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**A systems framework for remedying dysfunction in U.S. democracy**

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**Abstract: Democracy can fail to meet its ideals, and electoral institutions can intensify the failures. Unwanted outcomes include polarized institutions, unresponsive representatives, and the ability of a faction of voters to gain power at the expense of the majority. Various reforms have been proposed to address these problems, but their effectiveness is difficult to predict against a backdrop of complex interactions. Here we suggest that systems-level modeling can help understand and optimize repairs to U.S. democracy. Following the tradition of engineering and biology, models of systems include mechanisms with dynamical properties that include nonlinearities and amplification (voting rules), positive feedback mechanisms (single-party control, gerrymandering), negative feedback (checks and balances), integration over time (lifetime judicial appointments), and low dimensionality (polarization). To illustrate a systems-level approach we analyze three emergent phenomena: elite polarization, mass polarization, and antimajoritarianism in legislatures. In each case, long-standing rules now contribute to undesirable outcomes as a consequence of changes in the political environment. Proposed reforms can lead to improved function, and a theoretical understanding can help evaluate whether benefits will be lasting, especially as conditions change again. In this way, rigorous modeling may not only shape new lines of research, but aid in the design of effective and lasting reform.**

***Significance Statement:*** *We suggest that a systems-based theory provides a natural vocabulary for evaluating the effectiveness of electoral reform in the United States. Many principles identified by political science research can be described in the language of engineering and physical sciences, including mechanisms that interact in a complex manner to drive representational outcomes. Such translation eases the way for modelers to investigate political dysfunction, as well as understand the effectiveness and robustness of proposed reforms. Concepts such as feedback, nonlinearity, amplification, and cognitive bias may lead to a robust understanding of distorting and polarizing processes that bring institutions away from representing and responding to citizen preferences.*

In the face of record distrust and dissatisfaction with respect to American institutions, interest in reform measures has exploded. These reforms are aimed at addressing a range of ills, including political polarization, the failure of a majority of legislators to be elected by a majority of voters, loss of responsiveness of those legislators to constituents, governmental gridlock, and a host of other ills. Ideas for reform range from ranked-choice voting to redistricting reform to changes in the judiciary.

No matter how well-intended any reforms may be, their consequences are not always easy to predict. Research on the outcomes of reform often examines specific cases without extracting general principles. We suggest that it may be useful to develop a framework which is both consistent with empirical research and extends that research to generate a theory of applied reform. We hope to provide a perspective based on complex systems that will start to synthesize the efforts of reformers and academics, and help identify which steps might have the most leverage to achieve particular goals—for example, reducing political polarization and its consequences, or restoring majoritarianism--while avoiding undesirable, unexpected outcomes. The goal of this article, then, is not to offer new empirical claims about the causes or consequences of polarization—there is already a rich literature that does that—but rather to determine if considering findings from the extant literature through the lens of complexity offers any new insights.

In keeping with the theme of this issue of PNAS, we also address the question of bridging the gap between these problems of democracy and the research toolkit of those in the sciences. The articles presented here illustrate a variety of approaches that draw upon expertise in complex systems and other computationally and modeling-intensive disciplines such as mathematical biology. But despite the keen interest of these researchers, they face the daunting task of making a meaningful contribution in a discipline with its own mature traditions, political science. The terminology of any field can be daunting, and the study of politics is no exception. In our view, the problems of democracy are sufficiently important to warrant an attempt at translation.

We hope our effort to render the U.S. political system in mathematical and engineering terms of complex systems will encourage scholars of the natural sciences to give it more attention. Specifically, we hope it will allow three outcomes: (a) the ability to build models that reproduce political phenomena from realistic parts, (b) the creation of simulations to explore alternative scenarios, and (c) the design and evaluation of interventions that may improve the function of democracy. These goals are analogous to those of engineers or biological researchers.

