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Radical Complexity: Using Concepts From Complex Systems Theory to Think About Socialist Transformation

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ABSTRACT: Abolishing alienated labour requires the radical democratization of economic production. Complex systems theory offers tools for theorizing how this radical democracy could be constructed. In complex systems theory, the same structures and transformations appear across multiple domains in the physical and life sciences. Evolution is one such concept. Rather than being linear and gradual, evolution is a nonlinear process in which stable equilibria are punctuated by bursts of catastrophic change. Even catastrophic change, however, happens through an incremental process: the production of new forms through new combinations of existing forms. Each evolutionary permutation of a system is a step into its space of adjacent possibilities. The task of revolutionary theory can be conceptualized as that of plotting a course through capitalism's adjacent possibility space, bringing the system to a benign catastrophe that triggers a phase transition into socialism. The complexity of this mapping requires a distributed processing approach to theorizing that prefigures the distributed processing, or socialist general intellect, that must characterize any radically democratic worker control of production. This project suggests the expansion of a new role for professional intellectuals: that of tool makers, developing conceptual materials that feed a recursive process of the construction of socialist networks.

KEYWORDS: theory, socialism, complex systems, relational sociology, revolution

One of the crucial questions that must be answered in the process of transforming capitalist society predicated on the alienation of labour-power and the exploitation of labour to a socialist society predicated on democratic worker control of the forces of production is how radical socialism will work in practice. This is a ferociously difficult question. It is distinct from but intimately connected with the questions of how a socialist state should operate and of how radical socialist struggles within capitalist society should be organized. In this paper, I draw on a number of basic concepts from complex systems theory to present an analysis of why this question is so intractable, and to suggest some possible resources for making it more tractable.

The Need for Materialist Utopianism

In "Socialism for Realists," Sam Gindin distinguishes between "two central tasks the making of socialism demands": the "political battle to defeat capitalism" and "establishing popular confidence in the feasibility of a socialist society" (Gindin 2018). The "overwhelming focus" of socialists' energies has been on the former, he writes, and too little energy has been put into the latter. The very survival of socialism as a movement, in his view, depends on "presenting a framework that contributes to making the case for socialism's *plausibility*." This involves making concrete proposals of how a socialist society would actually function in practice, for what its institutions and norms will be.

In "Marxism, prefigurative communism, and the problem of workers' control" (Boggs 1977a; see also Boggs 1977b), Carl Boggs also stresses the need for deliberation on how socialism will work in practice. He writes: "A conspicuous deficiency of the Marxist tradition has been the failure to produce a theory of the state and political action that could furnish the basis of a democratic and non-authoritarian revolutionary process" (Boggs 1977a). Leninism on the one hand and liberal or social-democratic reforms on the other have failed to overcome authoritarianism at the level of production relations. Boggs argues that the tradition of prefigurative communism contains the democratic theory and practice that socialism needs, and advocates "asserting the prefigurative over the Jacobin."

These two tasks, making the case for socialism's plausibility and developing a theory and practice of democratic production relations, are intimately connected. Historical materialism proposes that human consciousness emerges out of material social relations: "It is not the consciousness of men [sic] that determines their being, but, on the contrary, their social being that determines their consciousness" (Marx 1971). Of course the causal interplay between base and superstructure is far more complex than implied by the word 'determines'; phenomena of the superstructure have relative autonomy and can affect class relations to some extent (Engels 1999; Althusser 2005). But the point is that

> the question whether objective truth can be attributed to human thinking is not a question of theory but is a practical question. Man [sic] must prove the truth, i.e., the reality and power, the this-worldliness of his thinking in practice. (Marx 1976b, 3)

As long as the relations of production remain firmly capitalist, there is only so far that culture and politics can bend towards socialist ideals.

Marx "thought communism on a world scale would appear organically and quite rapidly" as a mechanical product of the internal contradictions of capitalism (Boggs 1977a). Workers themselves, engaged in revolutionary struggle, would work out the concrete practices of socialist production. This leaves theorists with the task of critique, of clearing away the ideological obstacles to working-class political mobilization. Marx's assumption turned out to be wrong, however. It has been far from obvious how to build socialist societies on national scales, let alone globally. Boggs and Gindin both point to the difficulty of making democratic worker control of production operate beyond local scales. Boggs attributes this difficulty mainly to hostility of statist or Jacobin socialisms to prefigurative projects, but Gindin focuses instead on the *complexity* of the decisions that self-governing workers face:

> It is one thing to assert that workers will make the decisions but how, for example, would workers in an appliance plant weigh whether to increase their use of aluminum as opposed to leaving that aluminum for more valuable social purposes elsewhere? Or in deciding how to allocate their year-end "surplus," how much should be reinvested in their own firm versus other firms? Or if a group of workers wanted to exchange some income for shorter hours, how could they measure and compare the benefits to themselves versus the loss of product or services to society? (Gindin 2018)

Workers need effective ways to resolve these questions through radically democratic deliberation for production to retain a socialist character as it scales up from the local level to national and global levels. And socialists need to be able to point to actual or at least plausible solutions to these dilemmas to attract skeptical workers to the socialist project.

Gindin and Boggs both offer specific institutional models as solutions for the problems they raise (prefigurative communism for Boggs, a "layers of planning" system for Gindin). I'm not doing that in this paper. Instead of a specific institutional framework, I offer a specific theoretical language for deliberating over institutional frameworks. The main obstacles to making socialism work in practice have to do with complexity. Complex systems theory offers tools for addressing those complexities.

Simple and Complex Systems Theories

To define what we mean by a "system," we can use this formulation by Donella Meadows: "a system

is an interconnected set of elements that is coherently organized in a way that achieves something" (Meadows 2008, 11).[1] Defined this way, a system has three types of components: elements (which can themselves also be systems), the interconnections or relations among those elements, and the functions or outputs generated by the workings of the system. (Meadows describes these functions as the 'purpose' of the system, but, like Althusser (Althusser 2006, 187), we can do without this lapse into teleology.) System complexity "arises when the dependencies among the elements become important" (Miller and Page 2007, 9-10). In other words, the relations among elements produce qualities and behaviors not found in the individual elements, an effect called *emergence (Holland 1998)*. Complex systems behave nonlinearly and display sensitivity to initial conditions: small changes to the inputs of the system can produce large changes in its functional outputs (Bossel 2007, 133, 140).

Probably every human culture has some version of systems theory or theories. In sociology, systems theorizing appears at the very inauguration of the discipline, in Comte's work on social statics and social dynamics (Comte 1998). It appears in Spencer's claim that society is to individual human beings as a living organism is to its individual cells (Spencer 1971), and in Durkheim's proposition that social facts exist independently of their individual instances and interact directly with each other (Durkheim 1982). The most influential system theorist in sociology is unquestionably Talcott Parsons, whose assumptions can be seen at work in the thinking even of leftists who believe they reject his structural functionalism. This is worth looking at for a moment.

