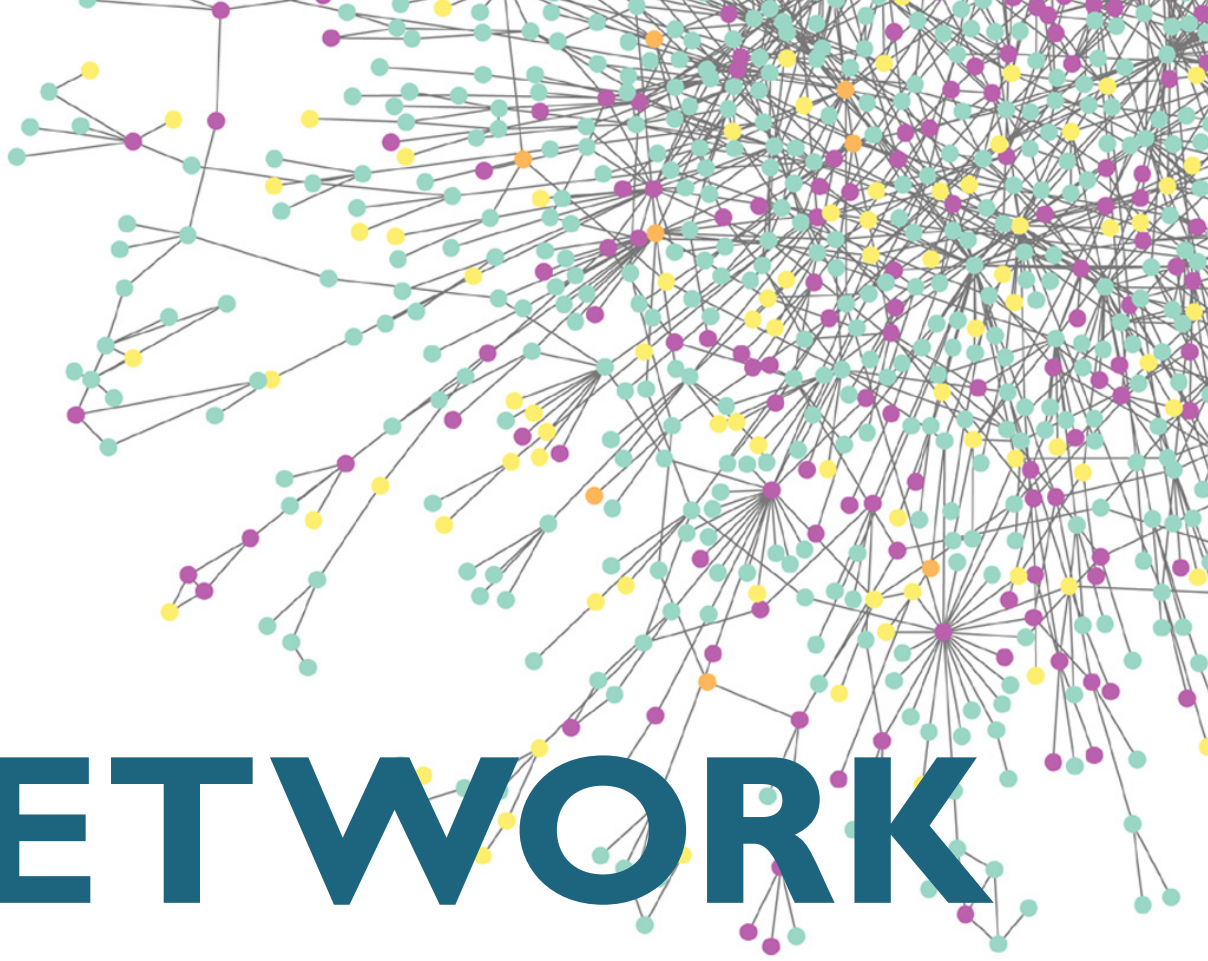


NETWORK LITERACY

Essential Concepts and Core Ideas

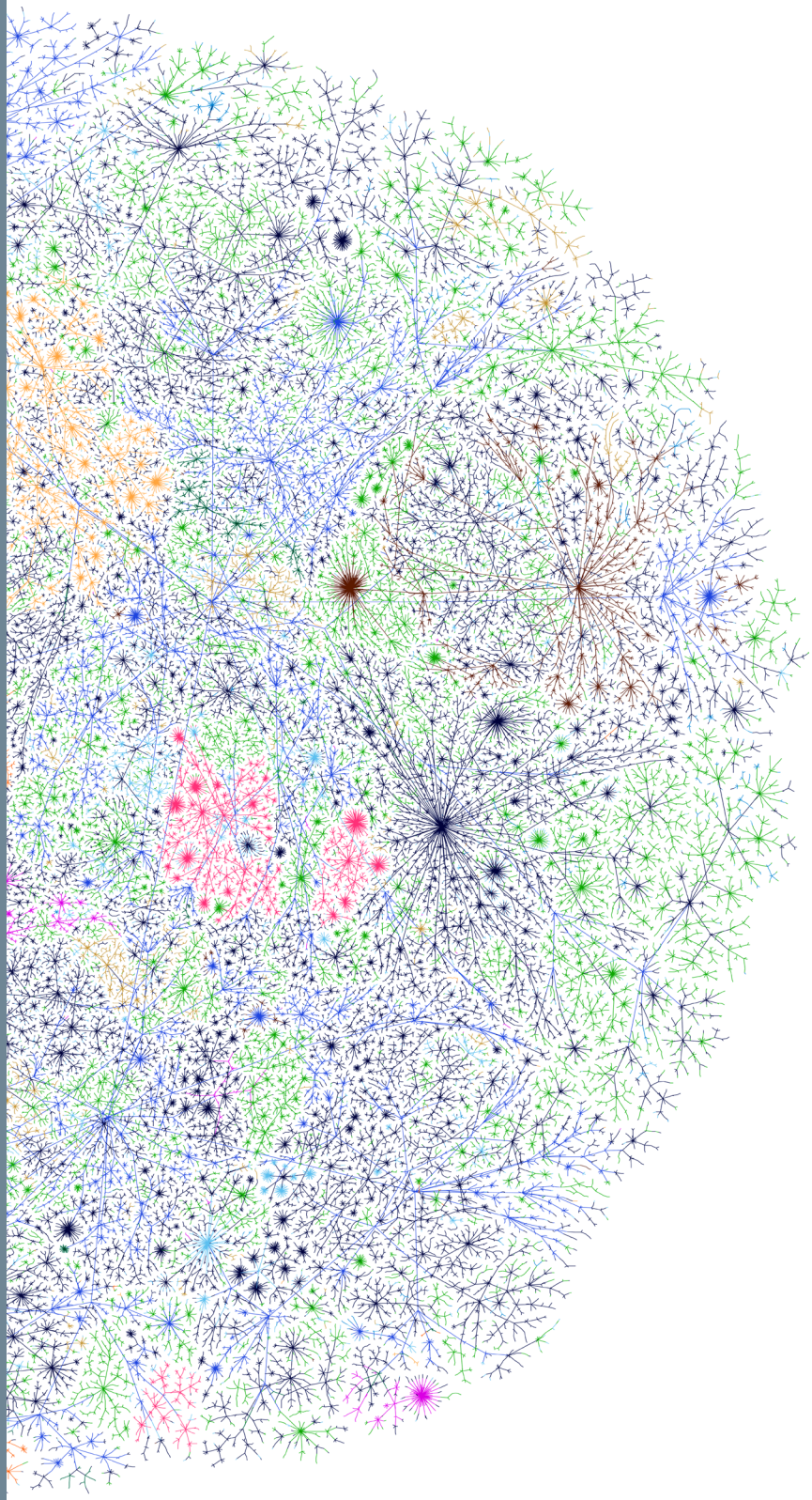
NetSciEd

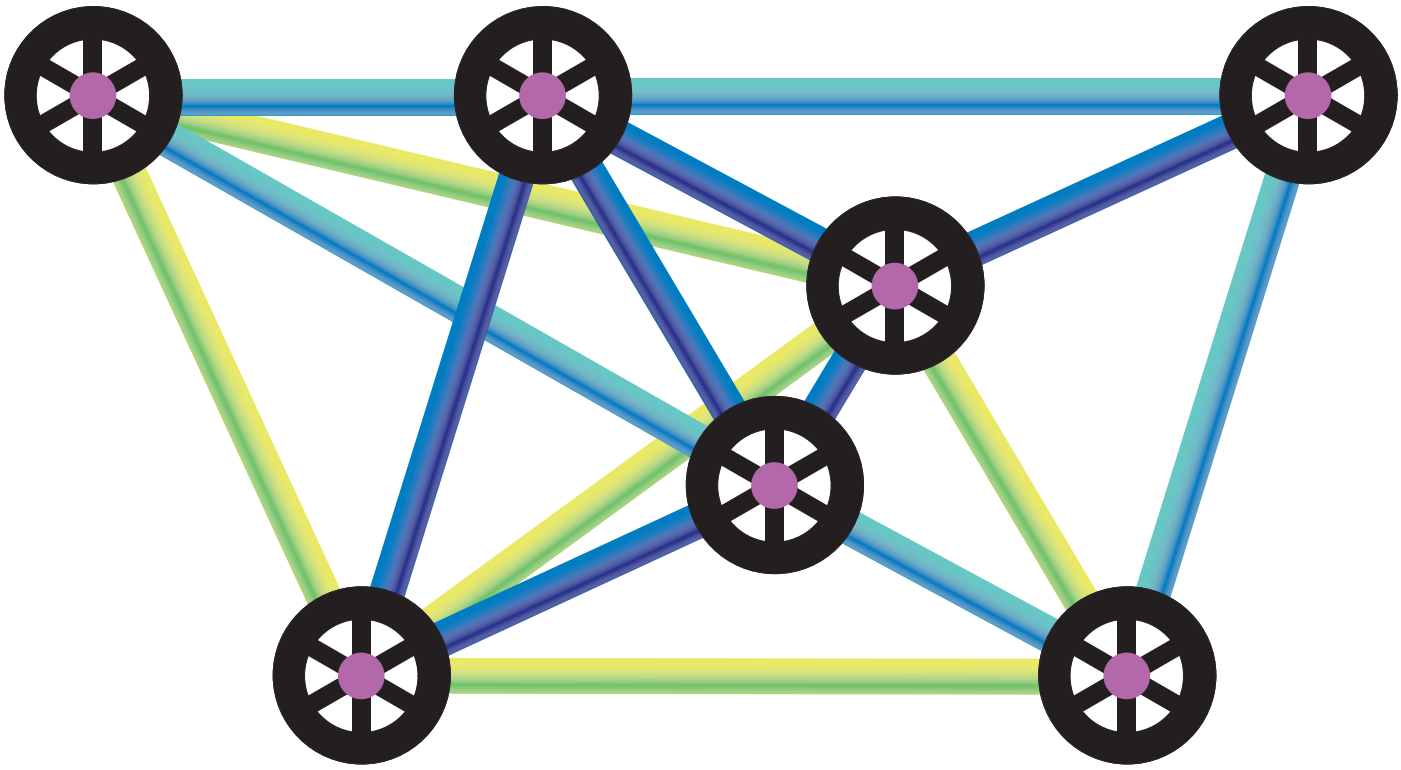
As our world becomes increasingly connected through the use of networks that allow instantaneous communication and the spread of information, the degree of people's understanding of how these networks work will play a major role in determining how much society will benefit from this heightened connectivity. In short, a networked society requires *network literacy*: basic knowledge about how networks can be used as a tool for discovery and decision-making, and about both their potential benefits and pitfalls, made accessible for all people living in today's networked world. Moreover, because even young children interact with networks all day, every day, it is important that network literacy begins at a young age, and because networks are present in all aspects of contemporary life, the consideration of networks should be reflected throughout teaching practice in a cross-disciplinary manner. Yet despite the importance and ubiquity of networks, the study of networks is absent from current educational systems.

