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Imprisoning Complexity in Modules

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ABSTRACT

In a modular system, complexity is effectively imprisoned within subsystems, thus mitigating the propagation of influences to distant parts of the larger system. This paper briefly outlines the idea of modularity as a design principle; explores its benefits – which go beyond the imprisonment of complexity – as well as its limitations; and applies the ideas of modularity to social institutions. Although modular design may or may not be an optimal response to a given environment (typically understood as a given optimization problem), modular design shines in the far more important realm of innovation, which is driven by the recombination of knowledge. The concepts of encapsulation and information hiding in the theory of modular systems turn out to be analogous in many ways to the principles of constitutional design articulated in constitutional political economy. The paper considers the difficulty of creating a modular-constitutional structure as well as the threats to established modular-constitutional systems that arise from rent seeking and externalities, including intangible externalities or moralisms. The paper concludes by applying these ideas to one particular set of social institutions, present-day Internet social networks.

JEL classifications: D02, D23, D71, D74, K11, P14, P16

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Everyone has heard of the butterfly effect.[1] The version articulated by Jeff Goldblum's supercilious mathematician in *Jurassic Park* (1993) has become a cultural touchstone: "A butterfly can flap its wings in Peking, and in Central Park you get rain instead of sunshine." The implication is clear. In a complex system, all things are interconnected. Our local actions may well ramify to distant parts of the system in unintended and unforeseeable ways. If we change or interfere with the system, even in what may seem an insignificant manner, we do so at our peril.

Jurassic Park was of course notable for its pathbreaking use of computer graphics to bring to life the terrifying dinosaurs that – as result of human hubris in tampering with a complex system – would run amok in the titular theme park. Yet rendering imagined dinosaurs on film was itself a process generated by a complex system. That system was provided by a California startup called Silicon Graphics, which manufactured specialized computers, called workstations, that were smaller than mainframes or minicomputers but more powerful than the personal computers of the era. These machines were not only complex but also finely tuned to the needs of 3-D graphics. In the larger workstation market, however, Silicon Graphics was a niche player, with something like a five per cent share in the early 1990s.[2] The largest maker of workstations, with closer to a third of the market, was Sun Microsystems, another California startup. Significantly, by the nineties Sun had risen to prominence, and had vanquished its arch-rival Apollo Computer, largely because it had mastered a strategy that tamed complexity and controlled the interdependency among parts of the system. Sun succeeded because it created a *modular system* (Baldwin and Clark 1997).

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1 For the correct understanding and intellectual origins of this idea, I leave the reader to the mercies of Wikipedia.

2 "Sun Leads in Work Stations," *New York Times*, January 22, 1990, p. D2.

Perhaps there is a very mild irony in this. As a principle of design in complex systems, modularity is arguably the antidote to the butterfly effect. In a modular system, complexity is effectively imprisoned within subsystems, thus mitigating the propagation of influences to distant parts of the larger system. The great fable of the butterfly effect was crafted with a complex system that forbade butterfly effects.[3]

In what follows I briefly outline the idea of modularity as a design principle; explore its benefits – which go beyond the imprisonment of complexity – as well as its limitations; and apply the ideas of modularity to social institutions, notably present-day Internet social networks.

Complexity and modularity.

In the mid-1960s, IBM introduced the 360 series of computers. This was a major departure for the company in computer design, and it would become a major landmark in the history of computing. Since its beginnings in the nineteenth century, IBM had thrived on what Henderson and Clark (1990) called *architectural innovation*: using a relatively stable inventory of slowly improving parts to assemble bespoke information-technology solutions for customers (Usselman 1993). The introduction of electronic technology did not initially change this model, but soon the problem of multiplying software products introduced a complexity bottleneck. IBM responded by radically transforming from a purveyor of bespoke architectures to the designer of a single stable architecture – the System 360 – that could be adapted to customer problems through standardized software and by mixing and matching standardized subassemblies. The IBM 360 would be a modular system (Baldwin and Clark 2000, pp. 169-194).

3 Silicon Graphics machines were somewhat less modular that Sun workstations, which may have worked to the company's advantage in tailoring its computers to the 3-D-graphics animation market. I return to this point below. Of course, with the relentless progress of Moore's Law, Sun and all other workstation makers would soon be swept away by increasingly more powerful – and highly modular – personal computers (Comerford 1996).

Controlling the complexities of such a general-purpose machine demanded an overarching control program, what would come to be called an operating system. Yet no one, even IBM, had had any experience writing such a program, and little was known about the complex interdependencies among subsystems (Baldwin and Clark 2000, pp. 191-192). The manager of the project, Fred Brooks, insisted on a conscious attention to all interdependencies and a high level of communication among all participants. This included the creation and maintenance of a formal project workbook that documented every aspect of the system so that, in principle at least, every worker could determine how changes elsewhere would affect his or her part of the project. Brooks decided "that each programmer should see all the material, i.e., should have a copy of the workbook in his own office" (Brooks 1975, p. 76). But within six months there was one small problem. "The workbook was about five feet thick! If we had stacked up the 100 copies serving programmers in our offices in Manhattan's Time-Life Building, they would have towered above the building itself. Furthermore, the daily change distributions averaged two inches, some 150 pages to be interfiled in the whole. Maintenance of the workbook began to take a significant time from each workday" (Brooks 1975, p. 77). The team soon switched to microfiche. And, clearly, with modern technology, the workbook could reside online and be updated rapidly. But it was obvious that in the end this approach was entirely unworkable.

In his telling of this story, Brooks briefly considers but dismisses a "radical" alternative proposed by David Parnas, whose "thesis is that the programmer is most effective if shielded from, rather than exposed to the details of construction of system parts other than his own" (Brooks 1975, p. 78). Parnas (1972) is the inventor of the notion of *information hiding,* a key concept in the modern object-oriented approach to computer programming. Programmers had long understood the importance of breaking programs into manageable pieces. But genuine modularity requires more, since one can easily break a system into "modules" whose internal workings remain highly interdependent with the internal workings of other modules. Parnas argued that, especially in large projects, programmers should abandon modularization based on simple flow charts and pay attention instead to minimizing interdependencies. If knowledge is hidden or *encapsulated* within a module, that knowledge cannot affect other parts of a system. Under this scheme, every module "is characterized by its knowledge of a design decision which it hides from all others. Its interface or definition was chosen to reveal as little as possible about its inner workings" (Parnas 1972, p. 1056).