**A Complex Systems Approach**

The approach we take to understanding polarization provides a united language those from other disciplines can understand, rooted in the theory of complex systems. In engineering or biology, one often encounters complex systems of interacting parts. Systems may be designed, such as a power grid or a mechanical clockwork, or naturally occurring, such as animal population dynamics or the evolution of new species. In both cases, a full understanding of a system’s behavior requires understanding individual rules, network interactions, and the effects of exogenous factors. Political behaviors arise from a combination of designed and naturally-arising features that include institutions, demographics, society, and geographic variation.

A complex-systems approach examines politics in terms of the emergent behavior that arises from such combination of features. Broadly, a complex system may have history-dependence, undergo sudden transitions (“criticality”), show nonlinear relationships, retain a memory of past events (“hysteresis”), and be nested (i.e. components may themselves be complex systems). A complex-systems approach to politics can help to identify interactions, understand long term dynamics and recognize ways in which changes in any part of the system can lead to unintended consequences when new conditions arise. Political Scientists often write about these features but use different terminology.

One of the difficulties of understanding reforms is that a symptom may have multiple causes, and vice versa. For example, the stress hormone response may mobilize energy to support temporary need such as normal exertion, yet also lead to dysfunction when chronically activated. Similarly, the rules of representative democracy may lead to stable governance or severe dysfunction, depending on the circumstances. Coming up with a treatment for what ails democracy requires some understanding of how remedies may lead to an abatement of symptoms – and whether the treatment is beneficial in the long run, or interferes with other treatments. In short, a system-level view can help us understand how conditions are filtered through rules and may help craft reforms that are effective in a lasting manner.

Below, we discuss some of the elements of a complex system and how they apply to a democracy, such as the United States. In addition, we discuss how rules and institutions can work to encourage (or discourage) dysfunctional emergent properties.

**Background Conditions**

A central design challenge to any reform arises from the fact that formal institutions are both mutually embedded and embedded in wider society (1). The wider society undergoes continual change. In the United States of 1790, voters comprised white male landowners and slaveowners in a nation of 4 million. Today, in a nation of 330 million, nearly all adult citizens can in principle vote (though embedded systems often work to preclude some from voting). The rules and institutions of yesterday may not be appropriate for the problems of today. Moreover, existing rules and institutions may amplify background conditions that drive polarization.

In the last half century, the country has undergone major economic and demographic changes that have made it more urban, diverse, and unequal. Americans seeking job opportunities in an increasingly non-agricultural economy have caused the population of the country’s cities to explode while its rural towns has declined. In 1960, ? JONATHAN FILL IN percent of the population lived in rural areas, while in 2020, just ? JONATHAN FILL IN did. During that time, the population structure of the nation also became substantially more diverse, reshaped profoundly by the Hart-Celler Immigration and Naturalization Act of 1965, which eliminated immigration quotas that favored northern Europeans. Since 1965, the number of immigrants in this country has increased from ? JONATHAN FILL IN to ? JONATHAN FILL IN. The Voting Rights Act of 1965 also changed the composition of the southern electorate, realigning the parties such that southern whites gravitated towards the Republican Party while Blacks in the South found a home with the Democrats.

Finally, income inequality has increased dramatically due to a concentration of wealth in the hands of the super-wealthy corresponding with only modest gains among those in the middle of the income distribution (**Piketty and Saez 2003**), and job losses that have been geographically concentrated and have disproportionately affected the working class.

The connection between these profound changes and polarization is not obvious until one considers what happens when the major cleavages they have produced – rural/urban, white/non-white, rich/poor – begin to align, especially in the context of a two-party system. Ideology has joined white, rural voters with the wealthiest Americans under the banner of the Republican Party while the Democratic Party has become a coalition of the rest (**Grossman and Hopkins XXXX**). When one considers the United States as a complex system these developments can be understood as a collapse of dimensionality that has produced an intensification of political conflict along a single axis of variation. In order to make diverse issues fit into an issue space that is defined by only two parties, multiple issue dimensions get projected into a single dimension (**Duverge 1954; Downs 1957; see also Hinich and Munger, 1996; Taagepera and Grofman 1985**).

