Universal Resilience... Or Robustness

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ABSTRACT Gao, Barzel, and Barabási attempted to devise a method to identify universal resilience in systems. This target was missed due to simplification in the methodology and to the confounding of the system-functions resilience and robustness. These two system-functions are distinct in both their form and in the roles they play in systems. There are many different kinds of both robustness and resilience. To clarify the difference between robustness and resilience, a short guide is provided consisting of six examples of robustness and six examples of resilience. There is a concluding discussion concerning the manner in which robustness and resilience are confounded in the paper "Universal Resilience Patterns in Complex Networks."

INTRODUCTION

Gao, Barzel, and Barabási attempted to devise a method to identify universal resilience in systems. (Gao 2016) Vesterby pointed out that the target, the identification of universal resilience, was missed primarily due to the problem of simplification. (Vesterby 2016) Also contributing to the miss is the problem that the paper is not about resilience—it is about robustness.

A robust system either resists a disturbance, and remains essentially unaffected by the disturbance, retaining its normal processes, or the system is damaged or altered in some manner, recovery processes do not occur, and yet the system retains some or all of its normal processes and roles. A robust system has an inherent capacity for toughness or some other factor, such as redundancy or active resistance, that prevents the disturbance from shutting down the system's processes or roles.

A resilient system is one in which recovery processes occur after the system has sustained a disturbance. A resilient system has a capacity for recovery in the form of inherent mechanisms or processes that when activated provide recovery from the effects of a disturbance. The recovery processes can be activated, directly or indirectly, by the effects of the disturbance. Or they can be ongoing processes within the system that play a role in recovery after a disturbance.

Many systems have capacity for both robustness and resilience, at first resisting the disturbance to various degrees and then recovering from the effects of the disturbance. This is common with living systems and with systems with living components. (For the distinction between living systems and systems with living components see Vesterby 2008)

ROBUSTNESS

Robustness Due to Toughness

Robustness Due to Strength of Chemical Bonds

The strength of a chemical bond between two atoms, the toughness of the bond, depends on what kind of bond it is. Types of bonds, such as covalent and ionic bonds, that share or transfer electrons between atoms tend to be stronger than those types of bonds that do not share or transfer electrons. Chemical compounds based on strong chemical bonds are tougher, more resistant to disturbance than compounds based on the weaker types of bonds, such as the hydrogen bond and the van der Waals interactions.

Robustness Due to Structural Organization

In the timber framing of buildings, trestles, and towers, the basic unit of structure is a rectangle of four beams joined at their ends. This rectangular unit of construction is susceptible to distortion due to lateral pressure on the vertical sides, forcing them to tilt. Such sideways distortion can result in collapse, especially if there is a load on the top cross beam.

The structural pattern-of-organization of the rectangle is weak. It can be transformed into a robust rigid structure by the addition of a fifth beam as a diagonal from a lower corner of the rectangle up to the opposite upper corner. This diagonal bracing resists both compression and tension (stretching) forces resulting from lateral pressure on the vertical support beams.

Lateral force applied to the upper corner where the diagonal is attached creates a compression force on the diagonal beam, which it resists. Lateral force applied to the opposite upper corner creates a tension force on the diagonal, which it resists. If two diagonal beams are added to the rectangle, forming an X structure inside the rectangle, lateral pressure on either upper corner creates resistance simultaneously to both compression and tension. This structural organization is exceptionally rigid, exceptionally robust.

There are several pictures of diagonal bracing at the Wikipedia page Trestle Bridge:
https://en.wikipedia.org/wiki/Trestle_bridge#/media/File:02_42_21_trestle.jpg

Robustness Due to Redundancy

Robustness Due to Structural Redundancy

An impact attenuator is a devise that lessons the destructive consequences of a motor vehicle collision. A Fitch barrier is one example, consisting of a line of plastic barrels filled with sand. They are placed in locations to prevent vehicles from violently colliding with large sign posts, overpass supports, and other such obstructions.

The momentum of the colliding vehicle is transferred to the sand, slowing the vehicle. The first barrels in the line have less sand, providing less resistance, with the following barrels progressively having more sand. The result is a progressive slowing of the vehicle.

A Fitch barrier is tough, robust, designed to be that way using the organized redundancy of the line of barrels. There is a picture of a Fitch barrier on Wikipedia, under Traffic Barrier, at bottom of the page under Barrier End Treatments.
https://en.wikipedia.org/wiki/Traffic_barrier#/media/File:FitchBarrels2008.jpg

Robustness Due to Process Redundancy
Process redundancy occurs where there are two or more duplicate processes operating simultaneously. When a disturbance takes out one of the processes, the others continue to play the role of these processes. The system is damaged, but still playing its role, albeit at a lesser level.