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	x			x		x	x
a_2		x	x		x		
a_3			x	x		x	x
a_4	x			x			
a_5		x			x		x
a_6	x		x	x		x	
a_7		x		x		x	x

(A) A non-decomposable system.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	x	x					
a_2	x	x					
a_3			x	x			
a_4			x	x			
a_5					x	x	
a_6					x	x	
a_7							x

(B) A decomposable system.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	x	x	x	x	x	x	x
a_2	x	x	x				
a_3	x	x	x				
a_4	x			x	x		
a_5	x			x	x		
a_6	x					x	x
a_7	x					x	x

(C) Modular system with common interface.

Figure 1. Decomposable and modular systems.

Theorists of complexity since at least Herbert Simon (1962) have emphasized that systems are almost always hierarchical. By this Simon explicitly did not mean that one module bosses other modules around. What he had in mind was that encapsulated subsystems can be treated as primitive elements by other subsystems.[4] It was crucial for Simon that systems be *decomposable*. Consider Figure 1. An entry of x in location a_{ij} means that element a_i communicates with element a_j. Matrix A is a fully non-decomposable system: every element communicates with every other element. That means that the behavior of every element potentially affects, and is potentially affected by, the behavior of every other element. That could be a real problem. It implies not only high costs of coordination but also the possibility of unforeseen and perhaps destabilizing interaction effects. By contrast, Matrix B is a decomposable system. Communication is encapsulated within clusters of elements – modules – that do not communicate with elements "far away."

Notice, however, that, although a decomposable system like Matrix B clearly solves the problem of coordination, it does so by creating autarkic clusters: it eliminates the costs of cooperation by the expedient of eliminating cooperation between clusters (though not within clusters). The term modular system takes on many meanings in the literature, but one important candidate definition is that a modular system is a nearly decomposable system that preserves the possibility of universal cooperation by adopting a common interface (Langlois and Garzarelli 2008). The common interface enables, but also governs and disciplines, the communication among subsystems. In terms of Figure 1, an interface would be a set of elements that communicates with most or all the other elements. In Matrix C, element a_1 is the common

4 John Holland similarly sees hierarchy as implicitly about encapsulation not "dominance." He defines a *default hierarchy* as a hierarchy of rules "in which general rules cover the most common situations and more specific rules cover exceptions" (Holland 2012, p. 122).

interface: a_1 communicates with all the a_{ij} and all the a_{ij} communicate with a_1. In other respects, however, Matrix C remains sparse off the diagonal. The modules communicate with each other only through the interface, never directly. Sparseness of the off-diagonal – what we might think of as the *leanness* of the system – is a crucial characteristic of a well-designed modular system. The basic idea is that "system details that are likely to change independently should be the secrets of separate modules; the only assumptions that should appear in the interfaces between modules are those that are considered unlikely to change" (Parnas, Clemens and Weiss 1985, p. 260).

Baldwin and Clark (2000) have their own useful language for talking about modularity. They distinguish between *visible design rules* and *hidden design parameters*. The visible design rules consist of three parts. (1) An *architecture* specifies the modules that will be part of the system and what their functions will be. (2) *Interfaces* describe in detail how the modules will interact, including how they fit together and communicate. And (3) *standards* test a module's conformity to design rules and measure the module's performance relative to other modules. Crucial to this schema are the ideas of encapsulation and information hiding. Not only do the parts not need to communicate extensively with one another, they are structurally forbidden from communicating with one another.

Conscious design and evolution.

Theorists of modularity have long seen themselves in search of a "science of design." The model of the digital computer, and in particular the model of software, has loomed large, because software illustrates principles of design in an especially clear way. Baldwin and Clark are concerned principally with the conscious design of artifacts by humans, even as they view human design and Darwinian processes as fundamentally similar (Baldwin and Clark 2000, pp.

221-230). Herbert Simon went so far as to suggest that we should observe modular designs in nature because modular designs would have superior survival value. Thus the famous parable of the watchmakers (Simon 1962, pp. 470-471). Tempus and Hora each made complex watches of some 1,000 pieces. Tempus made his watches as a single non-decomposable system, so when he had to put the work down to deal with a phone call from a customer, the whole thing fell apart and he had to start over from scratch. By contrast, Hora made his watches out of stable modular subassemblies, so when he was interrupted only one subassembly fell apart. Hora could thus make many more watches and was far more successful.[5] The implication is that a nearly decomposable system is more robust to exogenous shocks.

But what does this parable really tell us about evolvability in a Darwinian system? True enough, the point of evolution is that an organism survives if it is able to withstand the buffets of its environment. If the environment changes, Darwinian processes will select for organisms that better fit the new environment. But, even in a world of punctuated equilibria, that evolutionary process may well mean the accretion of changes to the original form, not a full-scale system redesign. The result could be a well-adapted complex system made up of parts that are highly interdependent with one another. For example, the aerodynamics of the flight of a bird is a system with far more non-linear interactions than the aerodynamics of the flight of an airplane (Holland 2012, pp. 22-23). Unlike many precursors who had tried to pattern mechanical flight on the flapping of bird wings, the Wright brothers succeeded because they made their plane more modular than evolved birds – by decoupling the system of propulsion from the system of

5 This is a lesson that Southwest Airlines – the one major American airline that doesn't use a relatively modular hub-and-spoke system – learned at great cost in December 2022. Alison Sider, "How Southwest Airlines Melted Down," *The Wall Street Journal*, December 28, 2022.

control.[6] Biological evolution had not needed, and had not produced, that kind of modular design.

