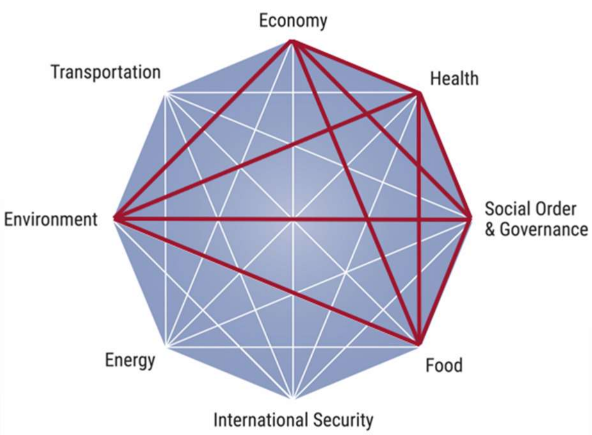
Pandemic Shock: Brief #9 • January 11, 2021

Network dynamics of the pandemic shock

Three network shifts and why they matter

Jinelle Piereder



Summary

This Brief analyzes three major shifts in humanity's networks that the COVID-19 pandemic has triggered or accelerated: (1) network centralization, (2) network fragmentation and reconfiguration, and (3) network formation. It then examines the impact of these shifts across economic, food, information, and governance systems.

Emerging trends

COVID-19 has triggered or further accelerated the following shifts in humanity's social and environmental systems:

- network centralization and concentration across many social and economic sectors;
- fragmentation and reconfiguration of knowledge, media, and social networks; and,
- formation of new networks and interdependent "networks of networks."

Implications for action

- COVID-19 presents a unique opportunity for decision makers and the informed public to improve their "network literacy" and their ability to understand and predict the behavior of complex systems.
- Building distributed network knowledge is crucial to identifying systemic vulnerabilities.
- Defending a network means building resilience by reducing unnecessary connectivity, adding key redundancies, and boosting diversity.
- Governance in a networked world requires robust and adaptive decision repertoires, coordination across interdependent networks, strategic dismantling and reassembling, and learning and adaptation.

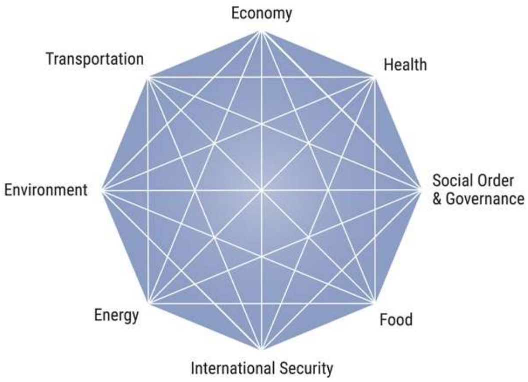
WGSI Waterloo Global Science Initiative
CASCADE INSTITUTE
POSSIBILIAN VENTURES

About the Cascade Institute

The Cascade Institute is a Canadian research center addressing the full range of humanity's converging environmental, economic, political, and technological crises. Using advanced methods for mapping and modeling complex global systems, Institute researchers identify *high-leverage intervention points* in cognitive, institutional, and technological systems that, if effectively exploited, could rapidly shift humanity's course towards fair and sustainable prosperity.

The Institute is located at Royal Roads University in British Columbia, a leader in training professionals to apply creative solutions to entrenched problems.

About the Inter-Systemic Cascades (ISC) Project



The Cascade Institute's *Inter-Systemic Cascades Project* maps causal routes through which the COVID-19 pandemic could sequentially destabilize associated national and global systems, causing cascades of change. This series of Briefs focuses on the pandemic's implications for the eight key systems highlighted around the adjacent octagon, and each Brief maps a possible causal route of destabilization among these systems. Cascades may be either "pernicious" (socially harmful) or “virtuous” (socially beneficial).

The analysis in this series starts from the assumption that societies are organized around cohesive sets of worldviews, institutions, and technologies (WITs), where:

- **Worldviews** are mental networks of concepts, beliefs, and values—often emotionally charged—that allow people to interpret things around them and plan their actions.
- **Institutions** are a community's rules governing social behaviour, including formal rules (constitutions, laws, and contracts), informal rules (customs and norms), and mechanisms of enforcement.
- **Technologies** are problem-solving tools that people create by harnessing phenomena of their physical and social environments.

Pandemic Shock: Brief #9

Network dynamics of the pandemic shock: Three network shifts and why they matter

Background

The year 2020 made it clearer than ever that we live in a highly networked world. A virus originating in a megacity in central China spread across the globe to cause what has now become the largest and most economically harmful pandemic since 1918. A black man was killed by police officers in Minneapolis and, within days, people all around the world were marching for racial justice. Disparate internet conspiracy theories converged into the "QAnon" movement, which made its way into the real world and even onto the ballot (Rogers 2020; Rosenberg 2020; Lawrence and Davis 2020).[1] And the American public is currently reeling in the wake of a highly contentious and polarized presidential election, in part due to highly clustered information and media networks.

Most of us know intuitively that somehow "everything is connected." The idea of "six degrees of separation" made its way into popular culture in the 1960s, thanks to the work of experimental psychologist Stanley Milgram (1967).[2] But looking deeper at the nature, structure, and dynamics of these connections can help us see emerging crises—and their potential solutions—in a wholly new light. The study of the dynamics of connected things is called **network science**, and this study is quickly becoming one of the most important areas of research across the social and natural sciences.

Insights from network science can help us understand many kinds of natural and social systems, from individual viruses to whole climate systems, from the brain to global social movements. They can also give us a more nuanced grasp of how power and influence work in complex social networks and a clearer picture of the network dynamics that contribute to or mitigate (un)desirable outcomes. The focus in network science on the *relationships* between nodes has led to major scientific discoveries in medicine, climate science, ecology, and more.

Perhaps most importantly, network science provides a common set of underlying concepts that can be applied across a wide range of disciplines to solve real-world complex problems.