Parsons proposes that any given social action operates simultaneously in a number of overlapping action systems and is subject to the internal dynamics of each of them (Parsons 1937, 1951). Primary among these are the personality system, consisting of the individual's psychological needs and motivations; the cultural system, consisting of societally shared beliefs and values; and the social system, consisting of norms and roles which may be general throughout society or specific to particular institutional settings. Each of these systems is emergent and tries to adapt to its environments, pursue its own goals, integrate its internal elements, and perpetuate itself over time. Any given action is subject to pressure from the internal dynamics of these multiple systems, and individual behaviour can be explained as an always-imperfect resolution of the constantly shifting tensions among the evolving actions systems (e.g. Parsons 1954). Actions, not individuals, are the constituent elements of society. Actions assemble into institutionalized structures, which are functionally interdependent in the sense that the behaviour of any one structure depends on the behaviour of all the others.

Parsons is often read as a conservative apologist for social order. There is some merit to this interpretation, but not for the reasons people usually think. As used by Parsons, the term 'function' does not necessarily imply a benefit to actual people. Instead: a function is a normal product of the workings of a system; a functional prerequisite is something a system needs to g o on working; and action is functional or dysfunctional depending on whether it contributes to or detracts from the functional prerequisites of a system (Parsons 1949; 1951, 28-29). In principle, whether an action that is functional for a given social system also benefits actual human beings depends on the system in question: racist violence is functional in a slave society, for instance. In this sense, Parsons's structural functionalism is a politically protean orientation to the causal interdependencies in a system, and could provide material for social critique if, for instance, certain forms of oppression are functionally necessary for the maintenance of a given social order (Alexander 1985).

In practice, Parsons never seriously considers this point, and often he writes as if social order is always good. But we can read this as a conservative

1 Meadows describes her own work as systems thinking, not systems theory. Systems theorists like Bossel or Thurner operationalize system parameters as quantitative measures and use mathematical models to theorize system dynamics. Meadows uses qualitative concepts and, in the interests of being as accessible as possible, uses very few specialized concepts. We can distribute theoretical work on systems along a continuum of greater or lesser formalization, with the systems thinking of Meadows, Stroh, and others at one end, fully quantified work on the other end, and non-quantified but rigorous social science such as Byrne and Callaghan (2014) or (Sawyer 2005) in between.

bias in his application of his own ideas. The *intrinsic* conservatism of Parsons's system theory, and its unsuitability for theorizing socialist praxis, comes from other assumptions baked in to his conceptual model. Three of these stand out emblematically. First, the Parsonian model conceptualizes society in idealist terms, treating the physical world, including bodies, machines, and the ecosphere, as belonging to one or another environment, separate from the social system per se (Parsons 1951, 1966). Second, Parsons assumes that all social order is premised on the acceptance by individuals of a common set of values (Parsons 1951, 42). Coercion and power are completely absent from his theory, and dissensus is treated as exceptional. Third, Parsons assumes that social systems usually operate fairly close to equilibrium (Parsons 1951, 204-5, 251). These assumptions, I would argue, are not just normatively pernicious but demonstrably false. They produce a theory that vastly overestimates the amount of voluntary normative consensus in societies and the degree to which heterodoxy and conflict threaten social order.

Complex systems theory corrects these errors, for the most part. Complex systems theory, and its predecessor general systems theory (von Bertalanffy 2015), adopts a materialist stance by treating social systems as merely one type of physical system among others. All complex systems, social or otherwise, can be modeled through a common set of concepts such as emergence (von Bertalanffy 2015, 18, 31, 55, 68), self-organization (von Bertalanffy 2015, 97), functional differentiation (von Bertalanffy 2015, 18, 31, 55, 68), hierarchical structures (von Bertalanffy 2015, 27-28), and feedback (von Bertalanffy 2015, 28). Complex systems are not unified but heterarchical (Kontopoulos 1993), consisting of multiple intersecting networks that are not subject to any overall unifying principle. And complex systems are permanently far from equilibrium, existing as driven dissipative processes not as homeostatic structures (von Bertalanffy 2015, 121, 142; Thurner, Hanel, and Klimek 2018, 86-88). Though not specifically radical, complex systems theory is politically protean enough to be adaptable for revolutionary socialist ends.[2]

Modes of Production as Attractors in State Space

Socialism is an essentially contested concept (Gallie 1956). Gindin and Boggs, for instance, both agree on the need for concrete theories of socialist futurity but propose differing models for realizing that futurity. Disagreement and debate about the specific institutional form that socialism will take are important, but disagreement always has the potential to interfere with collective action. To work together effectively, socialists need a certain amount of tolerance for each other's differing visions of the specifics of revolutionary practice. The concepts of system states and state space provide a useful way of justifying this tolerance.

If all of the relevant qualities of all of the elements and relations that make up a system can be validly quantified and measured, the set of those measurements provides a snapshot of the system. That snapshot is the *system state* (Bossel 2007, 36). If we imagine an n-dimensional space, where n is the number of parameters of the system, then the system state occupies a point in that space, which is called the *state space* (Bossel 2007, 37) or phase space (Thurner, Hanel, and Klimek 2018, 14, 127, 229) or parameter space (Thurner, Hanel, and Klimek 2018, 105). The line constituted by variations in the system state is called the *state trajectory* of the system (Bossel 2007, 37). A visual representation of the phase path of a system (a *phase portrait*) is only feasible if the system has three dimensions or fewer. Social systems have far more than three variables. However, the concepts of system state and state space help us to visualize a social system not as a static things, or even as a thing that changes, but as a *range of values in state space* or, in other words, *a range of possible permutations*.

Consider the distinction between capitalism and socialism as social systems. In public discourse, it's commonplace to conceptualize this distinction as some particular relationship between states and markets, and to debate what particular relationships, what degree of state 'intervention' into 'free' market dynamics, counts as socialism. Everything

2 Niklas Luhmann's work also corrects some of the limitations of Parsonian systems theory by incorporating complexity and theorizing society as an open system far-from-equilibrium. However, Luhmann's work is arguably even more idealist than Parsons's, which is why I've disregarded it for the purposes of this article.

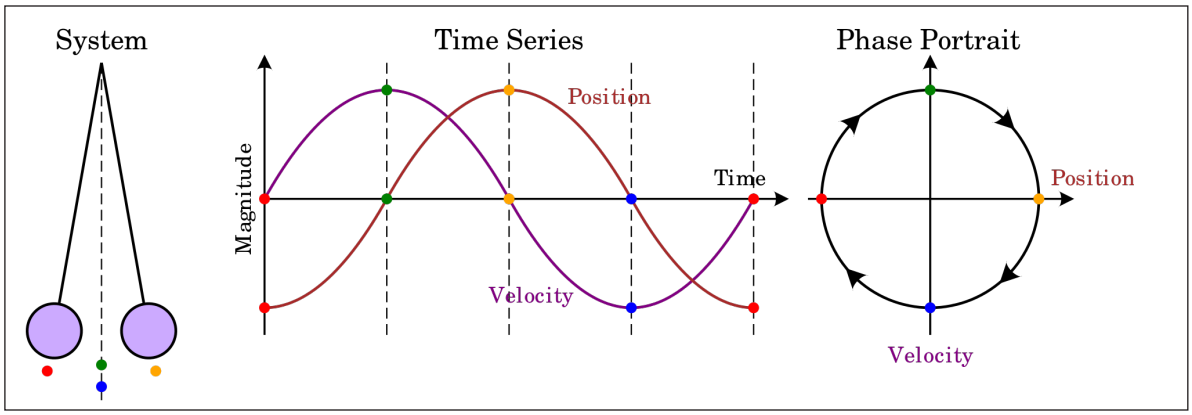

Figure 1. Illustration of how a phase portrait would be constructed for the motion of a simple pendulum. Source: https://commons.wikimedia.org/wiki/File:Pendulum_phase_portrait_illustration.svg. Author: https://commons.wikimedia.org/wiki/User:Krishnavedala. License: Creative Commons BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0/