There is also evidence that non-modular architectures can often outperform modular ones in many highly demanding settings (Christensen, Verlinden and Westerman 2002). If the phone calls that so discombobulated Tempus were extremely rare events, Hora would not be at an advantage – and might have been at a disadvantage if Tempus's interdependent system could fine tune a more accurate watch by taking advantage of capabilities within the system that Hora's design would have forbidden. In a sense, by restricting communication to the interface, a modular system may be leaving some stable-environment gains from trade on the table. As Brooks points out in criticizing the Parnasian approach to software, "a good information system both exposes interface errors and stimulates their correction" (Brooks, 1975, p. 78). To the extent that a nonmodular system tends to reveal errors more quickly and more visibly, such a system may stimulate learning by doing in a way that modular systems do not. This is indeed the benefit that so-called Japanese-style manufacturing systems (including just-in-time inventory systems) are said to take advantage of it: since the failure of any one part can cause total system breakdown, interdependency raises the cost of missing or poorly functioning parts, which in turn raises the incentive to make sure that each part is of high quality.

Following Kauffman (1993), many scholars have modeled adaptation to a given environment as a process of climbing hills in rugged terrain (so-called NK-models). If myopic agents cannot envision the terrain synoptically but know only whether they are ascending or

6 The Wrights did control the lateral stability of the plane by twisting the wing, an idea they got from watching buzzards fly (Bittlingmayer 1988, pp. 230-232). Soon, however, others, including Alexander Graham Bell, further decoupled mechanical from biological design by introducing the concept of the aileron to control lateral stability.

descending, the optimizing agents may find themselves trapped on a small hill (a local optimum) not on the highest of all peaks (the global optimum). Some have argued that a modular system is more likely to end up on a local optimum (Marengo and Dosi 2005), even though it may discover a pretty good hilltop ages before any non-modular alternative has slogged its way to Shangri-la. In any event, model results are highly sensitive to assumptions, and perhaps the most we can say is that a system faced with the problem of adapting to a given environment – a given optimization problem – is best served not by maximizing the modularity of its architecture but by finding the optimal degree of modularity (Frenken and Mendritzki 2012, p. 943).

Influenced by the success of highly modular systems in the computer sector, automobile manufacturers in the 1990s attempted a strategy of modularity-plus-outsourcing (Jacobides, MacDuffie and Tae 2016). This was essentially the Hora approach: conceptualize the automobile as an arrangement of stable complex subsystems that could be outsourced to capable suppliers and then easily put together on assembly lines shorter and simpler than was traditional, effectively distributing complexity upstream (Alochet, MacDuffie and Midler 2023, pp. 64-65). But the industry quickly learned that this was a mistake. By assembling vehicles as more-nearly unitary systems at final assembly, the car companies could retain control of the knowledge necessary to manufacture, and could better assure the quality of, a complex product that was in the end far less modular than the digital computer.[7] In effect, the automobile industry abandoned Hora for Tempus.

As Herbert Simon (1960) pointed out in a different context, one strategy for making complex interdependent systems more resilient is simply to protect them from change. Intel's

[7] It is a much-discussed topic in the literature of modularity whether the extent of modularity in the structure of production or of organization must "mirror" the modular structure of the product being produced (Colfer and Baldwin 2016).

"copy exactly" methodology was at the center of the resurgence of Intel, and thus of the entire American semiconductor industry, in the 1980s (Lécuyer 2019). Each semiconductor fabrication facility was a complex interdependent system, and – crucially – Intel knew that it did not, and could not, ever fully understand and control those interdependencies.[8] The company thus decreed that all new fabs copy previous successful fabs exactly, down even to the most minute (and often silly-seeming) detail, including the heights of technicians and the colors the bathrooms were painted (Winter and Szulanski 2001).

In the end, a modular design is an artificial design – even when nature designs it. It is a well-though-out, non-arbitrary architecture, even when there is not literally thought involved. For designers, whether human or Darwinian, uncovering the "true" modular structure of a complex system – the structure that minimizes interdependencies – is necessarily expensive (Baldwin and Clark 2000, p. 86). This implies upfront design costs that nature may not be willing to pay very often. At the same time, maintaining an existing modular structure may also be costly, as neither humans nor nature may be able to avoid the temptation to reveal hidden information and make destabilizing connections. This will be of considerable significance when we turn to the complex system of social institutions.

Modularity and innovation.

Even though a non-modular system might be able to surpass a modular one in fine-tuning adaptation to a relatively stable environment, a modular architecture dominates by far in the

8 The production equipment in a fab is to some extent "modular" in that it consists of discrete units manufactured by a variety of suppliers (Langlois 2006). But the subtle and complex process of tuning the system to generate a consistently high yield of chips requires a lengthy process of "qualifying" each machine, making it difficult in reality to swap out modules readily.

realm of dynamics – not so much because modularity is better able to withstand change but because it is better able to *generate* change.

In the long run, a strategy of *modular innovation* (Langlois and Robertson 1992) can outperform even a finely tuned non-modular system. One obvious way in which modularity can facilitate change is that exiting modules can be swapped out for better ones. In engineering this is called "best of breed": you can assemble your personal computer with the best parts available from suppliers and then upgrade when better parts come along. Modules can also undergo fission. For all the reasons Adam Smith long ago articulated (and more), when the functions of a module are partitioned out to submodules, productivity increases (Holland 2012, p. 157). Moreover, because modules in a well-designed architecture are largely independent of one another, the modules represent in effect a portfolio of options whose values are largely uncorrelated – yielding the same kind of benefits as a well-diversified portfolio of stocks (Baldwin and Clark 2000, p. 259).

With this in mind, we can reinterpret Tempus and Hora not as a parable about resilience to change but as a parable about evolvability, which is after all what Simon intended. Biologists believe that a certain degree of modularity is rampant in nature because, as we have seen, modularity isolates one subsystem from another.[9] This means that genetic changes can produce changes in the phenotype of subsystems of an organism with little or no effect on the phenotypes of other subsystems. And this in turn means that Darwinian processes can tinker and improve the fitness of subsystems without creating butterfly effects. Hora is well advised to create his

[9] "Modules are isolable in the sense that prospective interventions may result in difference-making changes or alterations to individual modules within a single system, without resulting in difference-making changes or alteration of adjacent or related modules, within the same system" (Matthews 2019, p. 2).

watch out of stable subsystems not because this better protects him from phone calls but because it allows him to innovate and improve those subsystems.