This brochure provides an initial step toward facilitating the development of network literacy. It states basic ideas for the study of networks in plain language, presenting seven essential concepts and more detailed core ideas that are described in a concise manner. It can be used by everyone for teaching and learning. This work was developed iteratively and collaboratively by a community of scientists and practitioners who develop and use the cutting-edge science of networks. For more information and additional resources about the network literacy initiative, please visit the project website: http://sites.google.com/a/binghamton.edu/netscied

1 NETWORKS ARE EVERYWHERE

- The concept of networks is broad and general, and it describes how things are connected to each other. Networks are present in every aspect of life.
- There are networks that form the technical infrastructure of our society—e.g., communication systems, semantic systems, the Internet, electrical grids, the water supply, etc.
- There are networks of people—e.g., families and friends, e-mail/text exchanges, Facebook/Twitter/Instagram, professional groups, etc.
- There are economic networks—e.g., networks of products, financial transactions, corporate partnerships, international trades, etc.
- There are biological and ecological networks—e.g., food webs, gene/protein interactions, neuronal networks, pathways of disease spreading, etc.
- There are cultural networks—e.g., language/literature/art connected by their similarities, historical events linked by causal chains, religions connected by their shared roots, people connected to events, etc.
- Networks can exist at various spatial and/or temporal scales.





2

NETWORKS DESCRIBE HOW THINGS CONNECT AND INTERACT

- There is a subfield of mathematics that applies to networks. It is called *graph theory*. Many networks can be represented mathematically as *graphs*.
- Connections are called *links, edges, or ties*. The entities that are connected to each other are called *nodes, vertices, or actors*.
- Connections can be undirected (*symmetric*) or directed (*asymmetric*). They can also indicate ties of different strengths, and can indicate either positive or negative relationships.
- The number of connections of a node is called the *degree* of that node.
- Many networks have more than one type of connection—e.g., offline friendships and Facebook connections, different modes of transportation, etc.
- A sequence of edges that leads from one node, through other nodes, to another node is called a *path*.
- A group of nodes within which a path exists from any one entity to any other entity is called a *connected component*. Some networks have multiple connected components that are isolated from each other.
- Some networks are studied using mathematical structures that are more complicated than graphs.