While the alignment of cleavages discussed above has facilitated the collapse of dimensionality in the system, the decline of civic life in America and the pluralism it once nurtured has hastened the process. The United States was once a “civic nation” where citizens enjoyed a rich associational life. Non-political associations, such as labor unions, churches, and bowling leagues, were often cross-cutting, bringing people from different backgrounds into contact with one another, building trust and teaching tolerance. To be sure, these associations often did not do enough to bridge certain cleavages, particularly those pertaining to race, but they did preserve some higher dimensionality in the system. Many of these associations have disappeared or have converted from membership groups that encouraged civic participation to managed groups focused on lobbying (**Skocpol XXXX; Olson 1965**). In other words, the groups that once structured a multidimensional issue space in the United States have collapsed.

One more background condition amplifies this increasingly unidimensional conflict: political competitiveness. When the two parties are closely divided in strength, as they have been for the last 20 years (5, 8), substantial advantage comes from small gains in support (**Lee 2016; Fiorinia 2017**). Such close partisan division has occurred for two extended periods in congressional and presidential politics, the first Gilded Age (1876-1896) and modern times, a second Gilded Age (1994 to present). Presidential races have been decided with popular-vote margins of less than five percentage points in 5 out the last 6 elections, the same number of close elections as the first Gilded Age. Control of the U.S. House of Representatives has switched parties four times since 1994, nearly matching the five changes of the first Gilded Age. Close divisions, especially when single-party control is seen as a possibility, exacerbate polarization (**Lee 2016**) leading to a more confrontational tone of “constitutional hardball” (**Tushnet 2004**) in which governing norms are broken and rules are bent, especially in the service of gaining advantage. Incivility and norm violations by one side are answered by incivility and norm violations by the other side when it returns to power. Violations such as gerrymandering, difficult judicial appointments, and abuses of election rules and laws foster a contentious and distrustful environment that further exacerbates this animosity.

These background conditions are refracted through existing rules and political institutions, yielding a variety of emergent properties. Below, we discuss a range of ways rule and institutions can interact with background conditions in greater detail before turning to a more focused analysis of the processes yielding three specific emergent properties: unidimensionality, polarization, and anti-majoritarianism.

**Rules and institutions of a political system**

The rules of democracy, and the political institutions they create (e.g. Congress, the presidency, and state legislatures), function within the complex system described above. While in evolution, rules change slowly through generational inheritance guided by survival fitness, rules pertaining to politics are created by interests with a variety of goals, which often work at cross-purposes. In addition, political rules exhibit a “path dependent layering” because political actors will fight to preserve those they find beneficial and existing rules constrain future moves (Schickler 2001, 16). Thus, rules can rarely be rewritten wholesale. Instead, new ones are layered on top of old ones creating “disjointed” institutions and processes (Schickler 2001).

These rules can interact with broader societal forces in a variety of ways. First, existing rules can act upon changing background conditions in ways that create new problems or reveal hidden problems in the design of government that were previously latent. Rules can exacerbate certain properties of the system (*amplification*) or entrench existing states, making change difficult (*hysteresis*). Legislators and judges can alter the rules to enhance such consequences, a *positive feedback* effect. Third, rules can serve as *integrators over time*, converting temporary shifts in power to long-lasting changes that resist change or mitigation. Finally, the combined effects of these mechanisms can generate nonlinear dynamics, leading to rapid acceleration of a particular characteristic of the system beyond a *critical threshold* (Leonard et al. 2021), leading to sudden change that is not predicted by gradualist analysis, i.e. revolution or collapse.

*Dependence on Background Conditions:* Existing rules and institutions can exacerbate or mitigate drivers of particular properties while remaining nominally unchanged for many years. As background conditions change, rules can act upon them to produce outcomes that are at odds with fundamental goals in a democracy. For example, if a country with a single member plurality district system like the United States has voters who are relatively ethnically and economically homogenous, as was the case when most of the population was rural and most voters were white male property-owners, it matters little for representation if districts have an unequal population size. As a population becomes more heterogeneous, however, and particular communities become more concentrated in certain areas, the equality of district populations becomes much more important for representation. While the Constitution requires Congress to reapportion districts in the House of Representatives based on population every 10 years, state legislatures had no such requirement prior to a series of Supreme Court decisions in the 1960s. This allowed powerful rural state legislators to ignore population growth in their states’ cities, maintaining their power. As a result, it was not uncommon for the most populous district in a legislative chamber to have a population a hundred times larger than the least populous district. Thus, changing background conditions produced gross distortions in representation, introducing a stress in the system that could only be ameliorated by a change in rules: the requirement that districts have equal population size.