---

[1] At least a dozen QAnon-linked candidates ran for Congress in the 2020 United States election (Rogers 2020). One candidate, Marjorie Taylor Greene—unopposed in a very conservative district—won a House seat in Georgia (Rosenberg 2020).

[2] The "Kevin Bacon Game" illustrates the small-world phenomenon using Hollywood actors: see https://en.wikipedia.org/wiki/Six_Degrees_of_Kevin_Bacon. Play the game here: https://www.oracleofbacon.org/.

The basics

A network is a mathematical object composed of **nodes** and the **links** between them.[3] The nodes can represent anything from individual people to airports or neurons. And the links represent the "flow" between these nodes of matter, energy, or information—the movement, for example, of virus particles, electrical signals, or rumors. Some networks are instantiated in physical space, in transportation systems or the brain's neural networks. Other networks, like those between like-minded people on the internet or representing interactions over time (for instance, the flow of ideas on Twitter) are more abstract. Networks can be made up of "agents"—entities with some sort of decision capability or power to act—or "non-agents." But agents are not necessarily human; animals and even viruses are agents. But regardless of the nature of their nodes and links, networks have similar properties and exhibit similar behavior in terms of their growth, structure, resilience, and vulnerability.[4]

The **degree** of a single node refers to the number of connections (in or out) it has with others. Nodes with a high degree are called **hubs**, and much of the matter, energy, or information flowing through the network passes through these hubs. In most networks in natural and social systems, the frequency distribution of nodes (sorted according to their degree) follows a **power law** distribution, as opposed to a "normal" or bell-curve distribution (Figure 1).[5] Such networks are called **scale-free networks** (Figure 2); they have many nodes of a low degree, some nodes of an average or medium degree, and just a few nodes of a high degree.[6] For example, the frequency distribution of the world's airports (sorted according to their connectivity with other airports) follows a power law; there are relatively few major airport hubs, but hundreds of thousands of medium and small airports (Mitchell 2009, pp. 235-236).

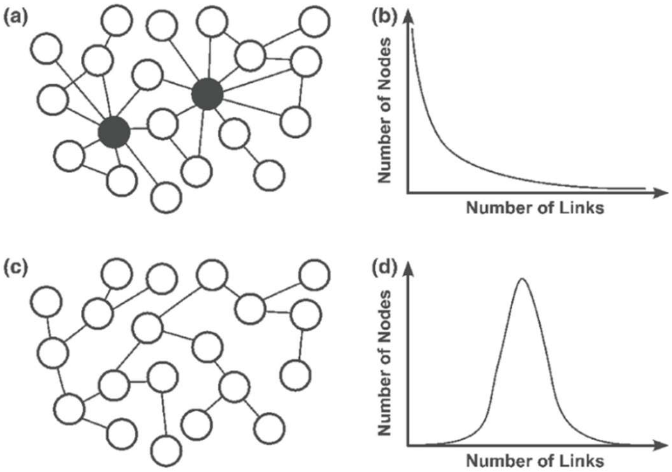


Figure 1. Scale-free network (a) have a power-law distribution of node frequency against degree (b); random network (c) have a normal distribution (d).

---

[3] In graph-theory terminology, nodes are called *vertices* and links are called *edges.*

[4] We can also understand networks as actors themselves—that is, as forms of organization with members working toward collective goals. In contrast to a hierarchical institutional form, *network actors* are distributed, but they pursue coordinated action through repeated and enduring relations (Kahler 2009). Examples are intergovernmental networks, terrorist networks, and activist networks; they can range from formal and tight (for instance, the International Campaign to Abolish Nuclear Weapons) to informal and loose (for instance, Extinction Rebellion).

[5] A power law is characterized by the functional relationship $f(x) = x^{-\alpha}$.

[6] See the Cascade Institute publication *Networks 101* for a full explanation of scale-free networks.

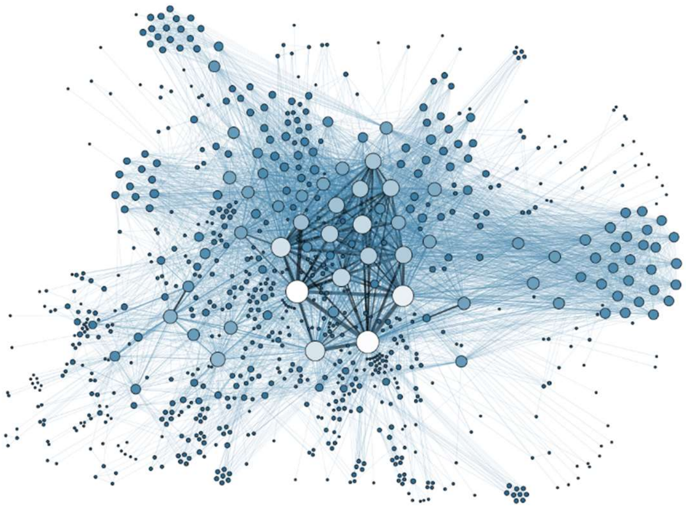


Figure 2. A representation of a scale-free network. Source: Wikimedia Commons.

A node may be relatively more “important,” “influential,” or **central** in a network than others. Many other nodes may depend on it for resources or information, or it might function as a crucial **bridge** from one area of the network to another. Often, some areas of a network are more densely connected than others; COVID-19 “super-spreader” events arise in part from such dense connectivity. These areas are called **clusters or communities,** and they typically form around separate hubs.

All these characteristics affect how a network will grow and change, how matter, energy, or information will spread across a network, and how vulnerable or resilient the network is to potential threats or attacks.
The remainder of this Brief uses these key concepts (and others highlighted in Boxes) to describe and discuss three major network shifts that the COVID-19 pandemic initiated, intensified, or revealed.

Analysis: Three network shifts brought on or strengthened by the pandemic

Significant shifts are currently occurring in networks across many social sectors. The pandemic has directly caused some of these shifts, while it has strengthened or accelerated others. This section focuses on the following three:

1. increasing network centrality and concentration;
2. increasing network fragmentation and reconfiguration; and
3. formation of new networks and “networks of networks.”