In the end, however, the most powerful way in which modularity can energize change is through *recombination*. Modularity makes it easier to bring together, in Adam Smith's words, "the powers of the most distant and dissimilar objects" (Smith 1976 [1776], I.i.9). As many have argued, it is the recombination of ideas that has driven modern economic growth (Ridley 2020). Notice that whereas substitution and splitting are about modular innovation – changing or improving the modules while keeping the architecture fixed – recombination is fundamentally about architectural innovation – keeping the modules relatively fixed but changing their arrangement.[10] It is this process that most clearly yields the essential characteristic of a complex adaptive system: *emergence*. A pile of LEGO bricks can become a model of the Mark Twain House.[11]

In general, a system can undergo both modular and architectural innovation simultaneously, and it can do so profitably if those types of innovation proceed at the appropriate rates. Language is a good example. A language is a complex system in which words can be recombined according to a shared set of rules in an essentially infinite variety of ways (Pinker 2000). Meaning is the emergent result of such recombination. But over time both the words and the rules change. New words can be added, old ones forgotten, and existing words altered in meaning. Grammars also change over time. A language that changed too rapidly would be

[10] The economies of substitution that come from swapping in superior modules within a fixed architecture arguably reflect a weak form of recombination.

[11] Which you can see at the actual Mark Twain House in Hartford, Connecticut. If you arrive via Bradley International Airport, you can also see a model of the Goodspeed Opera House. Unhappily, the Danish company is now moving its U. S. headquarters out of Connecticut (Kenneth R. Gosselin, "LEGO to Close Corporate Office in Enfield, Transferring 740 Jobs to Boston," *Hartford Courant*, January 24, 2023.)

useless for communication, but one whose words never changed would struggle to reflect novelty in the environments of the speakers. A similar process can occur with complex physical systems like computers. As the parts of the computer get better, the system architecture has to change to take good advantage of those improvements.[12] The trick is to change the architecture slowly enough that module-makers have an incentive to invest in better modules but fast enough that the technological standards keep up with the power of the modules (Garud and Kumaraswamy 1995).

Modularity and institutions.

Institutions are "systems of established and prevalent social rules that structure social interactions" (Hodgson 2006, p. 2). Institutions are thus complex systems. But what kind of system are they? And how do the rules operate?

John Holland (2014) and other complexity theorists distinguish between *complex physical systems* and *complex adaptive systems*.[13] In a similar vein, Carliss Baldwin (2019) distinguishes between *step processes* and *platforms*.[14] Although there are many subtleties involved, the principal distinction is that complex physical systems (including step processes) are directed at a particular goal or function, like manufacturing an automobile, whereas complex adaptive systems (platform systems) create an open-ended framework of learning, interaction, and adaptation. A platform can be embodied in technology: an iPhone is an open-ended system

[12] Unlike a computer, however, a language arguably doesn't "get better" as it evolves, except insofar as new words (and maybe new grammatical rules) improve communication. In general, linguists do not see any languages as "better" than other languages (Pinker 2000).

[13] Unlike complex physical systems, complex adaptive systems "concern themselves with elements that are not fixed. The elements, usually called agents, learn or adapt in response to interactions with other agents" (Holland 2014, p. 8).

[14] "A step process is a technology that changes the material world in a predictable way that humans find useful or valuable. In contrast, a platform system is a technology designed to support the creation of options" (Baldwin 2019, p. 1).

for which people are constantly imagining new uses. Alternatively, however, a "platform" can be a disembodied system of rules – of institutions. We have already discussed language. Social conventions in general are platforms: a shared rule that everyone must drive on the right-hand side of the road reduces transaction costs and enables an infinite variety of trips, in much the same way that a language enables an infinite variety of messages. A platform can have both physical aspects and disembodied rule-like aspects. Think of a city.

In the realm of social institutions, the distinction between goal-directed systems and platforms maps onto a distinction between *organizations* and *orders* (Hayek 1973). An organization is very much a system of rules, but one directed at a concrete end. A charity seeks to eradicate cancer, an army aims to win a war, and a corporation works to make computers (and ultimately profit). But an order – a social platform – has no purpose. As much as we might think that the output of New York is finance, the output of Washington is legislation, and the output of Los Angeles is movies, in fact a city has no purpose except to facilitate the multifold purposes of its inhabitants (even if many real-world cities facilitate badly). What makes a system of rules function like a platform is that its rules are *abstract* – they serve a wide variety of unspecified and unknown particular ends.[15] The idea of abstractness is closely related to the idea of a hierarchy or rules in a complex system: the more abstract the rules, the higher they are in the hierarchy. The more abstract a set of rules, the more those rules function as an interface.

A modular architecture of social institutions also requires design rules to ensure encapsulation and information hiding. As Hayek argued, a well-functioning social platform must "demarcate for every individual a range of permitted actions by designating … ranges of objects

15 Because there are degrees of abstractness, large organizations like business corporations can take on many features of a platform even while ultimately remaining dedicated to a concrete end (Langlois 1995).

over which only particular individuals are allowed to dispose and from the control of which all others are excluded. The range of actions in which each will be secured against the interference of others can be determined by rules equally applicable to all only if these rules make it possible to ascertain which particular objects each may command for his purposes. In other words, rules are required which make it possible at each moment to ascertain the boundary of the protected domain of each and thus to distinguish between the *meum* and the *tuum*" (Hayek 1973, p. 107).

At the broadest level, what Hayek has in mind is the system of private property rights. This is very much a modular system (Langlois 2002). It is a system of abstract rules that permit individual agents to pursue an infinite variety of goals. It also permits the recombination of ideas that generate economic growth. As Hayek famously argued, price becomes an anonymous interface allowing billions of individual agents to specialize and trade with one another without having to communicate rich information (Hayek 1945).