Of course, some rules are fixed by the Constitution. As a result, California’s two U.S. Senators currently represent a population that is 68 times the size of size of Wyoming’s. The recent implications of this malapportionment for polarization are discussed later.

*Feedback:* In addition, rules and institutions can affect certain properties by creating either positive or negative feedback. For example, in the case of polarization, a rule creates positive feedback when it further polarizes the elected officials who created it who was previously polarized. There is a paucity of research on how policy feedback drives polarization but there is a large literature on policy feedback and government support. For example, the implementation of policies that provide government programs often create constituent support among citizens who benefit from them. These citizens then become active in preserving these policies (**Pierson 1993; Skocpol 1992**). This is often offered as an explanation for why it is difficult to cut government spending. Interestingly, while less is known about the relationship between policy feedback and polarization, many scholars have noted how polarization can impede the feedback loop just described. Even when citizens benefit from certain policies, they are increasingly unwilling to give credit to administrations or elected officials who helped pass them if they are from the opposing party (**Hacker and Pierson 2019**).

Rules can create negative feedback as well. For example, it can occur when policy changes depolarize elected officials who in turn create less polarizing policies. Rules can also create negative feedback by allowing other depolarizing forces in the system to express themselves. For example, moderate representatives and/or voters are potential sources of negative feedback in the system. Rules that make the system more sensitive to their preferences could mitigate polarization.

*Integration:* Integration occurs in a political system occurs when a particular rule or institution entrenches political power, fixing a particular state. For example, federal judges are appointed by the President and serve for life. These judges then rule on cases that may affect the power of Congress and later Presidents. By outlasting the President’s tenure in office, the judiciary effectively integrates Presidential influence over time.

The integrative nature of federal judiciary power increases incentives for legislators and the President to intensify polarized conflict over judicial appointments. Indeed, any institutional rules that would give a long-lasting advantage provide an incentive to engage in hardball tactics (**4**). As judicial appointments take on outsized importance, they in turn become an issue that motivates polarization, thus creating a feedback loop. For example, confirmation of judicial appointments used to require the approval of both of an appointee’s home-state Senators as well as supermajority support on the floor of the Senate; now, confirmation votes now routinely follow partisan lines and require only bare-majority support.

*Criticality:* In complex systems, small events in interaction with one another may eventually trigger a sudden, large state change, either because a breaking point is reached or because a specific set of conditions is reached. Examples include avalanches, cardiac arrythmias, and bridge collapses. In a political system, “slow-moving causal processes” can have a negligible impact until they reach a critical threshold (**Pierson**, 83). Scholars have argued that gradual demographic change can account for the occurrence of revolutions (**Goldstone 1991**) and that the slow erosion of support for a regime results in realignments that occur when a new party comes to power (**Burnham XXXX**). The crucial characteristic of such processes is their nonlinearity. Several papers in this volume argue that polarization trends in this country exhibit the property of criticality (**CITES**).

Criticality is an emergent property: a collective property not predicted directly from the properties of individual components. Other examples of emergent properties include flocking and schooling, the brain, and cities.Viewed from a systems perspective, many dysfunctions of democracy are emergent properties, such as gridlock, antimajoritarianism, and notably in modern times, polarization of institutions and leaders.

**A systems-driven framework for reform**

Polarization and the breakdown of political traditions may seem like intractable problems. Some ways of addressing them require altering the Constitution, a step which requires ratification by a supermajority of states and is unsuited to current, closely divided times. At least one would require a constitutional convention — abolishing the Senate. Other changes may be implemented by passing a federal law, state law, or citizen initiative. In this section we focus on the latter. We describe several emergent dysfunctions in U.S. democracy, identify likely causes, and review potential reforms that can realistically be made law in the near future. We will then consider the known effectiveness of the reforms, and outline research directions to test their robustness and durability to varying conditions. This approach can both reveal anticipated short-term improved function, as well as long-term pitfalls. In each case, changes are consistent with the current system of rules, constituting only additions or modifications that are arguably consistent with the Constitution.