Network centralization

Many sectors—manufacturing, food processing, stock exchanges, the airline industry, and the communications sector, for instance—are seeing increased **network centralization**. More and more data, energy, money, and materials are passing through ever-larger hubs, while networks' overall functionality depends increasingly on these hubs (Box 1). The phrase "too big to fail" captures this reality of "central dependence."[7] While the trend dates back decades, it sharply accelerated following the Great Recession and again during the pandemic.

Box 1. Preferential attachment

Networks self-organize as they grow, and this growth usually follows consistent patterns or behavioral "rules" of **preferential attachment.** By the rule of **popularity,** a new node connects first to other nodes that have the most links ("connectivity begets connectivity"); by the rule of **affinity**, a new node connects first to nodes that are most similar ("like attracts like"). In real-world networks, node attachment usually involves some combination of both rules. These attachment processes explain how network hubs emerge and grow.

In sociology, research on networks differentiates between three types of affinity attachment that exploit different node characteristics: **homophily** (similarity of social characteristics), "shared foci" (similarity of interest or purpose), and "triadic closure" (shared "friends") (Hidalgo 2016, p. 6). The tendency of nodes to connect to other nodes with similar characteristics contributes to clustering and even fragmentation of the larger network. Attention to both *types* of nodes and *types* of links matters in social network research, but social scientists still need to effectively integrate quantitative and qualitative approaches to understanding the processes governing network growth (Pareschi and Fontana 2016).

For example, the Standard and Poor's 500 Index of stock prices in the United States is growing increasingly "top-heavy," with just five companies (all in the tech industry) making up 22 percent of the index's total market capitalization as of the end of July, 2020—the highest level of concentration since the early 1980s (Scheid 2020). The flow of investment capital to stable "mega-cap stocks" during the market crash in the spring of 2020 exacerbated this trend. Analysts see this flow "as a sign of [market] fragility," which could contribute to another—potentially more severe—financial collapse in the United States (Box 2) (Scheid 2020; see also Lawrence and Homer-Dixon, 2020).

Centralization is also increasing in food networks. Lin et al. (2019) used network analysis to discern which counties in the United States are the hubs of the national food supply network. They showed that the entire US food system is heavily dependent on just nine counties, mostly in California, and "a disruption to any of these counties may have ripple effects for the food supply chain of the entire country" (Konar 2019). Disruptions could include wildfires, extended power outages, failures in critical infrastructure (roads, railroads, waterways, and ports), or forced shutdowns due to a pandemic.

---

[7] The late Canadian systems theorist, John D. McReur defined central dependence as a function of "economies of scale obtained by capital intensive central processes that make extremely efficient use of energy, esoteric information, expensive artifacts, and rare skilled labour. The efficiency, and hence the low cost of their products, creates massive public dependencies on single systemic nodes." See http://www.sympoetic.net/Simulation_Models/GSS_files/Club%20of%20Rome%20GSS%20description.pdf.

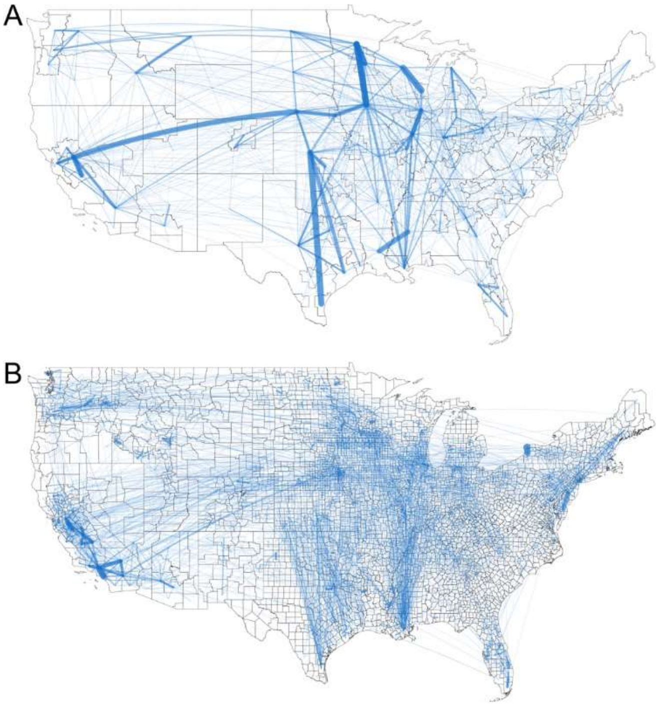


Figure 3. Maps of food flow networks within the United States. (Source: Lin et al. 2019[8]).

The COVID-19 pandemic has shown that the meat industry is especially vulnerable to disruptions. The processing and work conditions—cold temperatures, abundant metal surfaces, close proximity of workers to each other, loud environments that require people to shout, and lots of aerosols—facilitate virus transmission (Kaupferschmidt 2020; Middleton et al. 2020). As slaughterhouses and meatpacking plants have become "hot spots" or super-spreader venues, dozens across North America and Europe have shut down. But because of decades of industry consolidation, a relatively small number of plants now have disproportionate importance. In the US cattle industry, for example, about 50 plants—out of over 800 nationally—handle up to 98 percent of slaughtering and processing (Corkery and Yaffe-Bellany 2020). With this level of centralization, one industry expert compares shutting down a plant to closing an airport hub. "It backs up hog and beef production across the country, crushes prices paid to farmers, and eventually leads to months of meat shortages" (*Ibid.*) (Box 2). While North American meat supply rebounded by mid-September 2020, processing delays, lower overall demand, and slowed exports will have long-term negative impacts for producers (Bunge and Kang 2020).

---

[8] Used under Creative Commons License 3.0.

Box 2. Gatekeepers

Network hubs shape more than just network growth patterns. Hubs are central to network operation as gatekeepers, brokers, and conduits of whatever flows through the network. Gatekeepers have disproportionate influence over other nodes and can sometimes even change the rules of network membership. With this influence—which is rule/agenda setting and vetting power—gatekeepers enable some nodes and constrain others (Wasserman and Faust 1994), in turn shaping the structure of the network itself (Carpenter 2011; Stern et al. 2020) by setting up conditions for future network relations.