NETWORKS CAN HELP REVEAL PATTERNS

3

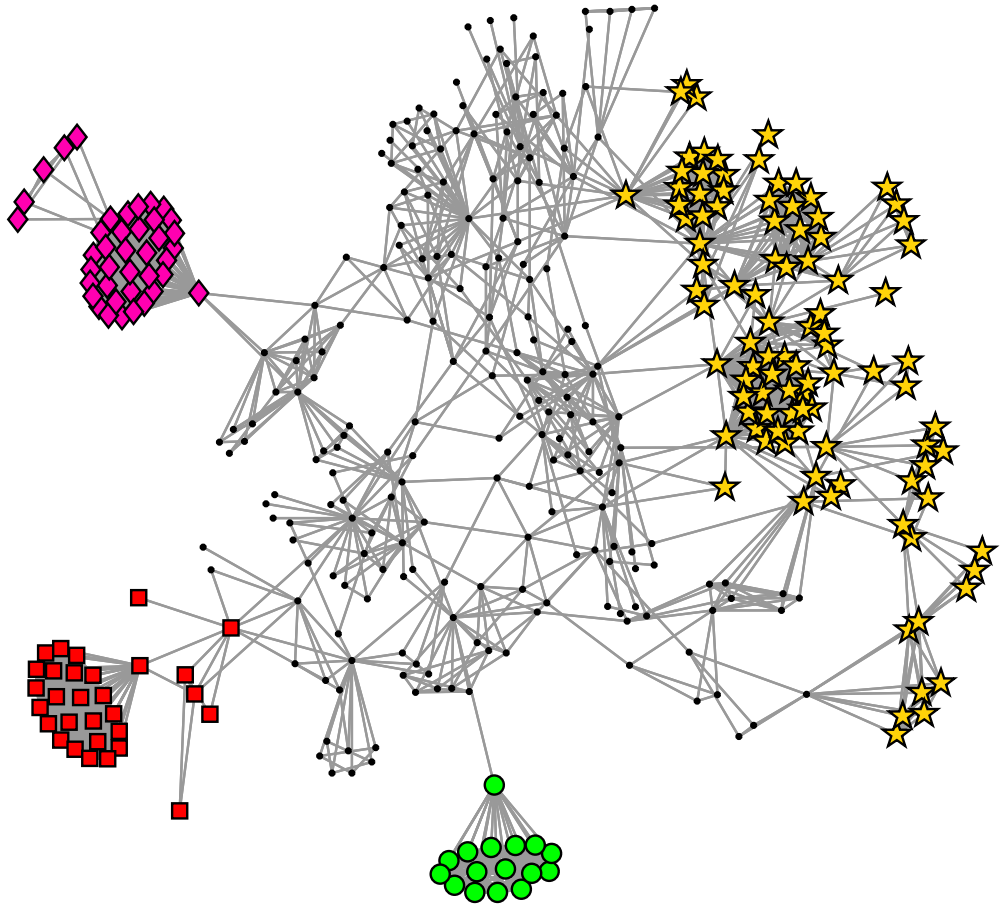
- You can represent something as a network by describing its parts and how they are connected to each other. Such a network representation is a very powerful way to study a system's properties.

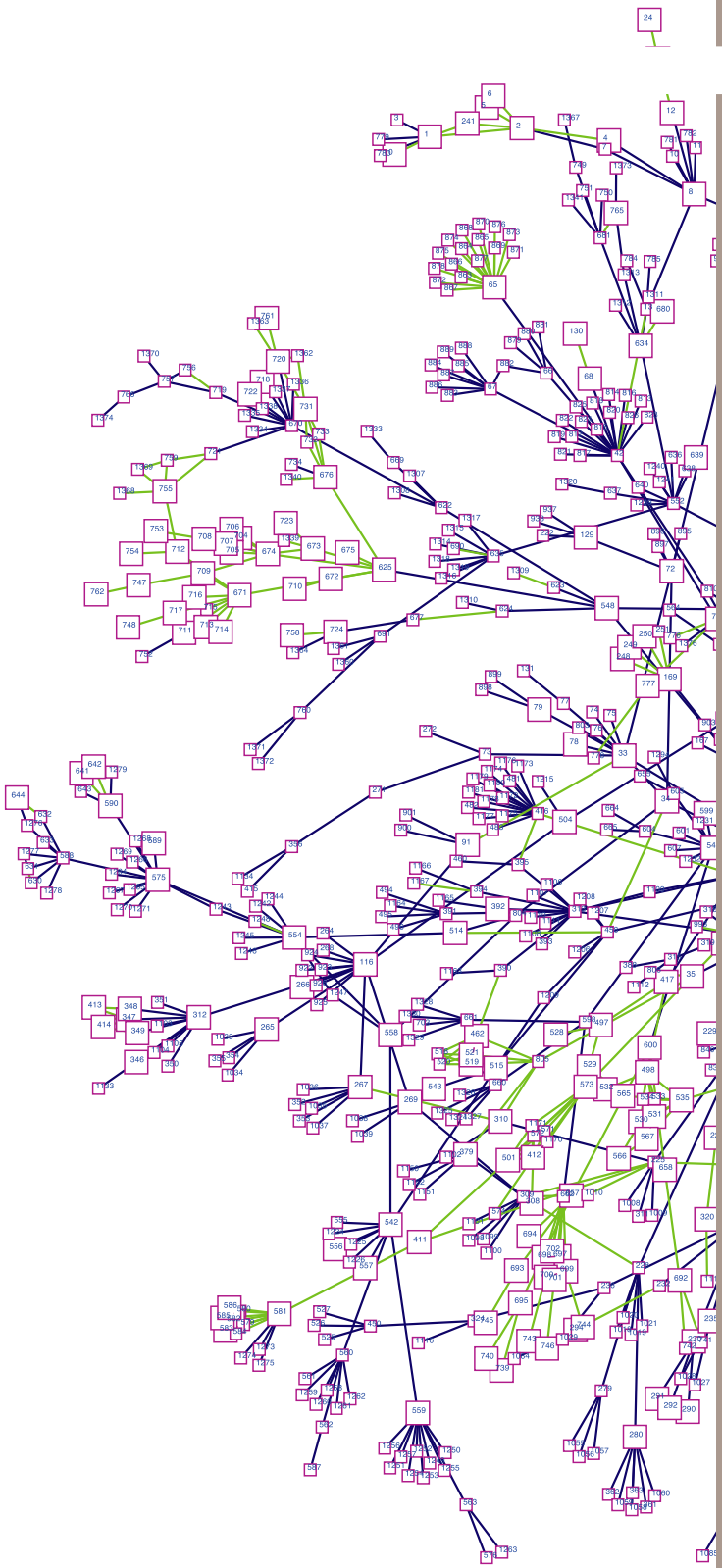
- The properties in a network that you can study include:
  - how the degrees are distributed across nodes
  - which parts or connections are most important
  - strengths and/or weaknesses of the network
  - if there is any sub-structure or hierarchy
  - how many steps, on average, are needed to move from one node to another in the network