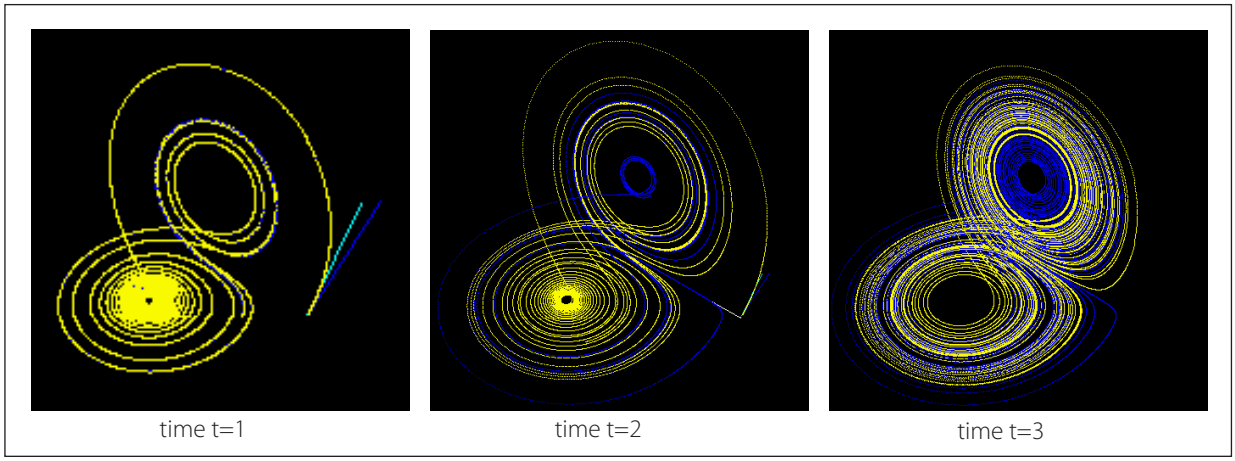

Figure 2. Phase portraits of the Lorenz system, showing sensitive dependence on initial conditions. "These figures – made using $\rho = 28$, $\sigma = 10$ and $\beta = 8/3$ – show three time segments of the 3-D evolution of two trajectories (one in blue, the other in yellow) in the Lorenz attractor starting at two initial points that differ only by 10^{-5} in the x-coordinate. Initially, the two trajectories seem coincident (only theyellow one can be seen, as it is drawn over the blue one) but, after some time, the divergence is obvious." Source: https://en.wikipedia.org/wiki/Lorenz_system

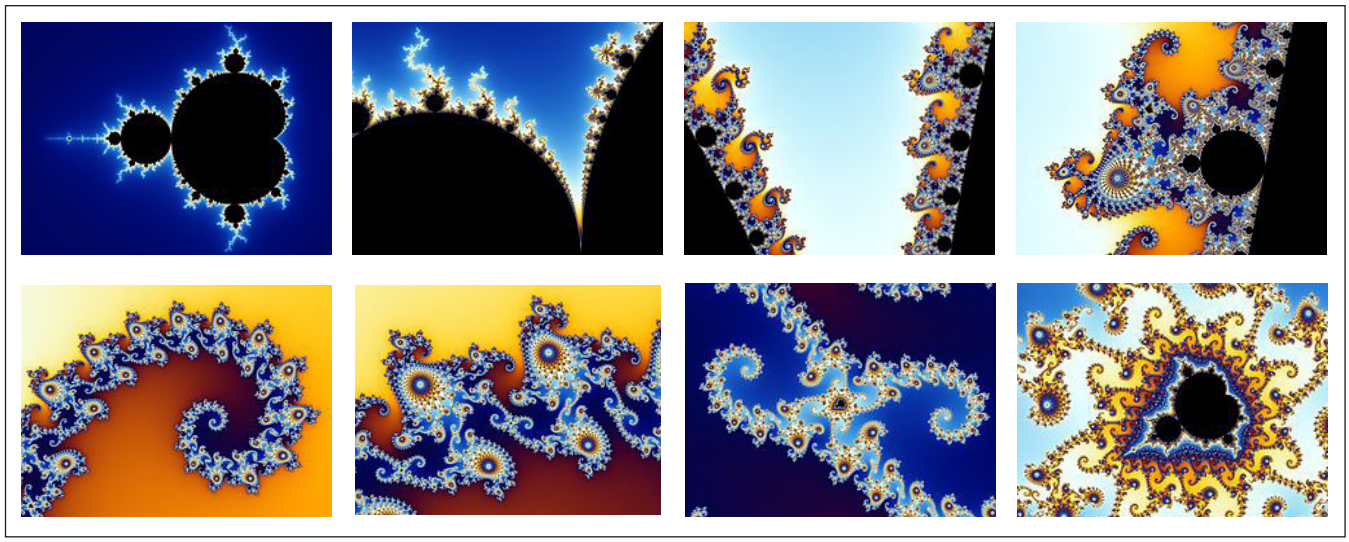

Figure 3. Phase portraits of the Mandelbrot set, zooming in on a single area. The magnification of the eighth image is 213,350 times that of the first. Created by Wolfgang Beyer with the program ***Ultra Fractal 3***. Source: https://en.wikipedia.org/wiki/Mandelbrot_set

from command economies to social democracy to the most timid forms of welfare liberalism, can be branded 'socialist' by supporters and opponents alike, using this thinking. Marxism, on the other hand, locates the defining features of capitalism in the expansion of capital through the appropriation of surplus value (Marx 1976a), made possible by the alienation of labour-power (Marx 1975, 270ff). This enables Raya Dunayevskaya, for example, to coherently argue that the USSR was a capitalist society (Dunayevskaya 1992), and for Immanuel Wallerstein to claim that command economies, social democracies, and other economic models involving statist redistribution of social wealth remain part of the capitalist world-system (Wallerstein 1983). In the terms of complex system theory, Marxism defines capitalism not as a particular system *state*, but as the underlying systemic *relations* that produce a range of possible states along a particular state space trajectory.

What's more, the movement of a complex system along its state trajectory is not always predictable. This is illustrated by the Lorenz system, a system of ordinary differential equations developed by Edward Lorenz for modelling atmospheric convection (Gleick 1987). For certain parameter values and initial conditions, the Lorenz system displays *sensitivity to initial conditions*: small variations in system state lead to large variations in trajectory. This makes it impossible to predict the behaviour of the system beyond the short term, even though the system itself is completely deterministic. At the same time, the system does produce a definite range of possible states, representable as a definite state trajectory known as the Lorenz attractor. In other words, it is impossible to predict where in state space the Lorenz system will arrive at a given moment in the medium to long term future, but it is possible to say with absolute certainty that it will be somewhere on the attractor.