But this centrality comes with risks. For example, hubs typically represent the network's most vulnerable spots; a failure, attack, or disruption at these points can threaten the survival of the entire network (Box 3). Also, in a social network, centrality comes with reputational costs and potential challenges to legitimacy, so hubs may have more to lose (Carpenter 2011).

Network fragmentation and reconfiguration

Somewhat paradoxically, given increased network centralization, we are also seeing increased **fragmentation and reconfiguration** across (1) global supply chains, and (2) media and social networks .[9] In the first, the pandemic's shock laid bare decades-old supply chain vulnerabilities and showed the danger of tightly optimized, just-in-time production (Queiroz 2020). In the second, the pandemic strengthened the impact of existing algorithmic sorting and recommendation systems (in traditional media, social media, and the internet more broadly), which accelerated the "epistemic fragmentation" of the public discourse during a period of heightened anxiety and uncertainty.

A recent report found that 94 percent of the companies on the Fortune 1000 list have faced COVID-19-driven supply chain disruptions (Kilpatrick and Barter 2020). The companies that are better prepared to respond to the pandemic are agile; they can quickly reconfigure their production and distribution networks to meet fluctuations in global demand. In contrast, the companies that are "scrambling" are inflexible, lack intelligence on their supply network, and fail to anticipate emerging risks. To pre-empt future disruptions, many companies are reconfiguring their traditional linear supply chains to "digital supply networks" and other more distributed forms (Queiroz 2020). In network terms, reconfigurations of this sort add flexibility, increase the resilience of the overall supply network, and make it less dependent on a few major hubs (that is, they lower central dependence). These changes reduce network vulnerability to the random or targeted loss of a few nodes or links. But such increased flexibility often means forgoing efficiencies and cost reductions that come with economies of scale.

The pandemic's disruption happened against the backdrop of (1) increasingly nationalist economic policies (for instance, "America First") and strident demands for reshoring manufacturing jobs; (2) intensified competition between the United States and China (each treating their supply-chains as matters of national security) leading to a decline in global integration; and (3) rising anti-globalization sentiment (Lawrence and Homer-Dixon 2020).

---

[9] Many of our personal social networks have also been reconfigured due to physical distancing and decreased mobility.

The pandemic (and other future human-made disasters) could further this de-globalization trend, because of firms' broadening recognition of the "increase[ed] costs and risks of global interconnection" (*Ibid*., p. 14)

Box 3. How to defend (or destroy) a network

Knowledge of network structure, growth, and dynamics can aid actions to either defend *or* destroy a network.

Scale-free networks exhibit resilience to random "attacks" on individual nodes, but they can be extremely vulnerable to targeted attacks on hubs. Attacks that hit random nodes are unlikely to strike a hub and thus unlikely to disrupt the overall network. But if such attacks deliberately target and disable hubs, the loss of just a few nodes can disconnect and disable the entire network.

Networks can also collapse due to an "overload" feedback process. Increased pressure or stress on the network causes one or more nodes or links to fail, which in turn causes bottlenecks and increased load on nearby nodes and links, which then fail in turn (Turau and Weyer 2019). Cascading electrical blackouts often occur this way. But the overload model also applies to social or agent-based networks. Homer-Dixon (2020) refers to rising "tectonic" stresses, including deepening economic inequality, rising political polarization, surging flows of migrants and refugees, and the climate crisis (p. 251) that—if left unchecked—can overload institutions and their decision-making processes.

"Dismantling" a network involves targeted changes to both nodes and links. For example, efforts to slow the spread of SARS CoV-2 (the virus that causes COVID-19) have involved "thinning" the global mobility network by closing borders and banning air travel, using community-level mobility restrictions and work-from-home orders to remove local nodes where the virus might flourish, and disrupting transmission pathways using public health measures such as mask-wearing and physical distancing. The hope is that these measures will sufficiently attenuate the transmission network so the virus can no longer spread widely, thus lowering the burden on hospitals and minimizing human and economic costs until a vaccine can be developed and deployed.

The trend towards greater **algorithmic and epistemic fragmentation** has even more stark consequences for humanity's social networks. At the corporate level, media networks and Big Tech are centralizing, just the way meat industry is centralizing. But at the user and content levels, we are seeing more rapid and extreme fragmentation than ever before.

Information transmission and storage are now nearly frictionless and costless, which means that people and firms have more opportunities for expression than ever before and, in turn, that everyone is inundated with vastly more information than ever before. From a capitalist perspective, this abundance of activity and data turns *human attention and engagement* into digital gold.[10]

---

[10] *The Social Dilemma,* a recent Netflix film created by the Centre for Humane Technology, explains how the algorithms at the heart of most social media platforms (including Facebook, Twitter, YouTube, Instagram, and Pinterest) can have negative effects on individuals (addiction, isolation, radicalization, and the like) and societies (severe polarization and threats to democracy, for instance).

Given the basic “bandwidth” constraints of our human brains, the fight for attention and engagement—in our competitive economies, a kind of information-generation “arms race”—has led to profound changes in our information ecosystems. First, as the amount of information we each receive soars, the information content (measured in bits) of individual messages tends to decline, as information generators try to increase the likelihood their messages will be received and absorbed. Second, information generators increasingly use their messages to evoke responses from our brain’s amygdala, by using emotional cues designed to trigger feelings of outrage, fear, anger, disgust, status anxiety, mortality anxiety, sexual arousal, and fondness (Homer-Dixon 2020, p. 256). And third, messages originating in or channeled through already dominant hubs—expressing content that is already popular or largely aligned with those hubs’ perspectives—are preferentially received and distributed (Box 1). Technology companies—and social media giants, in particular—are deliberately exploiting these features of modern information ecosystems or, in the terminology of some critics, “hijacking human psychology for profit.”[11]

But beyond profit motivation, political voices can harness both the fight for attention *and* the scale-free network structure of the internet and social media to actively shape political and cultural discourse. For example, a handful of social media accounts with huge followings have been “super-spreaders” of misinformation (Frenkel 2020)—just as “super-spreader events” (such as large weddings or choir rehearsals) have been responsible for most dispersion of SARS-CoV-2 (Chang et al. 2020; Endo et al. 2020) (Box 4)—except that *these* super-spreaders (of information as opposed to a virus) are intentionally promoting a “contagion” to “redefine the public narrative” (Frenkel 2020).