- In some networks, you can find a small number of nodes that have much larger degrees than others. They are often called *hubs*.

- In some networks, you can find a group of nodes that are better connected to each other than chance would dictate. They are sometimes called *clusters* or *communities*. Some of them can occupy a central, or *core*, part of a network.

- Using these findings, you can sometimes infer how a network was formed and/or make predictions about dynamical processes on the network or about its future structure.





1 VISUALIZATIONS CAN HELP PROVIDE AN UNDERSTANDING OF NETWORKS

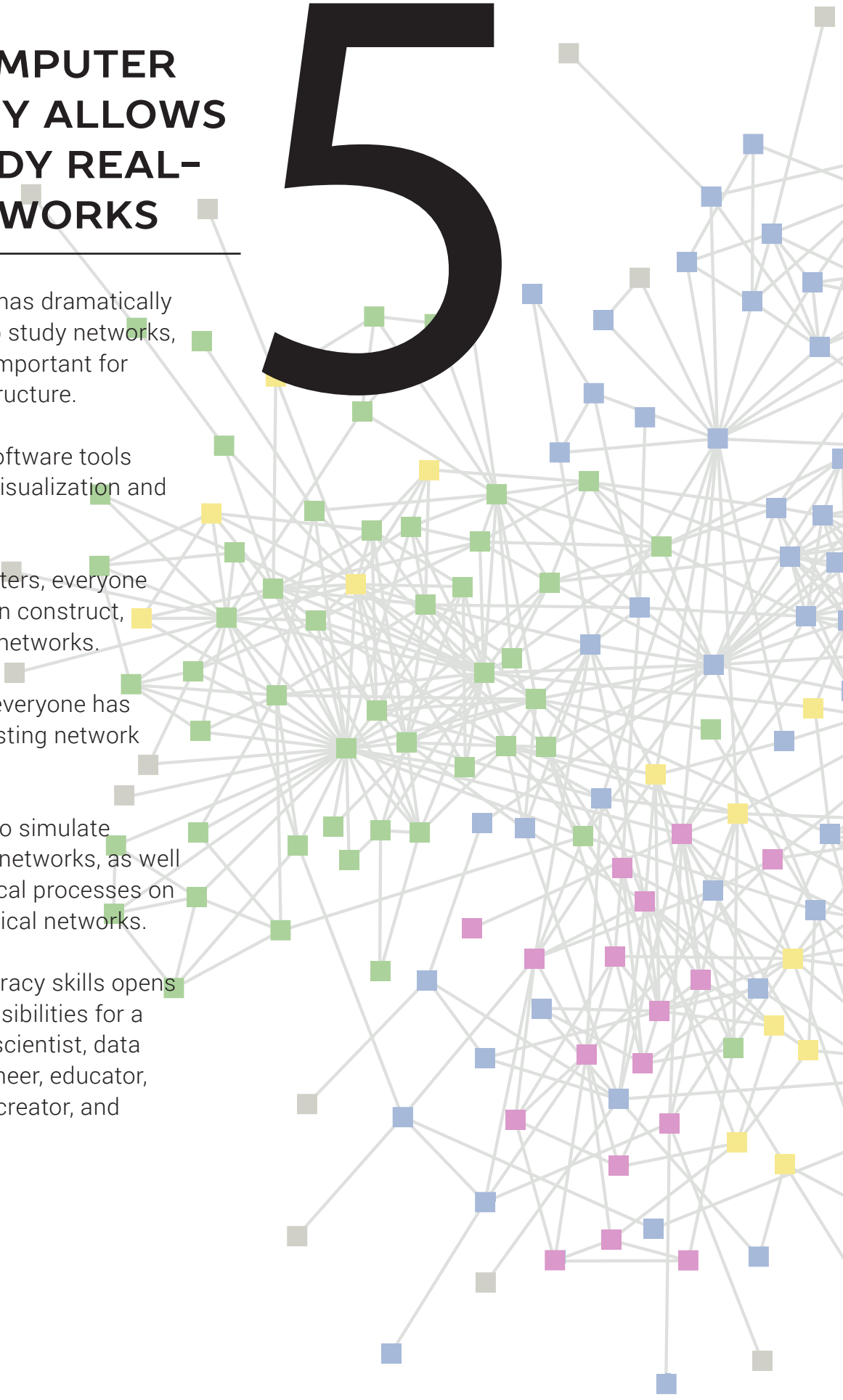
- Networks can be visualized in many different ways.
- You can draw a diagram of a network by connecting nodes to each other using edges.
- There are a variety of tools available for visualizing networks.
- Visualization of a network often helps to understand it and communicate ideas about connectivity in an intuitive, non-technical way.
- Creative information design plays a very important role in making an effective visualization.
- It is important to be careful when interpreting and evaluating visualizations, because they typically do not tell the whole story about networks.