Writing in the context of the so-called socialist calculation debate, Hayek emphasized that the price system makes it *unnecessary* to share complex (and largely tacit) local knowledge. But there is also a sense in which the system of property rights, like all modular systems, works best when modules – individuals, firms, or other goal-directed organizations – *may not* interfere with the inner workings of other modules. To say that property is importantly about *exclusion* is thus to say that property is about *encapsulation*. Henry Smith (2012) has proposed that the logic of modular systems should underpin our understanding of the law of property. For the most part, he argues, the law relies on an exclusion strategy. Non-owners do not have to know any of the details of how or why a piece of property is owned or how that property is being used. They need only know that as non-owners, they are excluded from interfering with the use of the property unless they receive permission to do so. This economizes dramatically on information and transaction costs.

As both Hayek and Smith are well aware, drawing module boundaries may not always be straightforward, and may be difficult when there are externalities. Indeed, we can think of externalities precisely as failures of encapsulation. As economists now understand, externalities are ultimately a manifestation of the character of things owned – of goods – themselves; and thinking about the characteristics of goods is a more general framework for thinking about ownership boundaries. Not all goods are simple private goods, which are rival in use and also easily excludable in use. Thus in many cases, Smith argues, the exclusion strategy of property law needs to be supplemented with a strategy of *governance*: the use of rules that are less general and more contextual than the abstract rules of ownership.[16] Governance strategies call for more of what Hayek famously called the "knowledge of the particular circumstances of time and place" (Hayek 1945, p. 521).

Some goods, for example, are what Elinor Ostrom (2015), following James Buchanan, called *club goods*: they are rivalrous in use – Ostrom preferred the term "subtractable" – but they do not lend themselves easily to the drawing of exclusion boundaries. Such goods thus frequently require governance strategies. Ostrom analyzed many such strategies in a multiplicity of situations in history and around the world. She found that in simple face-to-face societies – *within* modules, in effect – governance strategies work well in allocating resources. The information demands of small societies are low, and thus so are the costs of using information-intensive approaches and of tailoring rules to specific individuals and specific contexts. Ostrom

[16] This is in many ways the central message of Calabresi and Melamed (1972).

also found that in more-complex property situations, systems of rules often evolve spontaneously – rules that are more abstract than the highly contextual rules of small face-to-face groups but less abstract than the first-order rules of the law of property. Very often these rules involve multiple centers of authority over exclusion and use, what Ostrom called *polycentricity*.

In larger societies, of course, governance strategies work far less well than exclusion strategies. In the end, Hayek's complaint about socialism is precisely that it seeks to demodularize society by imposing concrete (less-abstract, less-general) rules on social agents. This desire to demodularize social institutions he ascribed largely to intellectual error. He believed that, flushed with the successes of the natural sciences since the Enlightenment, intellectuals had mistakenly come to believe that scientific knowledge, in the service of conscious rational planning, could tame and control complex economic systems – without all the messy groping, experimentation, and competition of a modular market.

Warren Weaver famously identified the differences among *simple problems* (like those of Newtonian or even Einsteinian physics); problems of *disorganized complexity*, as in statistical thermodynamics; and problems of *organized complexity*, as in the social sciences. Writing in 1948, Weaver enthused about the "new kinds of electronic computing devices" that had emerged out of World War II research. "They will make it possible to deal with problems which previously were too complicated, and, more importantly, they will justify and inspire the development of new methods of analysis applicable to these new problems of organized complexity" (Weaver 1948, p. 541). The power of computing devices since 1948 has advanced to such an astonishing extent that even so great a mind as Weaver could never have foreseen it. Yet the goal of fully understanding and controlling complex systems remains out of reach. Many researchers, notably those affiliated with the Santa Fe Institute, still hold that the unrealized objective of complexity theory “is to attain some ability to ‘steer’ the complex system”[17] (Holland 2014, p. 3). By contrast, Hayek always maintained that “the ideal of prediction and control must largely remain beyond our reach” (Hayek 1967, p. 34), a conjecture that is very likely to survive the dawn of quantum computing and so-called artificial intelligence (Phelan and Wenzel 2023).

In *The Road to Serfdom*, Hayek famously suggested that we should think not of controlling and steering a complex system but rather of tending it, much as a gardener tends his or her plants.[18] But Michael Polanyi, another great theorist of spontaneous order, pointedly lists a well-kept garden as an exemplar of a designed order. “This method of establishing order consists in limiting the freedom of things and men to stay or move about at their pleasure, by assigning to each a specific position in a pre-arranged plan” (Polanyi 1941, p. 431). Some have located the issue in the distinction between the rational, formal French garden – in which “pas un arbre au cordeau n’osa désobéir,” as an eighteenth-century poem would have it – and the more off-beat and meandering English garden.[19] Yet both types of garden are in the end carefully planned orders. The complexity theorist Brian Arthur has suggested what may be a better image than a gardener: a park ranger. A ranger does not put in place a designed arrangement of flora and fauna but merely seeks “to maintain dynamic and unpredictable processes” (Petit and Schrepel 2023). Notably, one of the tools at the disposal of a ranger is exclusion.

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17 Indeed, Holland hoped for “a rational discipline of complex adaptive systems providing genuine predictions” (Holland 1992, p. 198).

18 “The attitude of the liberal toward society is like that of the gardener who tends a plant and, in order to create the conditions most favorable to its growth, must know as much as possible about its structure and the way it functions” (Hayek 2007 [1944], p. 71).

19 Jacques Delille, “Les Jardins; ou l’art d’embellir les paysages” (1782), quoted in Conroy (1980, p. 252). Translation: not a single tightly aligned tree dared to disobey.