If modes of production are deterministic systems that are sensitive to initial conditions, then they would behave similarly: the precise system state of, say, the capitalist world-system would be predictable only in the short term, and capable of a wide range of variations in the medium to long term, but as long as the system remains determined by the same underlying relations, those variations will take certain forms and not others. We can think of command economies, social democracies, welfare liberalism, neoliberalism, right-wing dictatorships, and the Atlantic slave trade as so many different permutations of the same underlying class relations involving the alienation of labour-power and appropriation of surplus value. And, by implication, we can think of socialism as similarly complex. Just as the capitalist world-system comprises a multitude of formally diverse subsystems, of nation-states and individual enterprises pursuing different regimes of exploitation, it seems intuitively plausible that the socialist world-system of the future could also involve a multiplicity of social networks pursing different regimes of nonexploitative production. This implies that the aim of socialist revolution is not the production of any one particular institutional framework, but the development of generalizable relations of production that will be instantiated in a plethora of differing institutional frameworks. Neither the socialist pluralism of Laski and Cole nor the pluralist socialism of 1960s Czechoslovakia, in particular (Barnard and Vernon 1977; Eisfeld 1996), but a broader socialist multiplicity.

Evolutionary Transformation

If we imagine that successful socialist revolution will produce not one specific institutional order but a diverse multiplicity of institutional forms all characterized by the absence of exploitation and the presence of radically democratized relations of production, a state space rather than a particular system state, we still need to imagine how to transform the capitalist state space into that socialist state space. I would argue that that transformation is necessarily a form of social *evolution*. However, the word 'evolution' carries conservative connotations rooted in non-complex understandings of how evolution works. We therefore need to clarify how evolution is understood in complexity theory to understand the radical potential of evolutionary processes.

Non-Linearity 1: Punctuated Equilibria

The concept of evolution has a fraught history in socialist thinking. Bernstein (1961) invoked evolution as the basis of his argument against seizing state power by force. Levins and Lewontin distinguish between

> the 'minimal theoretical structure' of a science, which is dependent upon unspoken ideological assumptions, and a kind of ideological superstructure that is built upon the minimal structure but is not logically entailed by it. (Levins and Lewontin 1985, 179)

They brilliantly critique the ideological superstructure of evolutionary theory, including the Eurocentric equation of evolution with progress and the structural-functionalist assumption that evolution tends always to produce optimal distributions of resources. But the point I'd like to focus on here is Berstein's association of evolution with gradualism. In light of complex system theory, gradualism is not just part of the ideological superstructure of evolutionary theory but an error at the level of evolution's minimal theoretical structure.

Bossel defines evolution as "adaptation and self-organization under fitness competition in a population of similar systems" (Bossel 2007, 49). Thurner et. al. describe evolution as a three-step process: first, "a new thing comes into existence within a given *environment*"; second, that new thing interacts with its environment and is selected or destroyed; third, if the new thing is selected, it becomes part of the environment and thus transforms that environment, i.e. the thing and its environment co-evolve (Thurner, Hanel, and Klimek 2018, 15, 227). In biology, evolution happens at many different scales: molecules, cells, organisms, and populations. Evolution also happens in the domain of social practice: "the history of humankind itself is an example of evolutionary dynamics" (ibid.). The history of scientific and technological innovations provides one example of evolution in social practice, and it is easy enough for us to think of social movements, organizations, institutions, etc. as coming into form, being selected or destroyed, and, if selected, becoming part of and thereby modifying their social environments.

The three basic mechanisms of evolution are mutation, selection, and reproduction (Thurner, Hanel, and Klimek 2018, 15). The emergence of new elements in a system can happen through the introduction of elements from outside the system's normal environment: a storm brings a new species of bird to an island; a merchant brings a foreign word to their home country; a researcher brings an idea from biology into sociology (Thurner, Hanel, and Klimek 2018, 228). More often, however, evolution happens through a combinatorial process, the bringing together in a new way of elements that already exist within the environment: a gamma photon interacts with a piece of DNA to produce a genetic mutation; an ironmonger combines techniques from physics and engineering to produce a commercially viable steam-engine; and so on.

Although Thurner et. al. distinguish between evolution through the introduction of outside elements and combinatorial evolution, any outside elements must themselves have evolved somehow. It therefore stands to reason that all evolution is ultimately combinatorial, provided our definition of a system's environment is broad enough. This has two important implications: all evolution, and hence all system change, always happens by making use of existing materials; and all evolution happens incrementally and is in a sense continuous (Thurner, Hanel, and Klimek 2018, 15; Bossel 2007, 224-225). As Bossel says, "there can be no instantaneous creation or invention" (Bossel 2007, 225). Crucially, however, this does not preclude "the evolution over many generations of emergent properties or structural changes which produce qualitative jumps of development" (Bossel 2007, 225).

Evolution tends not to happen gradually, but in sudden bursts, a process called punctuated equilibrium. Suppose, for example, we are considering the amount of diversity in a system, such as an ecosystem or a sociocultural system. The gradualist model of evolution predicts that diversity will increase smoothly over time. The punctuated equilibrium model predicts that diversity will remain fairly constant for a long period, then fluctuate chaotically, then stabilize at a new equilibrium.

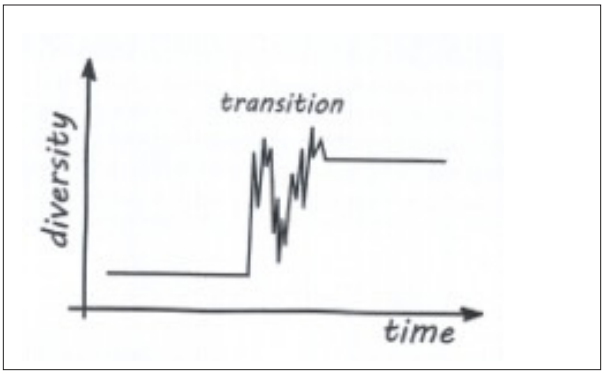

Figure 4. Schematic view of a transition from one equilibrium to another. Evolutionary transition events are usually disruptive and bursty." (Thurner, Hanel, and Klimek 2018, 225)

Punctuated equilibria appear in many different domains, in "the biological, socio-economical, technological, and linguistic contexts" (Thurner, Hanel, and Klimek 2018, 225). Why evolution should unfold through punctuated equilibria is not well understood and there seems to be no consensus yet on precisely how to theorize it. But the punctuated equilibrium model fits well with the Luxembourgian trajectory of thinking about socialist transformation. For example, Gorz writes that "there is not and cannot be an imperceptible 'gradual transition' from capitalism to socialism" (Gorz 1968, 112). Rather, "What can and must be gradual and cumulative in a socialist strategy is the preparatory phase which sets in motion a process leading to the edge of the crisis and the final trial of strength." Gradual reform within capitalism establishes the conditions for a sudden transformative explosion:

> Socialism can only come about through long term and conscious action, which starts with the gradual application of a coherent programme of reforms, but which can only proceed by way of a succession of more or less violent, sometimes successful, sometimes unsuccessful, trials of strength […]. (Gorz 1968, 111-112)

Both aspects of this process, the 'preparatory phase' and the 'trials of strength,' are evolutionary. Or, to put it the other way around, theories of complex evolution can, in principle, address both the gradual preparations and the sudden transformations involved in socialist revolution.

