITHMS - Empowering the 21st Century

Prüfer coding Tarjan's off-line lowest common ancestor's algorithm **Topological sort** Graph drawing **Force-based algorithms** Spectral layout spring-based algorithm Network theory Network analysis Link analysis Girvan–Newman algorithm Web link analysis Hyperlink-Induced Topic Search PageRank TrustRank Flow networks Dinic's algorithm Ford–Fulkerson algorithm Edmonds-Karp algorithm Karger's algorithm Push-relabel algorithm Almost Linear Max Flow **Routing for graphs** Edmonds' algorithm Euclidean minimum spanning tree Euclidean shortest path problem Longest path problem

Minimum spanning tree

Borůvka's algorithm Kruskal's algorithm Prim's algorithm Reverse-delete algorithm Woodhouse-Sharp Nonblocking minimal spanning switch

Shortest path problem

Bellman–Ford algorithm Dijkstra's algorithm Floyd–Warshall algorithm Johnson's algorithm Transitive closure problem **Traveling salesman problem** Christofides algorithm Nearest neighbour algorithm Warnsdorff's rule

Graph search

A* Tree Search Dijkstra's algorithm Jump point search

B*

Backtracking Beam search Beam stack search Best-first search Bidirectional search Breadth-first search Brute-force search D* Depth-first search General Problem Solver Iterative deepening depth-first search

Lexicographic breadth-first search Uniform-cost search State space search



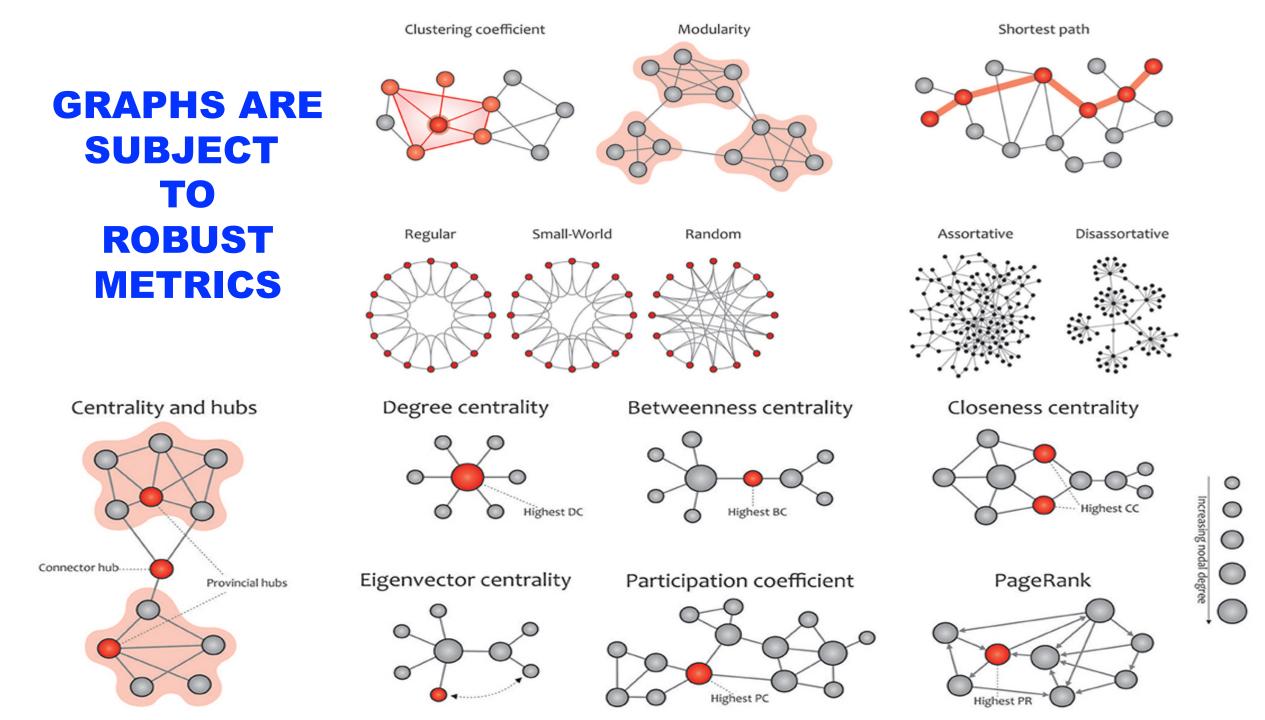
Subgraphs

Cliques

Bron–Kerbosch algorithm MaxCliqueDyn maximum clique algorithm Strongly connected components Path-based strong component algorithm Kosaraju's algorithm Tarjan's strongly connected componens algorithm Subgraph isomorphism problem

amazon





GRAPHS ARE ALL ABOUT RELATIONSHIPS

- Describe network phenomena
 - Static (no state changes supported)
 - Dynamic (with mathematical underpinnings)
- Extensible for Interoperability
 - Detachable subgraphs (for functional analysis)
 - Network of Network aggregate (Mathematically describable)
- Flexible Design Options
 - Formal Logic constrained
 - Event driven in real time
 - Emerging Dynamic architecture

- Language Usage Options
 - Self-organizing Natural Language
 - Controlled Vocabularies
 - Formal Logic Notation (e.g. DOL)
- Amenable to Graph Algorithms
 - Measurable
 - Quantifiable via metrics
 - Qualifiable via property assignment
- Ultimately Scalable

"Networks are ímportant because íf we don't understand networks, we can't understand how markets function, organizations solve problems, or how societies change."

Duncan Watts