4

5

TODAY'S COMPUTER TECHNOLOGY ALLOWS YOU TO STUDY REAL-WORLD NETWORKS

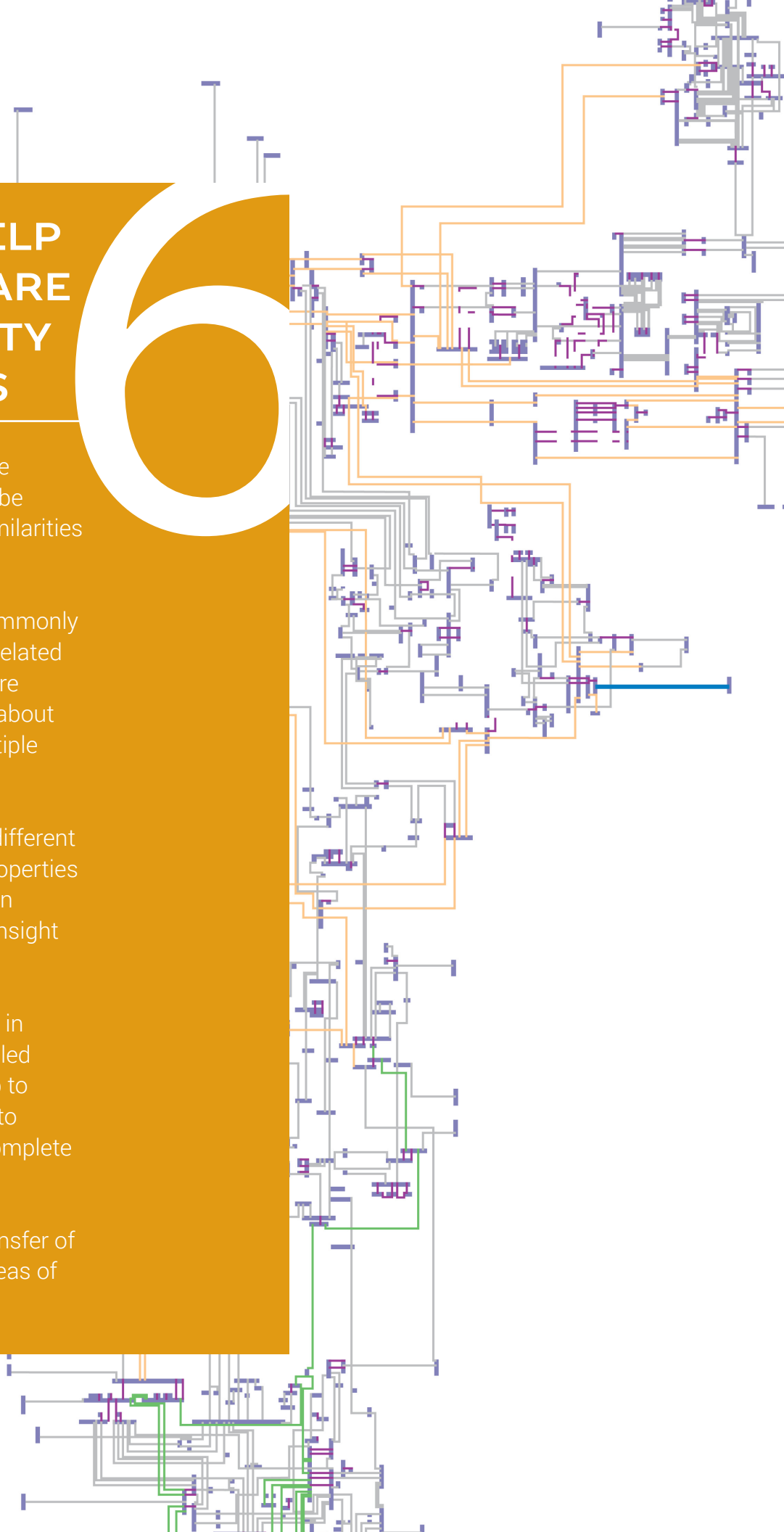
- Computer technology has dramatically enhanced the ability to study networks, and this is especially important for large ones with rich structure.
- There are many free software tools available for network visualization and analysis.
- Using personal computers, everyone (not just scientists) can construct, visualize, and analyze networks.
- Through the Internet, everyone has access to many interesting network data sets.
- Computers allow you to simulate hypothetical or virtual networks, as well as to simulate dynamical processes on both real and hypothetical networks.
- Learning computer literacy skills opens the door to myriad possibilities for a career. These include scientist, data analyst, software engineer, educator, web developer, media creator, and many others.