Together, these factors amplify real-world information “echo chambers” by reinforcing boundaries of identity and ideology between groups. Inundated with emotionally charged information that increases anxiety, people preferentially connect to already dominant information sources that provide distraction or cultural and normative security (Homer-Dixon, 2020). We are now seeing such severe fragmentation across media and social networks, that in many ways, people are living in parallel realities. The fragmentation is not just social, but “epistemic,” in the sense that it produces a weakening across groups of their shared understanding of reality.

Research on the growth of the QAnon conspiracy shows that Facebook’s decision to prioritize private groups over public feeds on its platform created the ideal circumstances for the conspiracy to thrive (Lawrence and Davis 2020). Facebook deliberately de-emphasized the shared “public sphere” and strengthened echo chambers, delegating much content monitoring responsibility to individual users that form and run private groups. But these groups are largely self-governed and self-moderated, and some have tens of thousands of members and thousands of daily posts, making them difficult to administer and manage. From a network perspective, the proliferation of private groups combined with recommendation algorithms that then suggest other similar groups to users (Lawrence and Davis 2020) dramatically increased the clustering effects and epistemic fragmentation over the entire network.

---

[11] This is a key argument in the *The Social Dilemma.* See also Shoshana Zuboff’s *Surveillance Capitalism* (2019).

Box 4. Diffusion

The structure (or *topology*) of a network—its distribution of hubs, overall density, and clustering patterns—shapes how things like energy, viruses, information, or behavioral norms can spread or "diffuse" through it. Economic goods, "viral" videos, infectious disease, and even conspiracy theories all spread more quickly through more densely connected networks. But we also know that this diffusion is not usually "even" across the network in question. The location of hubs, the prevalence of clusters, and the characteristics of nodes all matter.

Network diffusion often involves *contagion,* a process in which an "infected" node transmits a pathogen to its neighbors, and then those infected nodes pass the pathogen on to *their* neighbors. Network structure can affect the degree of "contagiousness," and sometimes the contagion itself is an existential threat to the entire network (as when malware brings down computer networks). Some network nodes may "infect" many others, while other nodes may not spread the contagion at all. Epidemiologists call the extent to which contagion results from a small number of nodes the "dispersion factor" (k); this factor describes how much a disease clusters in a population. A low value for k means that just a small fraction of cases is responsible for most of the spread; in other words, the network characterizing the disease's spread has a strong scale-free structure, with a few dominant hubs. For COVID-19, as few as 10 per cent of cases lead to 80 per cent of spread (Kupferschmidt 2020; Tufekci 2020).

More generically, though, we can think of diffusion as *patterns of effects* or *impact* across a network. When a change occurs in one node, how does that change subsequently change the nodes around it? In this framing, it is easier to think about things we *want* to spread across a network versus those we want to *stop* from spreading. For example, marketing research has studied the role of network hubs as "influencers" and "opinion leaders," where the goal is to encourage adoption of some innovation or product (Valente and David 1999; Valente and Yon 2020). While the mathematics of *contagion* is essentially the same as that of *impact patterns*, the former focuses on reducing the susceptibility of a node to a pathogen, while the latter focuses on increasing the likelihood of adoption or change.

Rise of new networks and "networks of networks"

In addition to the changes that individual networks are undergoing, entirely new networks and *"*networks of networks*"* are arising, as multiple networks become coupled or interdependent in some way. Again, these trends are not entirely new, but the pandemic has created new kinds of network interdependence.

In coupled networks, some nodes in one network depend on nodes in another network, and vice versa. When one of these nodes fails (by being eliminated or incapacitated), it causes the dependent nodes in the other network to fail, too, causing an iterative or recursive cascade of failures. For example, in a major blackout in Italy in 2003, failures in the power grid caused key nodes in the internet communication network to fail, which then led to further failures of power stations. Railway, health care, and financial services networks that were also dependent on the communication network experienced widespread failures (Sergy et al. p. 1025).

Networks of networks present unique and sometimes counterintuitive challenges. They can be vulnerable to *both* random failures and targeted attacks, because even randomly removing a small number of nodes from one network can start a cascade of failures across many interdependent networks (Parshani et al. 2010; Buldyrev et al. 2010; Gao et al. 2012). Helbing argues that these "interdependencies in our 'hyper-connected world' establish 'hyper-risks'" (2013, p. 51; see also Box 5). When networks have many cross-dependencies, the chance that failure (due to contagion, targeted attacks, overload, or dismantling strategies) in one will impact another is significantly higher. Consider, for example, a high-degree node in one network that is dependent on a low-degree node in another network. Even a random attack in the second network could incapacitate the low-degree node on which the high-degree node in the first network depends. In contrast, in a single network, a large number of nodes would need to be removed randomly to threaten the structure of the network as a whole.

Box 5. Networked Risk

"…systemic risk is the risk of having not just statistically independent failures, but interdependent, so-called 'cascading' failures in a network of N interconnected system components. . . . Even higher risks are implied by networks of networks, that is, by the coupling of different kinds of systems. In fact, new vulnerabilities result from the increasing interdependencies between our energy, food and water systems, global supply chains, communication and financial systems, ecosystems and climate." (Helbing 2013, p. 51).

Years ago, the Swiss expert on network dynamics, Dirk Helbing wrote, "today's quick spreading of emergent epidemics is largely a result of global air traffic, and may have serious impacts on our global health, social and economic systems" (Helbing 2013, p. 51). COVID-19 has revealed exactly how precarious these coupled networks can be and how vulnerable they are to cascading failures. The pandemic has made information communication technologies and the internet even more critical for keeping the economy running, keeping kids in school, and keeping communities informed about public health measures. Healthcare systems are dependent on digital communication technologies and energy and water systems. A failure in any of these systems (due to a cyber-attack, for example) could have devastating consequences for public health.