*Emergence 1: Mass polarization and low dimensionality.*

The loss of dimensionality has affected the attitudes of voters and elected officials. Political polarization is associated with three central features: (a) bimodality of opinions on issues and a high standard deviation; (b) increased cross-issue correlation, so that there are fewer voters or legislators who are cross-pressured in their choice among policy platforms (**7**); and (c) the sorting of voters and legislators into parties so that the parties are increasingly homogeneous with respect to any given issue and in overall ideological terms. All of this can be captured as a projection of politics onto a single axis.

At the level of public officials and activists there is strong evidence for all three phenomena. At the mass level, there is compelling evidence for sorting, strong evidence for growing cross-issue correlations, and equivocal evidence for strong polarization on individual issues (**8**) and beliefs (**9**). Even if voters are not ideologically polarized, there is abundant evidence that they are polarized affectively, i.e., that they dislike voters and elected officials from the opposing party simply because of their partisan identification (**Iygnger and XX XXXX**). When voters are unwilling to punish extreme candidates or incumbents by not voting for them, a crucial mechanism for moderating polarization in the system is lost.

Can mass polarization be reduced by intervention? Through elections, increasing the dimensionality by which voters make choices would be expected to reduce elite polarization. This would require getting voters to make choices based on some dimension that cuts across the urban/rural and white/nonwhite cleavages previously mentioned. This is not easy in the face of the nationalization of politics (**Jacobson XXXX**). Former Speaker of the House Tip O’Neill once famously said, “All politics is local,” suggesting that voters weigh how a representative serves their state or district’s needs more heavily than how the representative’s party is performing nationally when deciding how to cast their ballot. This is no longer the case, as candidates campaign based on national partisan loyalties. Conversely, reforms that force elected officials to address state and local issues, as well as to deliver on those campaign promises, should increase dimensionality. A winner-take-all plurality system consisting of single-member districts also makes multi-dimensionality more difficult by constraining the number of effective parties to two.

*Strengthen state and local parties*. Higher dimensionality may arise by enhancing the importance of regional issues via state and local parties. The pluralistic nature of state parties used to be a mitigating force against polarization (**Pierson and Schickler 2020**). Now, however, the state parties have started to emulate the national parties, irrespective of how well it meshes with the policy preferences of voters in the state. Strengthening state parties can build local independence and makes the parties more heterogeneous at a national level.

State-party independence depends in part on campaign finance. In the study of money in state legislatures, party money tends to flow to more moderate candidates while individual/group money tends to flow to more extreme members (**70**). The McCain-Feingold campaign finance reform weakened state parties, as has the rise of independent expenditures. La Raja and Schaffner (**XXXX**) suggest that the balance may be shifted back toward local interests by removing most limits on state party fundraising in addition to subsidizing them in other ways, for example with a publicly-financed matching program that matches in-state donations at a higher rate than out-of-state donations. A state could also adopt a voucher system, in which voters could give to candidates and state party organizations. The desired effect would be to strengthen state parties so they can withstand pressure from the national parties.

Understanding the source of orthogonal forces, how they are currently incorporated into the American system, and how they are translated into power and policy by voting rules and other institutions, are important areas for future work. Under current conditions, potential escapes from the main axis of polarization include Green New Deal support among Democrats, and insurrectionism and white nationalism among Republicans.