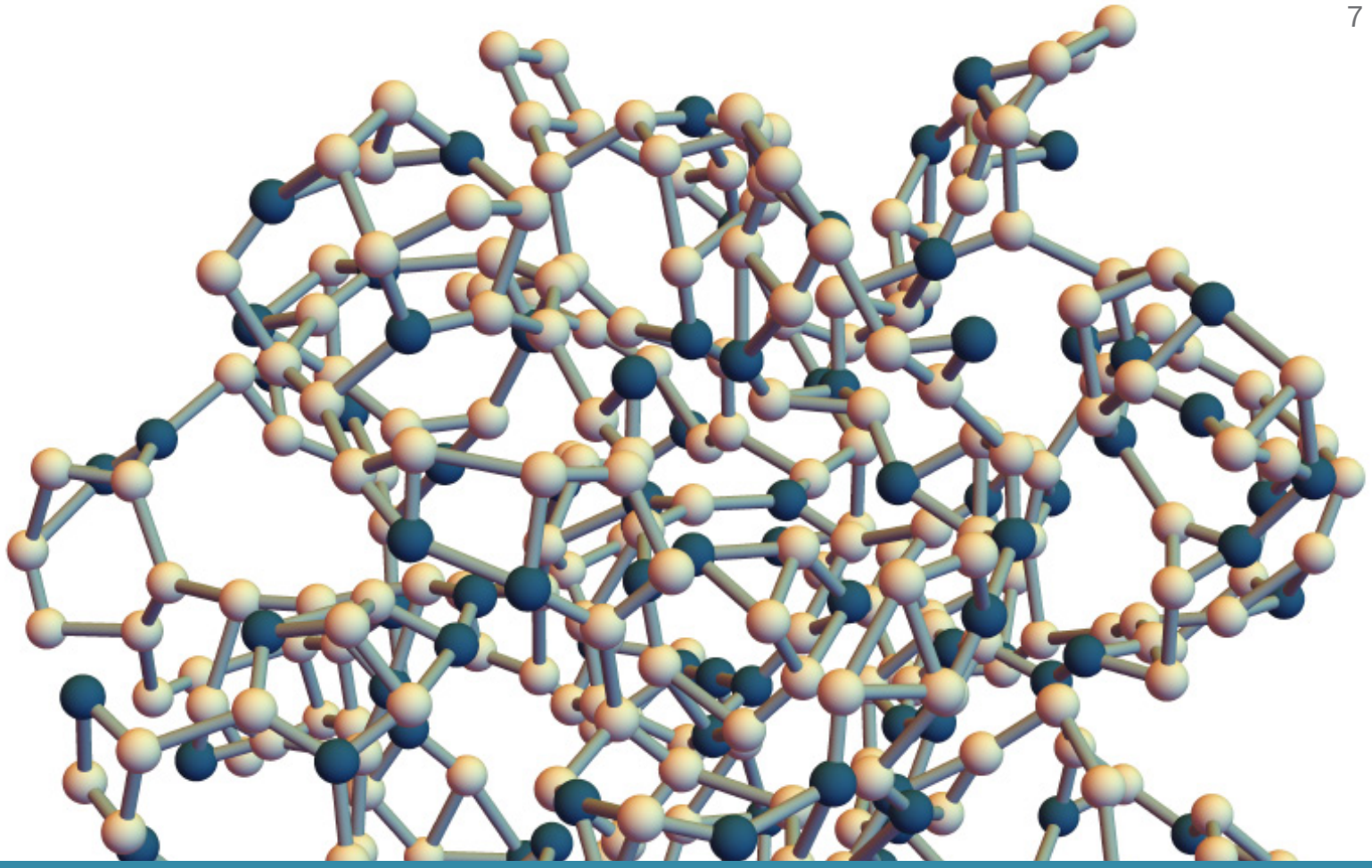


NETWORKS HELP YOU TO COMPARE A WIDE VARIETY OF SYSTEMS

6

- Various kinds of systems, once represented as networks, can be compared to examine their similarities and differences.
- Certain network properties commonly appear in many seemingly unrelated systems. This implies that there exist some general principles about connectivity that apply to multiple domains.
- Other network properties are different in different systems. These properties can help to classify networks in different families and to gain insight into why they are different.
- Science is typically conducted in separate areas of research called disciplines. Networks can help to cross disciplinary boundaries to achieve a holistic and more complete understanding of the world.
- Networks can assist in the transfer of knowledge across different areas of study.





7 THE STRUCTURE OF A NETWORK CAN INFLUENCE ITS STATE AND VICE VERSA

- Network structure indicates how parts are connected in a network.
- Network state indicates the properties of a network's nodes and edges.
- Network structure and state can each change over time.
- The time scales on which network structure and state co-evolve can be either similar or different.
- Network structure can influence changes of network state. Examples include the spread of diseases, behaviors, or memes in a social network, and traffic patterns on the road network in a city.
- Network state can influence changes of network structure. Examples include the creation of new "following" edges in social media and the construction of new roads to address traffic jams.