Regional and nation-wide lockdowns have emphasized the importance of schools to a functioning economy. When a school shuts down because of an outbreak, parents are forced to homeschool their children, putting further pressure on parents, children, and employers. Work-from-home protocols are now influencing where people decide to live, with major consequences for downtown cores and the value of commercial real estate. Given that so many of our modern systems are coupled in these or similar ways, policymakers need to take careful stock of system interdependencies when trying to strengthen or defend critical networks.

The concept of interdependent networks helps us understand not only cascading failures (the iterative incapacitation of nodes and links in multiple networked networks) but also diffusion, especially diffusion that occurs across the divide between physical (geographically based) and digital networks. In a recent study, Holtz et al. (2020) found that some American states had a larger "spillover influence" on other states when it came to COVID-19 shelter-in-place and social distancing policies, even when the states were not geographically close. Using a large database of digital trace mobility data plus Facebook connections data, the same study found that digital social connections—regardless of geographical distance—also influence *individual* public health behavior, such as, social distancing, reduced travel, and shelter-in-place actions. This finding suggests that coordinated policy action—at any level of government—between entities that are strongly geographically *and* digitally connected is important. Given our increased reliance on digital connections during the pandemic, to achieve coordinated public health response, the diffusion of "good" behavior and the containment of "bad" behavior needs to happen across both physical and digital networks.

Implications for action

The COVID-19 pandemic has initiated, accelerated, or made visible three network shifts: the centralization of networks, the fragmentation and reconfiguration of networks, and the formation of interdependent networks. The shifts are not normatively bad in themselves, but they contain potentially dangerous trends and raise challenges for protecting systems we rely upon. We need to understand network structure, growth, and dynamics if we are to disrupt or destroy "undesirable" networks and strengthen and make more resilient "desirable" networks.[12]

Network science identifies the following key lessons and implications for action. Any "systems interveners"—organizations, policy makers, activists, business leaders, or researchers—looking to reduce systemic risk should consider the implications of these lessons for their own strategic environments.

- **Build network knowledge.** Having a clear-as-possible understanding of relevant networks is crucial to identifying systemic vulnerabilities. Know where the hubs in these networks are, identify key nodes that bridge one area of a network with another, and consider the areas that are more tightly connected than others (the clusters).
    - *Encourage "network literacy."* Help decision makers and the informed public reframe their own understandings of risk and resilience.
- **Build network resilience.** Defending a network means making it resilient to external shocks or internal failures. By one influential definition in complexity science, "resilience" refers to the ability of a system to "bounce back," or more accurately, to be able to absorb and adapt to some shocks while maintaining most of the system's original structure and function (Homer-Dixon, 2006). Resilience is enhanced through measures adapted to the dynamics and needs of the specific network.
    - *Reduce unnecessary connectivity*. Network connectivity is a double-edged sword—what makes a network efficient is also what makes it vulnerable (Ramos and Hynes 2020). The simplest way to defend a network from targeted attacks or random failures is to reduce (hyper)connectivity among nodes and to separate (to a degree) tightly coupled or interdependent networks. Actively decouple

---

[12] Of course, whether we want to protect or dismantle a network depends on what/who makes up the network, what kinds of things flow through it, and what "we" agree are the larger goals of the network.

networks or parts of networks that do not *need* to be connected. Adding gaps, buffer zones, breaking points, frictional effects, or some other interruption can help contain contagion (Helbing 2013).

  - *Add redundancy.* One way to protect networks is to introduce redundancies that reduce central dependence, especially with regards to nodes that are essential to the network's functioning (hubs). If a targeted attack on the network disables a hub, other nodes are capable of taking up the slack. Redundancy also reduces the chance that several essential nodes will fail simultaneously.

  - *Maintain diversity of node and link types*. Ensuring a sufficient level of diversity and heterogeneity is also crucial for reducing contagion. With diversity, even if one type of node is vulnerable to a pathogen or destabilizing agent, other types may be resistant. In agent-based networks, diversity can also promote adaptability and innovation (Helbing 2013). Greater network diversity can also reduce hyper-fragmentation *and* hyper-centralization by dampening "connectivity-begets-connectivity" and "like-attracts-like" dynamics.

- **Build robust and adaptive decision repertoires.** It is impossible to completely prevent or avoid network threats, attacks, and failures, so decision makers and system interveners need a range of response strategies as well as decision support tools.

  - *Develop scenarios* based on the new network knowledge. Map potential cascading failures across the networks, including those based on diffusion *and* overload models. Do not assume linear spread—look for hubs to identify potential super-spreaders and for bridge nodes to identify potential spillover dynamics.

  - *Coordinate.* The possibility of spillover effects across networks raises the importance of coordination with "neighbours"—that is, with decision makers overseeing adjacent, connected networks. This coordination is especially vital in the periods leading up to and following the "peak" of a disruption.

  - *Dismantle.* In situations where a network is "dysfunctional"—because of attacks or shocks—intentionally "dismantling" the network by removing some nodes and links can restore or reset its intended functionality. This kind of strategic dismantling parallels the creation of "firebreaks" in forestry management, where thin stretches of forest are cleared to slow, stop, or control the spread of wildfires (see this interactive essay: Simler 2019). The method can be generalized to halt or hinder cascading failures across networks (Ren et al. 2019).

  - *Reassemble.* When networks become highly fragmented due to either internal dynamics or some external shock, strategically *adding* some nodes or links can help push the network in a different growth direction (Box 1).

- **Learn and adapt.** In complex networks, any response—even a well-informed strategic one—can yield unintended consequences. But each outcome helps system interveners learn more about the networks in which they operate and draw lessons to support future decision making under uncertainty and disruption.

References

Barabasi, Albert-Laszlo and Reka Albert. 1999. “Emergence of Scaling in Random Networks.” *Science* 286: 509-512. https://doi.org/10.1126/science.286.5439.509.

Barabási, Albert-László. 2009. “Scale-Free Networks: A Decade and Beyond.” *Science* 325 (5939): 412-13. https://doi.org/10.1126/science.1173299.