*Emergence 2: Polarized elites and election voting rules*

Polarized elected officials are pulled to extremes by interest groups and activists who threaten to “primary” them by funding more extreme candidates if the elected officials do not pass their desired policies. Party activists also ensure that the national parties include more extreme policy proposals across an ever-expanding set of issue areas, promoting “conflict extension” in their platforms (**CITE**). At the same time, it is generally recognized that contests for the U.S. Congress have become increasingly nationalized, so that the destiny of a candidate for federal office is tied to national political forces (**Abramowitz and Webster 2016; Carson et al 2019; Jacobson 2019**). If candidates of a given party cannot stray far from the national party positions, and those positions are in the extremes, then they cannot court the median voter in the district in the idealized fashion described by formal theory (**Downs 1957**). As interest groups and activists achieve more success it promotes “teamsmanship,” encouraging unaligned interest groups to choose a side and intensifies conflict (**CITE**).

Studies suggest these sources of feedback have pushed or are close to pushing elite polarization over a critical threshold [**Leonard et al.**]. Thus, reversing these processes will be incredibly difficult. There are rule changes that might mitigate this momentum, however. The most common rule for electing legislators in the United States a two-stage election, with a primary election to determine nominees, followed by a general election. Most often, both elections are determined by a plurality vote, also known as first-past-the-post. Under this rule, winners are only guaranteed to require majority support when there are two candidates. Legislators with extreme ideological positions can win office either by winning an extreme bloc of votes in the primary, and/or by splitting the vote among multiple opponents in the general (**50**). This system is known to generate representational distortion by rewarding off-median winners in party selection mechanisms, and by failing to elect Condorcet winners, *i.e.*, candidates who would win every one-on-one pairing with individual opponents (**51**).

When citizens vote in a polarized manner, these tendencies can be mitigated by changing the rules by which election winners are determined. In a low-dimensional system, one source of stabilizing outcomes between ideological extremes is the election of candidates who are close to the median voter. Yet under current rules, the decisive point on the spectrum (i.e. the pivotal voter) is often far from the median. Modern democratic theory (**48**) posits that the median voter ought to be the one whose policy preferences are realized, and that this is a desirable outcome.

*Ranked-choice voting.* Instant-runoff voting (often called ranked-choice voting, RCV) is designed to drive outcomes toward winners who are acceptable to the majority. By successive elimination of poor-placing candidates, the field is reduced to two finalists, one of whom is elected by a majority of all voters expressing a preference between the two. This method can be used in either primaries or the general election.

Ranked-choice voting has recently been adopted in a variety of jurisdictions, including Congressional and state elections in Maine, mayoral primaries in New York City, and statewide elections in Alaska. Alternative voting rules such as RCV can elect Condorcet winners more often than a plurality rule. They may also allow voters flexibility to show support for a long-shot candidate without hurting the chances of a less-preferred candidate with a higher likelihood of electoral success. Such rules may also temper extremism by providing an incentive for candidates to appeal to the median voter and reduce negative campaigning. However, new voting rules bring burdens, including a remaining risk that a centrist candidate can sometimes be eliminated in early rounds (**54, 55**), and an increased workload on voters to rank many candidates. Future research can use real voting records or simulations of voting populations to identify which rule would work most reliably in a particular community .

Jurisdictions that use RCV now span a range from towns to entire states, providing a rich source of natural experiments for probing differing levels of voter polarization, socioeconomic stratification, and engagement. For example, Alaska’s RCV election will feature the top four finishers from an earlier, all-comers primary. One-fifth of the primary vote is enough to guarantee a position on the general-election ballot. The primary may incentivize candidates to attend to locally salient issues such as native peoples, resource extraction, and climate change. These issues cut across the national dimension of politics, allowing the election of candidates representing a more complex coalition than a plurality at the extreme. Research into alternative voting rules appears ready to transcend the examination of individual examples. However, the number of data points is still limited and exposure to interacting conditions and natural experiments are limited. It may possible to create a general understanding of RCV independent of particular conditions still. For example, by simulating the dimensionality and heterogeneity of a voter population, it may be possible to optimize the choice of reform to accommodate particular local conditions. Such a research agenda may draw upon cognitive science and game theory.

*Eliminating closed primaries.* A first-past-the-post primary election can feature many candidates, in which case the nominee can win with considerably less than half of the vote. Because of this, a cohesive minority, including one composed of extremists, may potentially determine one or both nominees. In principle the power of a small number of voters is enhanced further by the fact that turnout is limited to party members who are engaged enough to vote. Through primaries, rank-and-file party members can reward loyalty to the party’s issue positions and tone, thus perpetuating polarization.