IMAGE CREDITS

Cover
"Map of Protein Interactions in Yeast"
Hawoong Jeong, Korea Advanced Institute of Science and Technology

Page 1 & Back cover
"Map of the Internet Showing Major Internet Service Providers"
Bill Cheswick

Page 2
"Build Your Own Network Graphic"

Page 3
"Think Locally, Act Locally: The Detection of Small, Medium-Sized, and Large Communities in Large Networks", *Physical Review E*, Vol. 91, No. 1: 012821.
L. G. S. Jeub, K. Balachandran, M. A. Porter, P. J. Mucha, and M. W. Mahoney [2015].

Page 4
"Topology of the MBONE, the Internet's Broadcast Backbone, Which Transmits Real-time Audio and Video Across the Globe"
Elan Amir, University of California at Berkeley

Page 5 & Inside of Back Cover
"Flow of Email Among a Large Project Team. Each Node Represents a Person Color Coded by Department."
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Page 6 & 8
"Router Pinball Graphic"

Page 7
"Binary-State Generative Network Automata Simulation"
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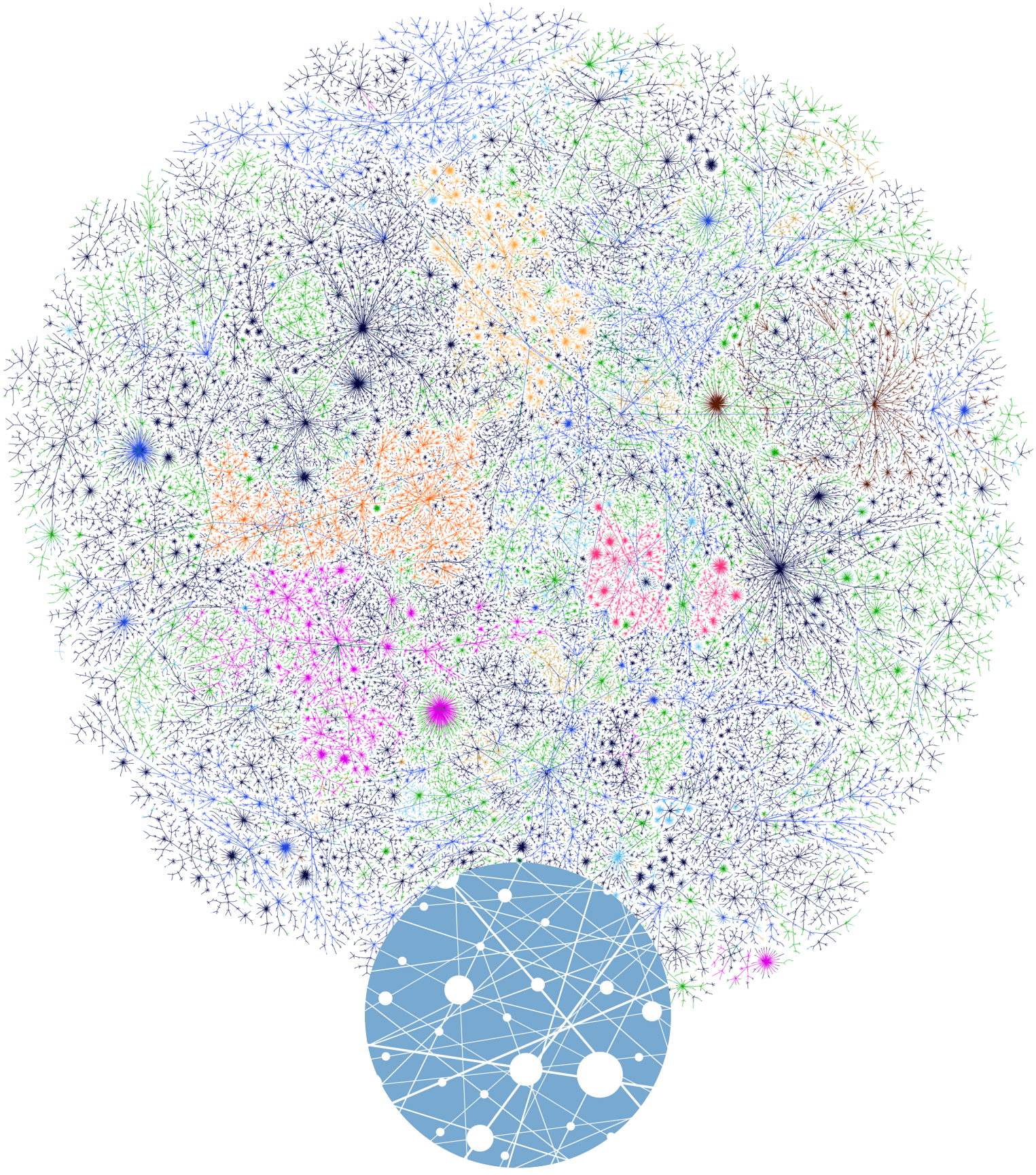

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