The problem, of course, is to build the park in the first place: to pay the up-front fixed costs of a (relatively modular) institutional architecture. The system of market exchange, the most abstract modular system in society, was not invented by humans. It evolved. In essence, humans merely discovered it (Hayek 1967, p. 43). The price system might thus be an example in which Darwinian or quasi-Darwinian processes were able to generate something like a modular system. This is no doubt because the idea of trade is so abstract and because at basic levels trade requires little institutional support. This means that the fixed set-up costs of modularity never needed to be paid all at once, and a modular system could evolve through (what was in effect) gradual tinkering. As Adam Smith famously noted, “the propensity to truck, barter, and exchange one thing for another” comes quite naturally to people (Smith 1976 [1776], I.2.i).

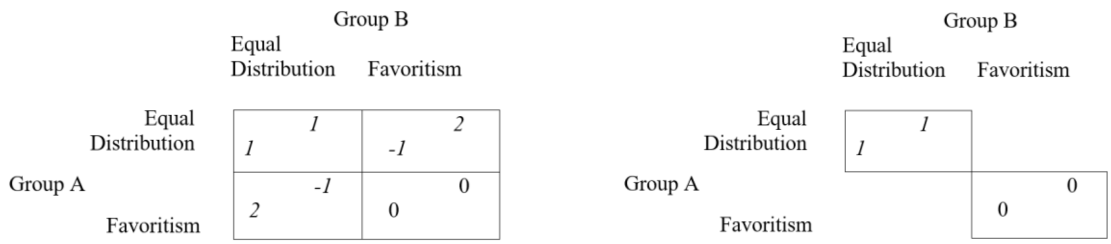
Nonetheless, an effective modern price system depends crucially on a variety of more complex institutions, including, as I have already suggested, institutions of private property. Such institutions may arise only under special circumstances, and indeed they did in fact initially arise only in some parts of the world and only fairly recently (by historical standards) even in those few places. As Hayek emphasized, the abstract rules supporting the market are in an important sense artificial. The architecture of the system is not intuitive to humans, who evolved in small face-to-face societies of hunter-gatherers over the course of more than 100,000 years. To put it another way, there is no “political Coase Theorem.” The institutions that the market needs are to a significant degree mechanisms for adjudicating disputes and enforcing contracts (Greif 2006). But how is it possible for people to agree on such institutions if there are not already in place mechanisms for adjudicating disputes and enforcing agreements? Although the creation of an abstract modular architecture of social institutions may be Pareto improving, political agents are typically unable to commit credibly to maintaining impartial institutions in the face of powerful incentives to engage in predation and rent seeking (Acemoglu 2003). The path to a system of liberal democratic institutions is thus a narrow one that societies tread infrequently and with difficulty (Acemoglu and Robinson 2019; North, Wallis and Weingast 2009).

Constitutions as modular architecture.

There is a flip side to the problem. Once a relatively modular system of institutions is in place, agents may have an incentive to undo that structure. This is so for the same reasons that a programmer might be tempted to improve the performance of his or her module by taking advantage of knowledge about the inner workings of other modules by making connections with those other modules that bypass the interface. To put it another way, agents may have an incentive to employ governance strategies instead of exclusion strategies. Again, intellectual error may play a role. But there are also clear incentives involved. Although it is in everyone's long-term interest to maintain the modular institutions, there are private short-run benefits – we may call them rents – available from circumventing the architecture.

The solution to the problem is a *constitution*. In the software case, there must be an enforceable rule maintaining information hiding and module isolation. The political case is analogous. There is a deep connection between a modular institutional structure and an impartial institutional structure.

As we saw, the system of property rights encapsulates by preventing intrusions on the



(A) Majoritarian voting. (B) The constitutional diagonal.

Figure 2. Majoritarianism and the constitutional diagonal.
The entry in the lower left of each cell indicates the payoff to Group A,
whereas the entry in the upper right indicates the payoff to Group B.
After Buchanan and Congleton (1998).

inner workings of modules without permission. Obviously, one way in which agents (or modules full of agents) can bypass that interface is by political means. Buchanan and Congleton (1998) model the issue in a simple and enlightening way. Consider two groups, A and B, which can affect the allocation of resources through some kind of majoritarian voting. The two groups could agree to allocate resources equally between them, or the group in the majority could choose to favor its own members and penalize the other group. For example, the majority could choose to provide public goods to its own members while taxing the members of the minority to pay for them. (Figure 2.) This looks like a prisoners' dilemma game, but that is not what the authors have in mind. In a prisoners' dilemma, the two players move independently at the same time. In majoritarian voting, only the winner moves. So if A is in the majority, it chooses favoritism, and the players end up in the southwest quadrant; if B is in majority, the players end up in the northeast quadrant. Neither is socially optimal.

For Buchanan and Congleton, the solution, simple in concept though not in execution, is to create a constitutional rule that makes the off-diagonal choices unavailable. Just as Ulysses had himself tied to the mast, and just as a dieter is well advised not to keep chocolate cake in the house, a polity can achieve a Pareto-superior outcome by eliminating some alternatives. This is the essence of a constitution: to remove certain kinds of alternatives from the province of majoritarian control. The framers of the American Constitution arguably had exactly this problem in mind, as James Madison famously did in his discussion of the problem of "faction" – the problem of interest groups – in *Federalist 10* (Madison 1961 [1787]). Although it is far from perfect, the analogy with modular design is striking. Modularity is about restricting actions in the system space – about keeping the off-diagonal lean.

In the example in Figure 2, the interaction between the groups (the modules) is essentially a pure transfer of rent. Though it may make the pie smaller, a pure transfer is not perhaps a worrisome source of unanticipated systemic interactions.[20] It is significant that, contrary to what many believe, Hayek was not opposed to income redistribution or the provision of public goods (Hayek 2007 [1944], pp. 86-87). It goes without saying that Hayek favored the internalization of externalities and that, as a constitutional theorist (Hayek 2011 [1960]), he understood the crucial role of abstract "interface" rules. What he was always arguing against was *planning*, by which he essentially meant the substitution of governance for exclusion. He was opposed to policies that unnecessarily violated the principles of encapsulation and information hiding.

Social networks.