Primary election reform would seem then to be a ripe ground for reform. For example, the selection rule could be changed to a ranked-choice election, or voters who are not party loyalists could be permitted to participate. Possible reforms include the opening of primaries to allow nonmembers to vote, merging party primaries to a single nonpartisan top-N system (followed by an N-candidate general election), or the introduction of new selection rules such as RCV or approval voting.

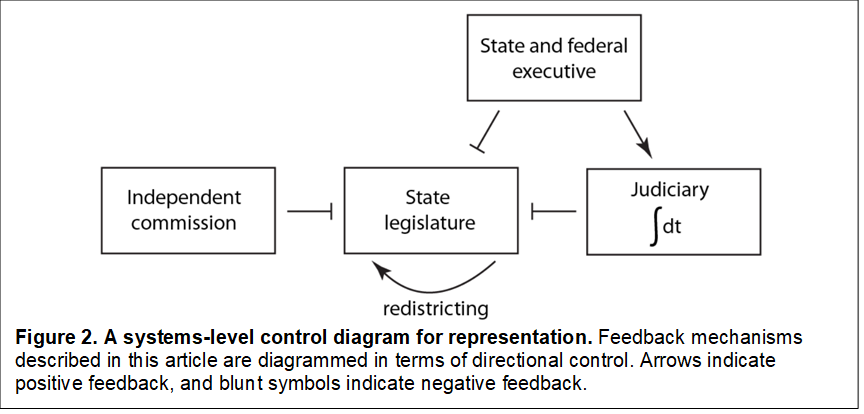
Although these reforms are logically appealing, their success in electing more moderate candidates is mixed so far. For example, open participation in primaries has been reported to cause some change or no change in legislator voting patterns (52, 53). Such studies may face the difficulty of stratification: the effectiveness of a reform may depend on particular local factors, yet examining particular situations may lack statistical power. As elite polarization increases, statistical power should improve, and indeed, using similar methods as a negative report focusing on state legislatures through 2010 (CITE MCGHEE), a more recent study encompassing Congressional seats through 2020 (CITE GROSE) found a moderating influence from California’s top-two primary system. A simulation-based approach may be useful in identifying the factors that determine the effectiveness of various primary election reforms.

*Emergence 3: Antimajoritarianism, redistricting, and geography*

A recent feature of national politics is antimajoritarianism, the tendency for a majority of voters to fail to take control of the House, Senate, or Presidency. This tendency has been highlighted by the closeness of national elections since the 1990s, and arises from a combination of demography, geographic variation, and redistricting.

As mentioned above, polarization has a spatial dimension with an urban-rural divide emerging in the last half century (41). By 1968, the distribution of partisan preference showed a strong skew, with high-density states being much more Democratic, and strong but weaker Republican tendencies in low-density states. Because Democratic-leaning states have higher population density and higher populations, representation in the Senate has taken an antimajoritarian turn. The urban-rural-derived partisan advantage arises from the fact that the Senate assigns two Senators per state irrespective of population (42, 43). Although the Senate is split evenly after the 2020 election, the fifty Democratic Senators represent 41 million more people than the fifty Republican Senators. The fraction of the national fifty-state vote needed to attain a 50-50 split has shifted from 49.3% Republican in 2012-2016 elections to 47.9% in 2016-2020 creating in other words, structural minoritaritan rule. These calculations do not include U.S. citizens in locations without Senate representation, namely Washington D.C., Puerto Rico, and other territories. A similar bias exists for selecting the President. Partisan bias in the Electoral College is similar to that in the Senate and has grown in the last two elections (44, 45).

The same density-partisanship correlation persists at a county and precinct level affecting congressional and state legislative districts. Members of Congress and most state legislators are elected from nonoverlapping districts whose boundaries must be redrawn every 10 years, following the decennial census. These districts must be of approximately equal population within each state and cannot cross state boundaries. A partisan advantage can accrue when one party controls redistricting and “packs” voters of the opposing party forcing them to waste vote. Because of Democrats tend to live in more densely populated areas, they are easier to pack, giving Republicans a natural advantage. The representational distortions that emerge from such partisan gerrymandering can be quite large (58).