The result of cumulative evolutionary change manifesting in a punctuated equilibrium will be a catastrophe — but a good catastrophe. "Catastrophe sounds terrible, but in a systems context it merely refers to a drastic change that may occur (in some systems, under some conditions) if one or a few control parameters change gradually" (Bossel 2007, 45). Bossel goes on to elaborate:

> Imagine standing near the edge of a cliff. If you are walking away from it, nothing very interesting will happen. But if you are gradually walking towards it, the eventual "catastrophe" is unavoidable. The topology of state space may contain such "cliffs" causing "catastrophic" changes of state. (Bossel 2007, 45)

The goal of radical socialism is precisely to take the capitalist system over a cliff in state space, producing an *irreversible* change in the range of possible forms that relations of production can take. This catastrophic intentionality distinguishes radical socialism from even the most equitable forms of social democracy or state-monopoly capitalism. To achieve this catastrophe, we need to produce non-exploitative relations of production that are self-stabilizing and self-propagating. In other words, social relations of production need to be resilient enough to withstand unfavourable political conditions and even active attempts to disrupt them, and they need to be rewarding enough that new actors will continually attach to them and reproduce them on an expanding scale. The result will be a viral takeover of capitalist society, rewriting its genetic code, until the remaining capitalist relations become non-viable and the whole system transitions irreversibly.

Non-Linearity 2: Evolutionary Divergence

The punctuated equilibrium model is one of three major ways in which evolution is non-linear. A second is the coevolutionary, non-teleological, predominantly divergent character of evolutionary adaptation.

One major limitation of classical ideas about evolution is their association with a linear scale of progress in which species are ranked as more or less 'highly evolved' than others (Lewontin 2007).

Historically, this way of thinking has been applied to human activity in ways that express and reinforce European racism, sexism, and classism (see e.g. Spencer 1896). Lewontin distinguishes between 'transformational' and 'variational' models of evolution: in transformational theories, evolution unfolds from developmental properties intrinsic to each individual, while variational theories explain evolution as the product of stochastic alterations in individuals that are then selected (or not) and passed on (or not), thereby altering the makeup of the entire species (Lewontin 2007, 276-277). Linear notions of evolutionary 'progress' are intrinsic to transformational theories but not to variational theories. Nineteenth century anthropologists like Lewis Morgan subscribed to transformational theories, until Boas and other cultural anthropologists rejected them (e.g. Boas 1940), as did physical anthropologists (American Association of Physical Anthropologists 1996). We can clearly see the influence of transformational theories on Marx's presentation of historical modes of production as a linear series of stages (Marx and Engels 1976) and on Engels's similarly linear account of the origins of the patriarchal family, the state, and private property (Engels 1972). It persists in Lenin's account of imperialism as the highest stage of capitalist development (Lenin 1988). Trotsky's theorization of uneven and combined development, however, pivots from a transformational to a variational theory of class struggle (Trotsky 2010, 269ff.). The conditions of class struggle in different countries do not represent different points along a single developmental path; rather, the contradictions of capital unfold along different, branching paths even as the dialectical as a whole tends towards a singular outcome. World-systems theory further extends this variational trajectory: Amin argues forcefully against treating European historical experiences as normative (Amin 1989), and Wallerstein shows how European universalism is a function of the historical privileging of European intellectuals in the capitalist world-system (Wallerstein 2006).

That being the case, how does complex systems theory stand? Systems theorists are not immune to ethnocentric errors (e.g. von Bertalanffy 2015, 200, 202, 213), but the underlying theory of evolution in complex system theory is clearly variational and non-teleological. Bossel explicitly stipulates that "teleology and teleonomy are not required to explain evolution: A niche-adapted organism may 'look as if' it had this goal from the beginning, although its development was simply shaped by survival and fitness selection" (Bossel 2007, 281). All systems may share general functional prerequisites, but these prerequisites can be fulfilled in radically different ways: "Environmental 'variability' and the 'security' orientation evolving as a consequence mean specific, but very different things to a bird, a railroad company, or a race-car driver, for example" (Bossel 2007, 231), which means that there is no single trait or collection of traits that define 'fitness' for all evolutionary niches, and therefore no universal standard for measuring the 'fittest' or 'most advanced' species.

This non-linear, non-deterministic quality of complex evolutionary theory mitigates strongly against using theories of evolution as an ideological justification for any particular social order. To borrow a phrase from Zizek, evolution is not the 'big Other' who legitimates capitalism, or white supremacy, or patriarchy. At the same time, evolution does not perform this role for socialism either. Evolution, even social evolution, is in itself a blind, amoral process, indifferent to human suffering or well-being. Directing it towards socialist ends requires conscious and informed intervention by human will.

Nonlinearity 3: Coevolution and Relationality

In order for evolution to take place, there has to be some ontological unit that is capable of varying, reproducing itself, and passing on its variations (Lewontin 2007, 286). In biology, this is the individual organism which varies and passes on its variations through its genes. What is this unit in social systems? For Parsons, it was 'action,' defined in Weberian terms. This leads to the idealistic slant of Parsonian systems theory. To reassert a materialist frame of reference, it's tempting to use 'practices' as the evolutionary unit. Practices, even intellectual practices, are physical, spatiotemporally local, embodied, and materially consequential. They are the products of

human creativity mixed with nonhuman bodies and forces, and can be viewed as embodying congealed expended labour-power. They do vary, and successful variations do reproduce themselves. However, there is still something potentially atomizing about making practices the unit of analysis in a theory of social systems. Depending on how practice is theorized, it can be missing the quality of relationality which is vital both to radical socialist theory and to complex systems theory.

For Marx, relations precede and produce identities, even class identities (Ollman 1976). Is complex systems theory similarly relational? Perhaps surprisingly, it is. Thurner et. al. define social systems as "*co-evolving* multilayer *networks*" (Thurner, Hanel, and Klimek 2018, 22, emphasis added). Network theory is, of course, at least somewhat relational (Bates and Peacock 1989), and if we follow Barad in supposing that all network nodes can be understood as products of their ties, i.e. that relations precede relata (Barad 2003), then network theory can be radically relational. The concept of co-evolution brings a dialectical quality to this relationality. Traditional models of evolution treat the system's environment as fixed; through evolution the system adapts to its environment. However, in actuality, both biological and social systems co-evolve with their environments (Thurner, Hanel, and Klimek 2018, 232-236). Any one system is part of the environment for the other systems in *its* environment, so as one system goes through evolutionary changes, the 'fitness landscape' for those other systems also changes, favouring further evolutionary change on their part. System and environment co-evolve together. A single point mutation in one system can potentially trigger a 'co-evolutionary avalanche' of adaptations in its environment (Thurner, Hanel, and Klimek 2018, 254), which in turn may favour further evolutionary change in the system, and so on.

It's worth remembering that the concept of 'system' can apply to any level of scale, from the capitalist mode of production in its totality to individual nation-states, corporations, social movement organizations, informal community networks, individual practices, and even smaller-scale relations. So if we imagine, for instance, a network of trade unions and other worker organizations as a mesoscopic system whose environment consists of a slightly more macroscopic assemblage of state and corporate actors, it's very easy to see how dialectical and co-evolutionary theories overlap around the basic insight that the two class formations transform each other through their mutual struggle (Levins and Lewontin 1985). In keeping with Marx's relationality, we can further observe that these formations emerge out of the struggle or contradiction between them. Therefore, although we are certainly interested in how the concrete social formations evolve, once we understand social formations and even practices in relational terms, we can in principle theorize history as the evolutionary transformation of relations through their encounters (Althusser 2006) with other relations.