For the processes of vision, hearing, breathing, and filtering blood, mammals have two eyes, two ears, two lungs, and two kidneys.

Robustness Due to Active Resistance

Robustness Due to Action of Immune System
While resilience usually involves system processes of one form or another, robustness usually does not occur through the roles of processes. There are exceptions, such as when the robustness, the toughness, of a system is based on active resistance to disturbance. The immune system is an example at the level of physiology, where cells of the immune system, phagocytes, engulf bacteria and kill them.

Robustness of Insect Colony Due to Reaction to Colony Invasion
Another example of active resistance to disturbance occurs at the social level with the resistance of an insect colony to colony invasion. There is a large wasp, the Asian Giant Hornet (*Vespa mandarinia*), that invades the hives of the Japanese Honey Bee (*Apis cerana japonica*) to collect the honey bee larvae, which the wasp then feeds to its own larvae. There is another wasp, the Japanese Yellow Hornet (*Vespa simillima xanthoptera*), that is also a predator at the honey bee hives.

There is a picture of a Japanese Yellow Hornet at a bee hive on Wikipedia, at Apis cerana japonica:
https://en.wikipedia.org/wiki/Apis_cerana_japonica

The honey bees use a special method to kill the attacking wasps. A large number of bees form a ball around the wasp, completely engulfing it. The bees then vibrate their wing muscles, which raises the temperature within the ball to a level that is too hot for the wasp. Additionally the concentration of CO_2 goes up within the ball of bees, and the wasp dies from the high temperature and high level of CO_2. There is a picture of a ball of bees at the same Wikipedia page.

The processes of the immune system and the process of the bees coordinating their behavior play roles that resist the disturbances of infection, disease, and colony invasion, providing the organism and the colony with a degree of toughness, making them robust against disturbance. These processes play roles with robustness, providing resistance to disturbance, but play no roles in the recovery from the damage due to infection or the damage done by the attacking hornets.

RESILIENCE

Resilience Due to Ongoing System Processes That Can Play a Role in Recovery

Resilience—Recovery Due to Dendritic Processes on Beach Sand

There is a beach composed of very fine sand on the shore of Puget Sound in Washington state. At high tide this sand becomes saturated with water, which at low tide drains out of the sand part way down the beach. As the water flows over the surface of the lower beach, it develops dendritic patterns of flow isomorphic to the flow patterns of deltas. The flowing water transports the fine sand, and over a period of minutes it is possible to observe some of the processes that create deltaic dendritic patterns. These deltas are small enough such that it is possible to place a tripod and video camera above them and record the dendritic system processes.

This system has a capacity for resilience based on the continuous flow of water and the transport of the sand, which are both ongoing natural system processes. If a scoop of sand is removed crosswise to the flow, the processes are stopped below the location of the disturbance, and the water begins to flow into the hole. The transported sand is now deposited in the hole, slowly filling it. When the surface of the sand is again smooth with water flowing over it in a normal manner, the interrupted deltaic process on the beach below the location of the disturbance are restored.

Resilience—Recovery Due to Reproduction in Insect Colony

In insect colonies, such as those of honey bees, ants, and hornets, there is generally only one, or a very few, individuals that play the reproductive role—that lay eggs. In these colonies this egg laying is an ongoing process, which slowly builds up the size of the population of the colony. When disturbances such as predators or adverse weather kill off many of the colony's workers, lowering the size of the colony, the natural system process, laying eggs, slowly restores the population of workers.

Resilience Processes Activated by the Effects of the Disturbance

Resilience—Recovery Due to Elasticity

Possibly the most widely known case of resilient recovery is that of rubber. A rubber band when stretched, or a solid rubber ball when compressed, returns to its original configuration when the force of the pulling, or the force of the compression, is removed. The disturbance of stretching and compression subjects the molecules of the rubber to tension, which distorts their shape. When the stretching or compression is removed, the tension is relieved, and the internal forces that determine the shape of the molecules returns them to their undisturbed configuration.

Resilience—Recovery Due to Epicormic Buds

Epicormic buds are vegetative buds beneath the bark of various species of plants. These buds are maintained in a dormant state by hormones originating in the active shoots of the plant. When the active shoots are destroyed, for example by fire, the hormones are no longer produced and the epicormic buds sprout, providing recovery for the plant after the fire.