The diagram in **Figure 1** illustrates how the redistricting process can be understood from a complex system’s perspective. Such a diagram may be useful for making the interactions of legislation accessible to those in the sciences.An engineering or biology-style interaction diagram reveals positive or negative feedback steps and integration over time which together can account for partisan gerrymandering. In this diagram, steps that have a positive effect on power or representation are indicated with arrows, and restraining or inhibitory steps are indicated with blunt symbols. Some effects persist over time, and are indicated with an integral sign.

**Positive feedback,** indicated by an arrow that circles back toward its origin, can occur when a legislature acts to preserve its own power. Redistricting to protect incumbent legislators from voter opinion is called gerrymandering. With modern technology for tracking voter behavior and drawing districts, it is possible to generate districts that perform in a predictable manner for an entire decade.

**Inhibitory steps,** indicated with arrows ending with a blunt end, indicate ways in which one branch of government may block another from acting. American systems of government have an unusually high number of veto points, including presidential or governor’s vetoes of legislation, limits imposed by the judiciary, and even rules that prevent a whole body (the Senate) from acting if it fails to have a supermajority. These inhibitory steps act to counteract branches of government acting alone. If enough inhibitory steps are removed, it becomes possible to enter a regime of runaway positive feedback. In other words, an unchecked legislature may potentially be able to gerrymander itself into power and stay there for ten years, all the way to the next cycle.

The Supreme Court has weakened protections for partisan and racial fairness in recent years and further erosion may arise in a Supreme Court case pending at the time of this writing (March 2021). In short, both racial and partisan gerrymanders are now easier to commit than in 2010, effectively removing one of the inhibitory feedback steps in **Figure 1**.

Reform can be accomplished by shifting the power of redistricting away from the legislature and to a non-partisan or bipartisan commission, or potentially by establishing explicit neutral (good government) or fairness criteria that can be enforced by courts. The potential for change in rules varies by state, especially in terms of whether the state allows for use of the citizen initiative. During the past decade, initiatives have taken redistricting away from the legislature and put it into the hands of a commission and the number of states with commissions has grown, though many of these commissions are only advisory. Independent redistricting commissions are currently considered to be constitutional the recent rightward turn of the court indicates that the use of such commissions for federal redistricting may now be in question.

**Future research**

We have focused on institutional rule changes that can be characterized as “good government” and might cut across the ideological dimension of current politics. Institutional reforms of the Progressive Era helped to break the logjam of polarization of the early 20th century (Putnam and Garrett, 2020). A new wave of institutional reforms may help us escape the present morass. However, attaining these reforms may require a degree of coming down from present levels of polarization. This may be a lengthy undertaking, since it took fifty years to get to current extremes. By whatever means reform is achieved, the broader problem is how to create long-term institutions in which all citizens feel bought into a shared, fair system of governance.

Our aim in this paper has been to encourage those interested in complexity to begin studying how political systems produce emergent properties like polarization. Modeling dynamical processes in political systems is daunting due to the complexity of human psychology, but the articles in this issue illustrate that it can be done and in a manner that produces important insights. Political scientists are already familiar with many of the dynamical processes discussed above and have rich literatures on many emergent properties of interest. For example, those who study how political institutions develop understand that it is often nonlinear, can reach critical thresholds for change, and may contain amplifying feedback loops. These concepts may be captured in generality by quantitative modeling, opening the way for specific observations to be generalized to a useful framework for understanding when dysfunctions arise and when reforms may or may not work..

As fruitful collaboration arise between the natural and social sciences, we believe the natural scientists can be particularly helpful in three domains: (a) the ability to build models that reproduce political phenomena from realistic parts; (b) the creation of simulations to explore alternative scenarios without waiting for them to occur naturally; and (c) the design and evaluation of interventions that may improve the function of democracy. In this way, a complex-systems approach may be useful to help formulate a durable reform agenda.

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