Bright, Jonathan. 2018. “Explaining the Emergence of Political Fragmentation on Social Media: The Role of Ideology and Extremism.” *Journal of Computer-Mediated Communication* 23 (1): 17-33. https://doi.org/10.1093/jcmc/zmx002.

Buldyrev, Sergey V., Roni Parshani, Gerald Paul, H. Eugene Stanley, and Shlomo Havlin. 2010. “Catastrophic Cascade of Failures in Interdependent Networks.” *Nature* 464: 1025-1028. https://doi.org/10.1038/nature08932.

Bunge, Jacob and Jaewon Kang. 2020. “Meat Was Once in Short Supply Amid Pandemic. Now, it’s on Sale.” *The Wall Street Journal*, September 20, 2020. https://www.wsj.com/articles/meat-was-once-in-short-supply-amid-pandemic-now-its-on-sale-11600614000.

Carpenter, R. Charli. 2011. “Vetting the Advocacy Agenda: Network Centrality and the Paradox of Weapons Norms.” *International Organization* 65 (1): 69-102. https://doi.org/10.1017/S0020818310000329.

Corkery, Michael and David Yaffe-Bellany. 2020. “The food chain’s weakest link: Slaughterhouses.” *New York Times*, April 18, 2020. https://www.nytimes.com/2020/04/18/business/coronavirus-meat-slaughterhouses.html.

Endo, Akira, Sam Abbot, Adam J. Kucharski, and Sebastian Funk. 2020. “Estimating the Overdispersion in COVID-19 Transmission Using Outbreak Sizes Outside China (Version 3).” *Wellcome Open Research* 5: 67. https://doi.org/10.12688/wellcomeopenres.15842.3.

Frenkel, Sheera. 2020. “How Misinformation ‘Superspreaders’ Seed False Election Theories.” *New York Times*, November 23, 2020. https://www.nytimes.com/2020/11/23/technology/election-misinformation-facebook-twitter.html.

Gao, Jianxi, Sergey V. Buldyrev, H. Eugene Stanley, and Shlomo Havlin. 2012. “Networks Formed from Interdependent Networks.” *Nature Physics* 8. https://doi.org/10.1038/nphys2180.

Helbing, Dirk. 2013. “Globally Networked Risks and How to Respond.” *Nature*, Research Perspective, 497: 51-59. https://doi.org/10.1038/nature12047.

Hidalgo, Cesar A. 2016. “Disconnected, Fragmented or United? A Trans-disciplinary Review of Network Science.” *Applied Network Science* 1: 6. https://doi.org/10.1007/s41109-016-0010-3.

Holtz, David, Michael Zhao, Seth G. Benzell, Cathy Y. Cao, Mohammad Amin Rahimian, Jeremy Yang, Jennifer Allen, Avinash Collis, Alex Moehring, Tara Sowrirajan, Dipayan Ghosh, Yunhao Zhang, Paramveer S. Dhillon, Christos Nicolaides, Dean Eckles, and Sinan Aral. 2020. “Interdependence and the Cost of Uncoordinated Responses to COVID-19.” *PNAS* 117 (33): 19837-19843. https://doi.org/10.1073/pnas.2009522117.

Homer-Dixon, Thomas. 2020. *Commanding Hope: The Power We Have to Renew a World in Peril.* Toronto: Knopf Canada.

Homer-Dixon, Thomas. 2006. *The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization.* Toronto: Knopf Canada.

Kahler, Miles. 2009. “Collective Action and Clandestine Networks: The Case of Al Qaeda.” In *Networked Politics: Agency, Power and Governance,* edited by Miles Kahler, 103-124. Ithaca, NY: Cornell University Press.

Kilpatrick, Jim and Lee Barter. 2020. “COVID-19: Managing Supply Chain Risk and Disruption.” *Deloitte*. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/About-Deloitte/gx-COVID-19-managing-supply-chain-risk-and-disruption.pdf.

Krause, J., D.P. Croft and R. James. 2007. “Social Network Theory in the Behavioural Sciences: Potential Applications.” *Behavioral Ecology and Sociobiology* 62: 15-27. https://doi.org/10.1007/s00265-007-0445-8.

Konar, Megan. 2019. “The First Map of America’s Food Supply Chain is Mind-boggling.” *Fast Company*, October 28, 2019. https://www.fastcompany.com/90422553/the-first-map-of-americas-food-supply-chain-is-mind-boggling.

Kupferschmidt, Kai. 2020. “Why Do Some COVID-19 Patients Infect Many Others, Whereas Most Don’t Spread the Virus at All?” *ScienceMag*, May 19, 2020. https://www.sciencemag.org/news/2020/05/why-do-some-covid-19-patients-infect-many-others-whereas-most-don-t-spread-virus-all.

Lawrence, David and Gregory Davis. 2020. “QAnon in the UK: The Growth of a Movement.” *Hope Not Hate,* October 2020. https://www.hopenothate.org.uk/wp-content/uploads/2020/10/qanon-report-2020-10-FINAL.pdf.

Lawrence, M. and T. Homer-Dixon. 2020. “The Roubini Cascade: Are we heading for a Greater Depression.” Inter-Systemic Cascades Brief #7, v1.1 *Cascade Institute*: pp. 1-24. https://cascadeinstitute.org/isc-brief/roubini-cascade/.

Lin, Xiaowen, Paul J. Ruess, Landon Marston, and Megan Konar. 2019. “Food Flows Between Counties in the United States.” *Environmental Research Letters* 14 (8). https://doi.org/10.1088/1748-9326/ab29ae.

Middleton, John, Ralf Reintjes, and Henrique Lopes. 2020. “Meat Plants—A New Front Line in the Covid-19 Pandemic.” *The BMJ*, July 9, 2020. https://doi.org/10.1136/bmj.m2716.

Milgram, S. 1967. “The Small World Problem.” *Psychology Today* 1 (1): 60-67.

Mitchell, Melanie. 2009. *Complexity: A Guided Tour*. New York, NY: Oxford University Press.