The Internet, and especially the social networks that operate on it, provide an illustration of many of the issues of complexity, modularity, and constitutional architecture. They are platforms in Baldwin's sense. They have no purpose except to permit agents to transmit information at low

[20] But the example could be vulnerable to cycling between the northeast and the southwest quadrants to the extent that the majority switches over time, as interests, ideology, or demography change (Shepsle and Weingast 2012).

cost to other agents.[21] The transmission of cheap and abundant information on the wider Internet has spurred recombination and innovation on a massive scale. The flip side, however, is that the participants in social networks often visit intangible externalities upon one another, in a way that can threaten to destabilize the system.

As we saw, externalities are a failure of encapsulation. Economists are well familiar with externalities that involve the transmission of physical effects like pollution. But information can also produce both benefits and harms that are real (or "technological") externalities.[22] These can be both positive and negative. For example, a scientist or engineer may produce a new idea that, in combining with the ideas of others, generates benefits that the inventor does not fully capture. But intangible externalities may also be negative: the utterances, the behavior, and even the identity of one agent can harm (annoy, offend) another agent outside of the price system. Calabresi and Melamed (1972) called such intangible externalities *moralisms*. In many cases, these are bound up with the nature and practice of individual or group identity (Akerlof and Kranton 2000, p. 717).

One response to the problem of intangible spillovers has long been a kind of endogenous modularization. Charles Tiebout (1956) long ago pointed out that people will sort themselves geographically – they will vote with their feet – in order to achieve their desired mix of local taxes and public goods. The practice of zoning is usually justified as a mechanism for sorting groups according to their externalities: manufacture can be zoned industrial while housing is

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21 Internet marketplaces like Amazon and eBay are also platforms in the sense that they enable millions of independent sellers to offer their wares and connect with customer. But supplying customers with goods and services efficiently is ultimately a step process.

22 Not all harms are externalities. If I set up next door to your hamburger stand and make better and cheaper hamburgers, I harm you through the price system not outside of it. The harm I inflict would technically be a "pecuniary" externality.

zoned residential. In the same way, people can also attempt to sort away identity externalities.[23] People can vote with their feet in order to reduce the costs of the identity externalities in their daily lives.[24]

Sorting doesn't have to be geographic. As Anthony Downs long ago observed, voters are confronted with innumerable complex questions of public policy on which it is far too costly to become informed. People thus adopt an ideology as a mechanism to economize on the costs of becoming informed (Downs 1957, p. 99). Identities, of which ideologies are a part, serve a similar function. Denzau and North (1994) argued that competing clusters of shared "mental models" naturally emerge in society.

In many cases, such clusters take on the form of organizations. Baldwin (2008) has described business firms as modules that communicate with other modules only at "thin crossing points," which correspond roughly to Hayek's interface of the price system. The firms themselves are "transaction-free zones" in which rich information can be transmitted at low cost. Similarly, identity organizations – religions, political parties, even hobbyist groups – are *externality-free zones* in which members can practice their identities without imposing costs on those within the group. In effect, identity groups can solve problems of intangible externalities internally using governance mechanisms, much as the small face-to-face groups that Ostrom analyzed can solve more-tangible problems of externality.

23 In the United States in the twentieth century, sorting for physical externalities was also a way of sorting for identity. Existing white areas tended to be zoned residential while existing minority areas were often zoned commercial or for mixed use (Shertzer, Twinam and Walsh 2021).

24 Bill Bishop has argued that Americans are increasingly doing this, choosing, almost instinctively, to move to localities where the lawn signs and bumper stickers match their own. Over the period 1980 to 2000, while racial segregation in American counties declined slightly, segregation by political party increased 26 per cent (Bishop 2008, p. 6).

But what sets the Internet (and its social networks) apart from historical precursors – like the outburst of pamphleteering that attended the invention of the printing press or the cornucopia of nineteenth-century newspapers offering yellow journalism – is the astonishing reduction in the cost of communication it has brought about. This has made it cheaper for agents (or modules of agents) to know what is happening in other modules – and to be offended by what they learn. The result may be destabilizing to the system.

As many have argued, going back at least to Gordon Allport (1954), interacting with people different from oneself could instill greater tolerance of differences, meaning a reduction in the costs of identity externalities. The other side of the coin, as an equally large number of commentators have observed, is that significant identity differences in society can erode the necessary common understanding of society's "visible design rules." As Douglass North put it, "with growing specialization, common ideologies and norms of behavior break down as people have increasingly different experiences and hence different perceptions of the world around them" (North 1988, p. 18).

Many have argued that there are *positive* externalities when a large variety of identities interact with one another. In the framework of Baldwin and Clark, we can think of each identity as a kind of option, an experiment trying out ways of being human; and a multiplicity of such experiments enriches all. As we saw, recombination in a modular system is a driver of economic growth. This is also the process underlying John Stuart Mill's argument in favor of free speech (Mill 1859). Yet the possibility of high-level benefits of interaction among identities does not rule out – and history confirms – the likelihood that such interaction can at the same time lead to conflict. The externalities that are positive in the long run at a system-wide level are often perceived as negative by participants on the ground. Indeed, to the extent that conflict among identities leads to reduced system-wide interaction, it can threaten the positive learning externalities extolled by Mill. If free speech is perceived as causing harms, political efforts will arise to limit speech. Thus it is worth thinking about how agents respond to the perceived negative effects of identity.

In one account, the Internet and its social networks have led to a dangerous increase in polarization, which we can understand as modularization. As we saw, people will tend to sort themselves into groups to minimize external effects. Within the groups, the intangible externalities that are negative to outsiders become positive to insiders, often creating a positive-feedback loop. In the view of Bill Bishop, "like-minded, homogeneous groups squelch dissent, grow more extreme in their thinking, and ignore evidence that their positions are wrong. As a result, we now live in a giant feedback loop, hearing our own thoughts about what's right and wrong bounced back to us by the television shows we watch, the newspapers and books we read, the blogs we visit online, the sermons we hear, and the neighborhoods we live in" (Bishop 2008, p. 39).