This returns us to the issue of what goal theories of socialist futurity should aim at. If the concept of state spaces encourages us to imagine socialism less as any one particular institutional structure and more as a macroscopic *range of possible structures* defined by a common quality of non-alienated labour, a radically relational theory of the coevolution of complex systems encourages us to think about the potential microscopic dynamics of capitalist versus socialist relations of production. Capitalism is at the same time a macroscopic, totalizing, global system of relations, a dynamic multiplicity of mesoscopic institutional structures, and a species of microscopic social relation comprised of even more microscopic practices/relations. Socialists have theorized and continue to theorize capitalism at the genetic level, capitalism as a virus that has injected its genetic material throughout social bodies everywhere (to use a slightly creaky metaphor). We could do more than we have done to also theorize *socialism* at the genetic level, socialism as a system of micropractices or microrelations that could spread virally through the capitalist body.

The Adjacent Possible

Evolution is formidably complex. Thurner *et al*. write that "it seems impossible to predict future events in evolutionary systems. This, however, is not the goal

of the science of evolutionary processes. The challenge there is to understand the underlying statistics" (Thurner, Hanel, and Klimek 2018, 309). At this time, complex systems theorists are still just beginning to develop statistical models of evolutionary dynamics; we are a long way from being able to use their models to guide action in any effective way. But even if and when those models will become available, mathematical discourse is inherently esoteric, and therefore not well suited (to say the least) as a vehicle for radically democratic deliberation. An immediately available alternative to statistical modeling as a means to collectively deliberate on social transformation is the concept of the *adjacent possible*.

First proposed by Stuart Kauffman, (Kauffman 1999), the 'adjacent possible' refers to the set of all possible states that a system could occupy in the next increment of time, given the present state of the world (Thurner, Hanel, and Klimek 2018, 15).

> In other words, the adjacent possible is the subset of all possible worlds that are reachable within the next time step and depends strongly on the present state of the world. In this view, evolution is a process that continuously 'fills' its adjacent possible. (Thurner, Hanel, and Klimek 2018, 15)

For very simple systems, the adjacent possible can be a line or a curve. For instance, if I throw a stone, then the moment the stone leaves my hand, its position from one moment to the next (ignoring air resistance and relativistic effects) is completely determined by Newton's laws of motion and can be graphed as a parabolic trajectory.[3]

If I flip a perfectly fair coin n times, the total possible sequences of heads and tails can be graphed as a tree that branches n times and ends with 2^n equally likely outcomes. And if the coin isn't perfectly fair, for instance if it lands heads 60% of the time and tails 40% of the time, this too can easily be mapped.

While it's nice to be able to use precise mathematical models to map the adjacent possible, it's not necessary. We can still map possibility space

3 Note that for this extremely simple system, the adjacent possible maps directly onto the state trajectory; in other words, the state trajectory can be predicted because there is only one possibility in the adjacent possible at any given time.

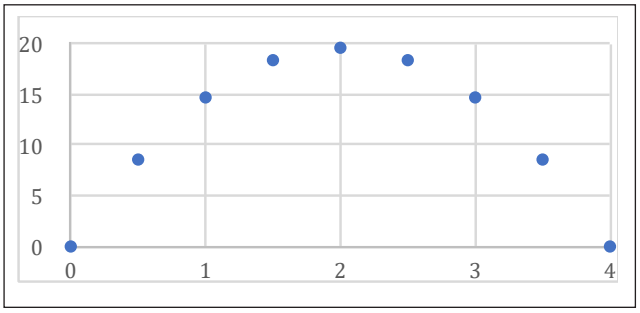

Figure 5. This scatterplot showing the height in meters at half-second intervals of a ball thrown upwards at 19.6 m/s also doubles as a map of its developmental trajectory through the adjacent possible (also measured in half-second increments). This is possible because for a simple deterministic system the adjacent possible only has one possibility at any given time.

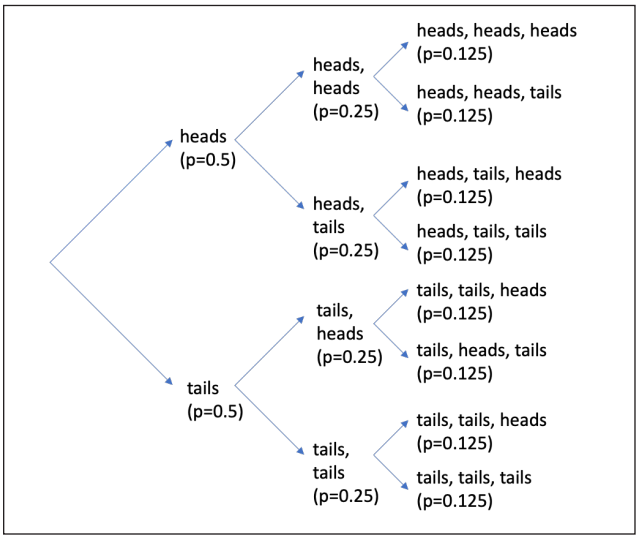

Figure 6. Possibility space of a fair coin flipped three times

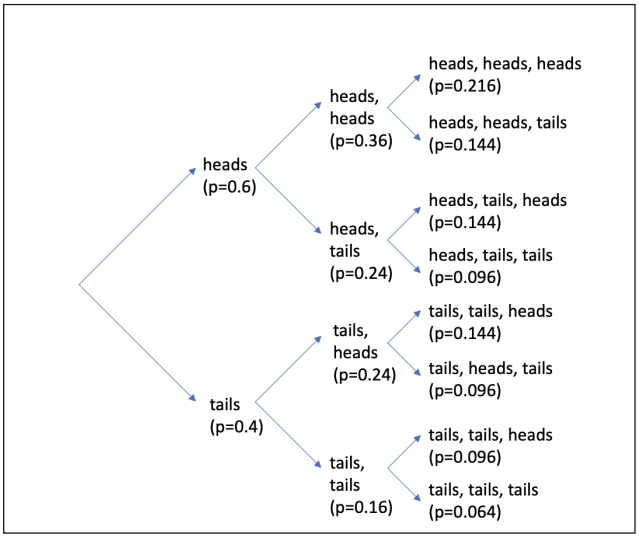

Figure 7. Possibility space of a weighted coin flipped three times.