Papadopoulos, Fragiskos, Maksim Kitsak, M. Angeles Serrano, Marian Boguna, and Dmitri Krioukov. 2011. “Popularity versus Similarity in Growing Networks.” *Nature* 489: 537-540. https://doi.org/10.1038/nature11459.

Parshani, Roni, Sergey V. Buldyrev, and Shlomo Havlin. 2010. “Interdependent Networks: Reducing the Coupling Strength Leads to a Change from a First to Second Order Percolation Transition.” *Physical Review Letters* 105 (048701). https://doi.org/10.1103/PhysRevLett.105.048701.

Pareschi, Remo and Franscesca Arcelli Fontana. 2015. “Information-driven Network Analysis: Evolving the ‘Complex Networks’ Paradigm.” *Mind Society* 15: 155-167. https://doi.org/10.1007/s11299-015-0172-1.

Queiroz, Maciel M., Dmitry Ivanov, Alexandre Dolgui, and Samuel Fosso Wamba. 2020. “Impacts of Epidemic Outbreaks on Supply Chains: Mapping a Research Agenda Amid the COVID-19 Pandemic through a Structured Literature Review.” *Annals of Operations Research,* June 16, 2020. https://doi.org/10.1007/s10479-020-03685-7.

Ramos, Gabriela and William Hynes. 2020. “A systemic resilience approach to dealing with Covid-19 and future shocks.” *OECD*, April 28, 2020. http://www.oecd.org/coronavirus/policy-responses/a-systemic-resilience-approach-to-dealing-with-covid-19-and-future-shocks-36a5bdfb/.

Ren, Xiao-Long, Niels Gleinig, Dirk Helbing, Nino Antulov-Fantulin. 2019a. “Generalized Network Dismantling.” *Proceedings of the National Academy of Sciences* 116 (14): 6654-6559. https://doi.org/10.1073/pnas.1806108116.

Ren, Xiao-Long, Niels Gleinig, Dirk Helbing, Nino Antulov-Fantulin. 2019b. “Supplementary Information for Generalized Network Dismantling.” *Proceedings of the National Academy of Sciences* 116 (14). https://www.pnas.org/content/pnas/suppl/2019/03/14/1806108116.DCSupplemental/pnas.1806108116.sapp.pdf.

Rogers, Kaleigh. 2020. “QAnon Isn’t Going to Take Over Congress in 2020. But it’s Found a Home in the GOP.” *FiveThirtyEight,* October 29, 2020. https://fivethirtyeight.com/features/qanon-isnt-going-to-take-over-congress-in-2020-but-its-found-a-home-in-the-gop/.

Rosenberg, Matthew. 2020. “A QAnon Supporter is headed to Congress.” *New York Times*, November 3, 2020. https://www.nytimes.com/2020/11/03/us/politics/qanon-candidates-marjorie-taylor-greene.html.

Scheid, Brian. 2020. “Top 5 Tech Stocks’ S&P 500 Dominance Raises Fears of Bursting Bubble.” *S&P Global Market Intelligence*, July 27, 2020. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/top-5-tech-stocks-s-p-500-dominance-raises-fears-of-bursting-bubble-59591523.

Schindler, Ines, Georg Hosoya, Winfried Menninghaus, Ursula Beermann, Valentin Wagner, Michael Eid, and Klaus R. Scherer. 2017. “Measuring Aesthetic Emotions: A Review of the Literature and a New Assessment Tool.” *PLoS ONE* 12 (6): e0178899. https://doi.org/10.1371/journal.pone.0178899.

Simler, Kevin. 2019. “Going Critical.” *Melting Asphalt,* May 13, 2019. https://meltingasphalt.com/interactive/going-critical/.

Stern, Samuel, Giacomo Livan, and Robert E. Smith. 2020. “A Network Perspective on Intermedia Agenda-setting.” *Applied Network Science* 5 (31). https://doi.org/10.1007/s41109-020-00272-4.

Tufekci, Zeynep. 2020. “This Overlooked Variable is the Key to the Pandemic: It’s not R.” *The Atlantic,* September 30, 2020. https://www.theatlantic.com/health/archive/2020/09/k-overlooked-variable-driving-pandemic/616548/.

Turau, Volker and Christoph Weyer. 2019. “Cascading Failures in Complex Networks Caused by Overload Attacks.” *Journal of Heuristics* 25: 837-859. https://doi.org/10.1007/s10732-019-09413-0.

Valente, Thomas W. and Rebecca L. Davis. 1999. “Accelerating the Diffusion of Innovations Using opinion leaders.” *Annals of the American Academy of Political and Social Science* 566 (1): 55-67. https://doi.org/10.1177/000271629956600105.

Valente, Thomas W. and George G. Vega Yon. 2020. “Diffusion/Contagion Processes on Social Networks.” *Society for Public Health Education* 47 (2): 235-248. https://doi.org/10.1177/1090198120901497.

Wasserman,S. & Faust,K. 1994. *Social Network Analysis*. Cambridge: Cambridge University Press.

Westaby, J.D., Pfaff, D.L., and Redding, N. 2014. “Psychology and Social Networks: A Dynamic Network Theory Perspective.” *American Psychologist* 69 (3): 269-284. https://doi.org/10.1037/a0036106.

Zuboff, Shoshana. 2019. *The Age of Surveillance Capitalism: The fight for a human future at the new frontier of power.* New York, NY: Hachette Book Group.

About the author

Jinelle Piereder is a Doctoral Researcher at the Cascade Institute and a doctoral candidate in global governance at the Balsillie School of International Affairs. She uses complexity science to study the relationships between worldviews and social networks, especially in emerging and rapidly evolving areas of governance, such as climate change and the energy transition.

Citation Information

Piereder, Jinelle. 2021. “Network Dynamics of the Pandemic Shock: Three network shifts and why they matter.” Inter-Systemic Cascades Brief #9, *Cascade Institute*: pp. 1-19.

Partners and Collaborators

Partner Institution:

Royal Roads University

Collaborating Institutions:

La fondation McConnell Foundation

The Winslow Foundation

University of Waterloo

Mitacs