Pictures of recovery by this process are located at:
https://en.wikipedia.org/wiki/Epicormic_shoot#/media/File:Banksia_attenuata_resprouter.jpg

Resilience—Recovery Due to Healing

Healing provides an organism with a process of recovery after injury or disease. With mammals, the occurrence of a wound, such as a cut, prompts a four phase cascade process that results in the healing of the wound—(1) clotting phase, (2) inflammation phase, (3) proliferative phase, (4) maturation phase.

This healing cascade is initiated by the occurrence of he wound. The wound results in bleeding. When platelets in the blood come in contact with collagen, in the tissue outside the blood vessels, the platelets produce glycoproteins that play roles in the aggregation of the platelets, initiating the formation of a blood clot that stops the bleeding. The platelets further produce inflammatory factors which initiate the next stage of the healing cascade.

Bleeding initiates the healing processes. Bleeding is a consequence of the disturbance, the wound. Thus the recovery processes are activated by an effect of the disturbance.

Resilience—Recovery Due to Replacement Redundancy

Recovery can be provided by switching from malfunctioning unit to redundant unit. Shipping containers are sometimes fitted with refrigeration units. To ensure preservation of temperature-sensitive cargo, the shipping container is provided with two refrigeration units, with one unit on and the other unit off. When one unit loses its capacity to keep the cargo cold, the other unit starts automatically, thus recovering the correct level of refrigeration. There is a picture of such a container on Wikipedia under Refrigerated Container, at the bottom of the page under Redundant Refrigeration. The refrigeration units are marked 1 and 2.
https://en.wikipedia.org/wiki/Refrigerated_container#/media/File:Redundantreefer.JPG

DISCUSSION: CONFOUNDING ROBUSTNESS AND RESILIENCE

Robustness is the ability or capacity of a system to resist or to take damage while retaining its normal processes to at least some degree. Resilience is the recovery that occurs within a system after some form of disturbance to the system. Factors of resistance and toughness (without factors of recovery) are characteristic of robustness, while factors of recovery (restore, repair, resume, compensate) are characteristic of resilience.

Robustness and resilience are two distinct system-functions that play roles in system maintenance. Robustness plays a protective role, while resilience plays a restorative role. Robustness generally occurs prior to resilience—protection first, then recovery. While there are some factors, such as redundancy, that in one form or another play roles in both robustness and resilience, the manner in which robustness plays its roles in the protection of the system are generally distinct from the manner in which resilience plays its roles in the recovery of the system.

The paper by Gao, Barzel, and Barabási, "Universal Resilience Patterns in Complex Networks," is not about resilience—it is about robustness. The use of the term, *resilience*, in the paper does not make it clear that the authors are aware that resilience in real-world systems, from bouncing balls to ecosystems, involves recovery from disturbance. It involves restoration, repair, resumption, or compensation. Neither the term, *recovery*, nor these other four terms are used in the paper.

Instead, there are multiple statements referring to the "lose of resilience," without ever making it clear exactly what resilience system-functions are lost. The systems are damaged through the removal of components, or removal of relations between components, until the systems can no longer exist in their normal state. The systems are damaged beyond the capacity of both robustness and resilience to play their roles in maintaining to some degree the system's normal processes—for example the cases involving the death of the cells. (p. 310)

When the authors use the term, *resilience*, what they are actually referring to is the capacity of the system to endure when subjected to repeated disturbance. Consider the sentence, "Equation (13) helps us to identify the network characteristics that can enhance or weaken a system's resilience." (p.311) It is not factors of resilience that equation (13) helps to identify. No mention is made of any factors of recovery. Equation (13) helps identify factors that enhance or weaken a system's capacity to endure.

The authors give examples of factors that affect system endurance when subjected to repeated disturbance. "However, Fig. 4d shows that while the source of Net11's resilience [endurance] is its high density $\langle \rangle$ s , the source of Net12's resilience [endurance] is its high heterogeneity H." Density and heterogeneity are not processes that contribute to recovery. They are factors of quantity and diversity that can play roles with robustness, such as contributing to the endurance of a system repeatedly subjected to disturbance. Endurance here is a consequence of robustness.

While the distinction between the robust and the resilient qualities of systems is important for the general understanding of all systems, this distinction is particularly significant for the design and management of integrated social-ecological systems, such as agricultural systems and power production and transmission systems.

When studying systems, it is important to know what system-functions are present. What are their specific roles in the system? And what are the consequences if those system-functions do not play their roles?

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