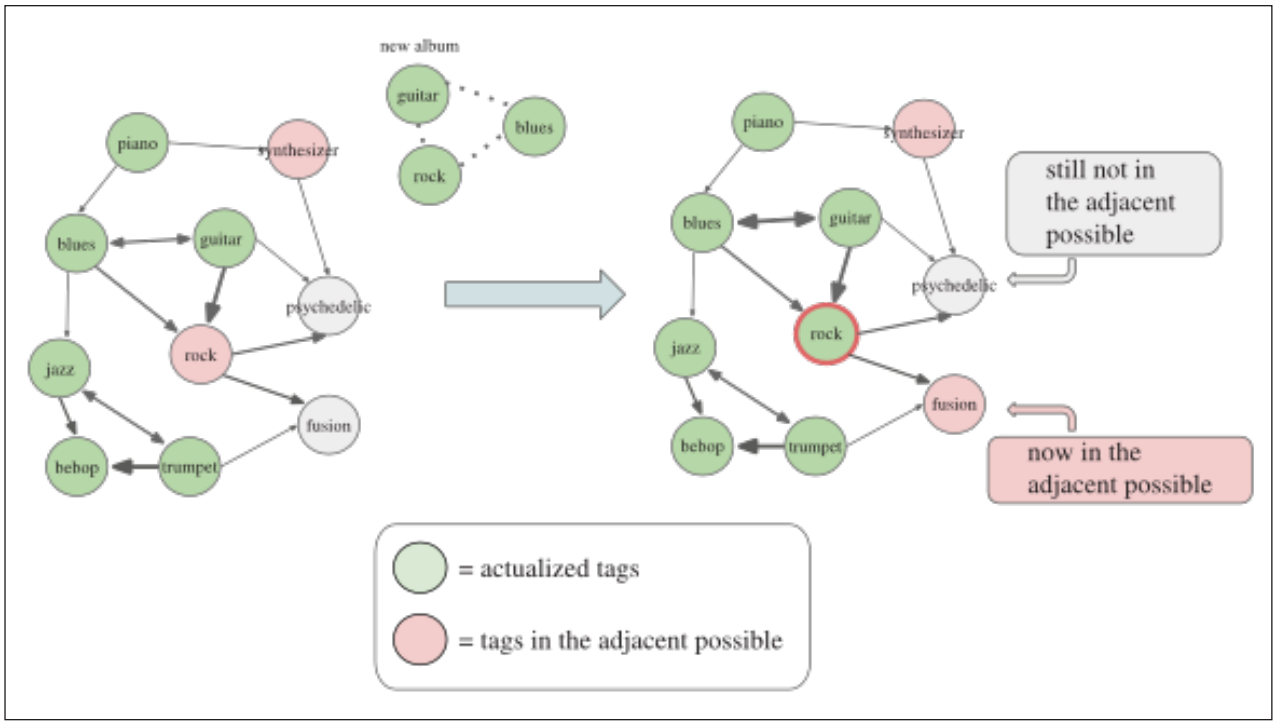

Figure 8. Adjacent possible. Cartoon illustrating the structure and growth of the adjacent possible space after the release of a new album labelled with the three tags ***guitar***, ***rock*** and ***blues***" (Monechi et al. 2017, 6)

using purely qualitative knowledge. For instance, Monechi et. al. (2017, 6) graph the adjacent possible for a newly released album receiving user-generated tags on an online music platform.

The graph from Monechi *et al*. still represents a very simple system. But like the quantitatively based graphs above, it illustrates the process of system change, the movement of a system from one state to another, as a movement into one adjacent possible after another. We can call this the movement of a system through its possibility space or, equivalently, movement through 'the' adjacent possible.

The concept of the adjacent possible emphasizes the materiality of systems. Every change in system state involves the expenditure of available energy to reconfigure some relation or relations in the system. Every possible new form the system could take, i.e. every evolutionary change of the system, requires some expenditure of energy to recombine the existing elements of the system and/or to connect the system to new elements. *Emergence*, the appearance of qualities in a complex system not found in its simpler components, does not supersede this basic fact. Any possible system transformation, including socialist revolution, can only happen through the production of new relations among elements available in the system and its environment, including available energy.

The concept of the adjacent possible emphasizes the *historicity* of complex systems. Every system, without exception, has reached its current state through a series of incremental transformations from one current state into a state in its adjacent possible. (Here, 'incremental' does not necessarily refer to *small* changes in the system, only to the arbitrarily small increments of time over which the system changes from one state to another; even large, sudden changes, like revolutions, happen incrementally in this sense.) At the same time, every possible future for a system exists as one or more incremental 'steps' through a series of adjacent possibles, i.e. through the possibility space that surrounds it. So, for instance, supposing that a system currently exists in some state S_0, and we would like to transform it into a different state indicated by S_x. Unless S_x is in the adjacent possible for that system, then for the system to reach S_x, it must pass through some series of states S_1, S_2, etc.,

until it reaches a state S_{x-1} for which S_x is in the adjacent possible. In other words, there must be an evolutionary path through possibility space from S_0 to S_x. If not, then S_x is unreachable and does not exist as a possible future state for S_0, even if S_x is a possible viable system on its own terms. If there is no way to 'get there from here', so to speak, then our desired state does not exist as a possible future. Intentional change, directed change – such as transforming capitalist society into socialist society, or even any modest reform such as changing a neoliberal policy into a social-democratic policy – gets much easier if we can theorize an evolutionary path from here to there. Without such a theory, we can succeed only through blind luck.

What's more, change in *complex* systems is non-Markovian and non-ergodic (Thurner, Hanel, and Klimek 2018, 337-338, 350-351). A Markovian process is one in which the probabilities of the system at S_0 of changing into any one of its adjacently possible forms S_a, S_b, S_c, etc. depends only on the current state S_0. Markovian processes can be modeled by synchronic theories. The moves in a game of chess are an example: the strategic implications of a move at any stage of the chess depend only on the current state of the board, and not at all on past states of the board. In non-Markovian change, on the other hand, the probability of transformation in any particular direction is influenced not only by the current state of the system (S_0) but by its past states (S_{-1}, S_{-2}, etc.). Conversations, for instance, are non-Markovian. An ergodic system is one that will eventually visit all points in its possible state space, evenly and randomly. A fair-six sided die being rolled repeatedly will eventually assume all of its possible states (every one of its six faces will face up) with equal frequency. A non-ergodic system will move through its state space unevenly, visiting some states more than others and some not at all. A cat patrolling the neighbourhood, for instance, behaves non-ergodically. Non-Markovian, non-ergodic systems are path-dependent; their current and future behavior depends on the evolutionary path they have traversed to reach their current state. In this sense, a complex system contains within itself the entire history of its transformation up to the present. And the future of a complex system is not a line or a curve, but a tangled profusion of branching pathways of various thickness, spreading outwards in many (but not all) directions.

The non-Markovian, non-ergodic movement of complex systems through possibility space is made even more complex by coevolution: any change in the state of a system changes both its own adjacent possible, and the adjacent possibles of all systems in its environment, and vice versa. So, for instance, as workers form self-conscious and radical workers' movements, the adjacent possibles for private firms, state authorities, families, churches, and so on change in response, with new possibilities opening up for them in potentially unforeseen ways. Capitalism changes as we struggle with it. Revolutionary theory also has to reckon with this basic likelihood.

Implications

Complex system theory in itself does not provide a theory of socialist transformation, or any one particular theory of social change. (In practice, most complex systems theorists today either pursue a neoliberal politics, or social democracy, or no coherent praxis at all.) What this theory provides are a set of tools that potentially could augment radical socialist praxis, if used critically and carefully. That being said, I would argue that we can extrapolate certain insights even from the rudimentary concepts that I have presented here.

The first has to do with intersectionality. Intersectional theorists, like standpoint theorists, reject what Amin would call the 'false universalism' of assuming that any competent observer can *objectively* model the entire social world. As Smith (1990) argues, the only way to know a social world is from some location in it, and different forms and aspects of oppressive relations are only *directly* observable to those who experience them first-hand. Intersectionality theorists (e.g. Crenshaw 1989, 1991; Collins 2000) further argue that the combination of multiple forms of oppression produce specific conditions of struggle, that for instance the conditions faced by Black American women are qualitatively distinct from Black men or white women, and so on. However, it is easy to interpret these arguments

as essentially moralistic and even as tied to a liberal rather than a socialist praxis. Certainly, they are open to (neo-)liberal appropriations, and it's not obvious how to incorporate the multiple incommensurate knowledges of different intersectionally constituted standpoints into a unified socialist project.