For most of the twentieth century, radio and television broadcasting – but, strikingly, not print journalism – was heavily regulated by the Federal Communications Commission, arguably in flagrant violation of the First Amendment (Pool 1983). Content was restricted to inoffensive mainstream fare, and the so-called fairness doctrine raised the cost of expressing opinion by requiring a station (in principle at least) to give free equal time to other views. "There is not room in the broadcast band for every school of thought, religious, political, social, and economic, each to have its separate broadcasting station, its mouthpiece in the ether," said the FCC mendaciously (McChesney 1993, p. 27). When Americans all heard the same news, in the comforting voice of Walter Cronkite, distinct identity groups in the society were connected by a common interface, which had the effect of moderating communication between groups and providing sources of identity at a national level. By contrast, it is widely believed, the Internet has fractionated communication and thereby fractionated public opinion and cultural values, multiplying intangible externalities and creating a tragedy of the identity commons.

The solution to this kind of problem is a governance structure – a constitution – not unlike that of a political state. Creating such a constitution, and setting in place the necessary institutions of exclusion, is perhaps the central problem facing social networks and similar Internet platforms today. To prevent instability, a social network may find itself forced to forbid some interactions, perhaps including violence, pornography, "hate speech," and "fake news." Because a social network is a voluntary contractual organization not a state, its principal enforcement tool is ostracism.

When he started what became Facebook in 2004, Mark Zuckerberg understood this principle implicitly (McCullough 2018, pp. 265-293). The site was originally designed as an exclusive platform for Harvard students to network; and it expanded judiciously, initially limiting membership to patrons at other elite universities. Only with this high-quality network in place did Facebook open up to the world, in September 2006. Users were required to employ their true identities; those who didn't were deleted and banned. And from the start, Facebook policed a wide variety of content that it believed most of its serious users might find offensive. Already in April 2009, 18 per cent of Facebook's 850 employees were patrolling the website for violations (Evans 2012, p. 1230). All of this made Facebook attractive to advertisers. The high-quality strategy quickly toppled Myspace, which had been the dominant social-network platform. Membership exploded almost overnight, from six million in 2006 to 350 million in 2009 to 1.55 billion in 2015.

From the point of view of a platform, “quality” is defined by the preferences of the community of users. The objective is to manage content to make the system function as effectively, and as profitably, as possible. But when users come to number in the billions, representing a vast array of points of view, it becomes increasingly difficult – and perhaps impossible – to define the criteria of quality in a way that will not elicit dissatisfaction from large segments of the user community. Facebook’s decisions about content moderation are frequently understood in terms of the politics of identity: one person’s expression of identity is another person’s sinful act. In forbidding some expressions of identity, a social network is foreclosing some off-diagonal exchanges. And the political battle is over which off-diagonal – or neither – will win.

Calls have gone up to amend or repeal Section 230 of the Communications Decency Act of 1996 (47 U.S.C. §230), which shields Internet providers from liability for the content that flows through their platforms. If they were to become liable for content, Internet providers would be forced to exclude a wide variety of content that significant numbers of users might potentially find offensive. Some voices have even argued that the Internet platforms should be regulated in precisely the heavy-handed ways in which broadcasting was regulated for most of the twentieth century (Carr 2021). By contrast, other voices have suggested going beyond Section 230 to treat platforms as common carriers, thereby forbidding them from discriminating among viewpoints (Volokh 2021). Advocates of free speech point out that a social network as large as Facebook serves much the same function as the larger political institutions it must to some extent emulate. Nadine Strossen (2018), a former president of the American Civil Liberties Union, has argued that Facebook and other social networks should adopt the same rules the U. S. federal government must follow under the First Amendment, even though, like private universities, social networks are voluntary organizations not directly subject to the Amendment. This would be the constitutional-diagonal solution, which – as with free speech in the larger society – would not please those who would have benefited from being in one of the off-diagonals.

The problem for Facebook is that a neutral and inclusive policy may not be stable let alone profit maximizing. The company's original strategy was to maintain high quality; but with almost three billion users, that problem has become unmanageable. In 2018, fearing that external content from news feeds was increasing social anger and political polarization, Facebook tweaked its algorithms to encourage more active interaction among users themselves, which Mark Zuckerberg felt would be better for everyone's mental health.[25] Instead, for reasons we have analyzed, users became angrier and more polarized. During the Covid-19 pandemic, Zuckerberg made it his personal goal to use Facebook to increase vaccination rates.[26] The network was quickly flooded with vaccine-hesitant posts. The threat of popular protest of and government intervention in Facebook's policing policies is arguably making its problems fully intractable. It is thus perhaps no surprise that Zuckerberg has called for government regulation to remove from his shoulders the burdens of content regulation.[27]

Conclusion.

In a modular system, complexity is effectively imprisoned within subsystems, thus mitigating the propagation of influences to distant parts of the larger system. Although modular design may or

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[25] Keach Hagey and Jeff Horwitz, "Facebook Tried to Make Its Platform a Healthier Place. It Got Angrier Instead," *The Wall Street Journal*, September 15, 2021.

[26] Sam Schechner, Jeff Horwitz, and Emily Glazer, "How Facebook Hobbled Mark Zuckerberg's Bid to Get America Vaccinated," *The Wall Street Journal*, September 17, 2021.

[27] Mark Zuckerberg, "The Internet Needs New Rules. Let's Start in These Four Areas," *The Washington Post*, March 30, 2019.

may not be an optimal response to a given environment (typically understood as a given optimization problem), modular design shines in the far more important realm of innovation, which is driven by the recombination of knowledge. The concepts of encapsulation and information hiding in the theory of modular systems turn out to be analogous in many ways to the principles of constitutional design articulated in constitutional political economy. But creating a modular-constitutional structure is costly, whether in nature or in society. Threats to established modular-constitutional systems can arise from the temptation to violate the principles of encapsulation through rent seeking and externalities, including intangible externalities or moralisms. Many of these issues of institutional design are visible in present-day Internet social networks.

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