The concept of the adjacent possible may help to overcome this difficulty and commensurate the incommensurate. We can say that workers who experience multiple forms of oppressive relations are thereby presented with *different immediately adjacent possibility spaces*. White supremacy, settler colonialism, gender, disability, and so on all change the adjacent possible for the people oppressed by them. To speak a bit metaphorically, the boundary between compliance and struggle in capitalist society is as infinitely ragged and infinitely detailed as the boundary of the Mandelbrot set. At the same time, this infinite detail is grounded in a single ubiquitous system, the capitalist mode of production, whose vast complexity emerges out of relatively simple underlying relations. The epistemological task of socialism is to commensurate these differing adjacent possibles, integrating their complexity into a coherent praxis oriented to a relatively simple relational transformation. This is necessarily a *collective* project, one that must include as many different situated knowledges as humanly possible.

Complexity has a further implication as regards the relation between objective and subjective forms of knowledge. A system can be modeled 'objectively' to the extent that one can define a model in terms that mean the same thing, or can be used according to the same rules, by many different actors. But the most rigorously objective model in this sense is still only *valid* in relation to subjectively defined values. This is because a sufficiently complex system cannot be modeled in its totality, but instead can always be modeled in many different ways.

> The number of system elements of the real system and of their functional connections is extremely high; in addition, the mutual dependencies are generally complex and rarely linear. The total system which has to be considered consists of a multitude of subsystems and decision units, of flows and levels of information, matter, energy and organisms in constantly changing configurations. A description only becomes possible through radical reduction of complexity which requires the distillation of important components and connections. From this fact follows the unavoidable subjectivity of model construction. The degree of subjectivity increases with a growing degree of complexity. (Bossel 2007, 55, emphasis added)

As a result, "we therefore do not speak of the 'correctness' of a model but only of its validity relative to the model purpose." (Bossel 2007, 23; Cilliers 2005). And while the *ultimate* purpose of modelling can be defined in terms of socialist revolution (for example, as the production of a socialist state space), the *immediate* purpose of modelling will vary for different actors according to the specific adjacent possibles.

This line of thinking might seem to take us further away from our goal: from the complexity of conditions of struggle we derive a complex profusion of theoretical standpoints. However, this actually is a good problem, because it anticipates (one might say, it prefigures) the problems that will be faced by working people making decisions about production in a socialist society. Consider again the issues raised by Gindin that I cited near the beginning of this paper: how workers in, say, an appliance plant would decide how much aluminum to use, how to allocate their year-end surplus, how many hours per week they should work, and so on. These kinds of decisions are just as complex as decisions about how to struggle against oppression in a capitalist society, and the adjacent possible for differently situated actors are just as complexly variable in both instances. Therefore, *how to make collectively beneficial decisions in the face of complexity is one of the fundamental problems of socialist theory*.

This is a difficult problem to solve. We all know from abundant historical experience that establishing a viable radical democracy even on a small scale, let alone on any large scale, is not as simple as giving everyone a voice or a vote or a veto. But I think there is something reassuring, when faced with a seemingly intractable practical problem, in finding a very difficult intellectual problem at its root. This suggests an untapped potential, a useful contribution for specialized intellectual labour that is still waiting to be made.

Epistemic Toolmakers

One way to think about this contribution is in terms of the processes or tools through which individuals know one another. Imagine an (impossible) ideal society in which every human person's primary goal is the egalitarian well-being of all. The ability of people to achieve this goal in practice would depend on more than the purity of their intentions. It would depend on their knowledge of each other's 'objective' and 'subjective' conditions and needs. It would depend on knowledge of how resources are allocated throughout the social system. It would also depend on knowledge of the *emergent* dynamics of systems, the way that feedback loops, network topologies, combinatorial evolution, and so on produce material effects *independently of human intentionality*, many of which can thwart human attempts at egalitarianism. We could call this type of knowledge, knowledge of the totality (Jay 1986), or knowledge of the monads (Latour *et al*. 2012), or simply system knowledge.

Historically, radical intellectuals have worked to help people acquire system knowledge in a variety of ways: through critique (e.g. Horkheimer and Adorno 2002), as interpreters (e.g. Bauman 1987), through reconnaissance (McKay 2005), and so on. What these labours have in common is that, to some extent, they involve the intellectual 'going out' and mapping or modeling the system, and then offering the fruits of their labours to everyone else, or, one might say, to the general intellect (Krasavin 2020). At the same time, of course, everyone is always trying to map the system for themselves. So intellectual labour of critique or interpretation or reconnaissance is, to some extent, doing people's work for them. This is valuable, necessary work, and will continue to be for the foreseeable future. But it does involve reproducing, however benignly, the distinction between intellectual and non-intellectual labour engendered by capital (Gramsci 1971, 115).

Therefore, to the established forms of radical intellectual labour we can add one more: toolmaking. The toolmaker does not primarily aim to critique or interpret or reconnoitre society on behalf of other workers. Rather, the toolmaker analyzes the emergent dynamics of social systems that produce either hierarchical or egalitarian relations and, instead of trying to solve the problem of hierarchy themselves, translates their analysis into terms that anyone can use, to aid people in their own efforts to mitigate hierarchy and strengthen equality. The goal of this labour is to facilitate the broadest possible distribution of intellectual labour, what in computer science is called a distributed system, and thereby facilitate a radically democratic deliberation over the productive forces of human society.

Conclusion

I framed this demonstration within the need for positive models of how a socialist society might actually function: not its superstructure, but the actual form of non-alienated, non-exploitative relations of production. Rather than offer such models, however, I present an analysis of why it is so difficult to formulate them. This analysis begins by introducing the concept of systems and the distinction between simple and complex systems. From there, the concept of systems state and state space helps us to conceptualize socialism as a range of possible institutional structures rather than any one particular institutional structure. The transformation of capitalist state space into socialist state space will necessarily be an evolutionary process, which we can more fruitfully theorize if we bear in mind three considerations from complexity theory: that evolution unfolds not through smooth gradual transformation but through intermittent and sudden punctuations; that evolutionary development does not follow a single line from 'lower' to 'higher' but branches profusely into diverse niches; and that all evolution is coevolution, making evolution a relational and dialectical process. This process unfolds through the adjacent possible, the range of possible states a system can reach from its current state. For capitalism to transform into socialism, socialists must find a developmental path consisting of a series of incremental variations through successive adjacent possibles. However, the adjacent possible for any subsystem of capitalism, e.g. for groups experiencing different intersectional oppressions, is highly complex and context-dependent, making it effectively impossible to map the

adjacent possible for the whole system from any one social standpoint. Formulating a developmental path to socialism requires that socialist deliberation be distributed as broadly as possible. The complexity of this task prefigures the complexity of actually managing a socialist economy, which makes theorizing complexity one of the core challenges for socialist praxis.

This vision of socialist politics as a distributed system, and of intellectuals as humble toolmakers, may seem utopian and may or may not seem plausible or desirable. But my primary goal in this paper has not been to argue for this particular vision of socialist praxis. Rather, I hope to have shown that complex systems theory speaks to important questions of radical social transformation in ways that offer new hope for addressing long-standing obstacles to superceding capitalism.

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