A FOUNDING PROGRAM ON ROBUSTNESS IN SOCIAL PROCESSES

1 Program Statement

In a world of uncertainty, rapid change, and increasing complexity, it might be thought that failure of social processes should prove the rule rather than the exception. And yet both the past and the present provide many examples of social processes that we instinctively label as *robust* to failure, whether because of the agility with which they have responded to changing circumstances, or because of their record of surviving deliberate internal or external attack, or merely because they have proved so longlived. Robustness is a term that captures our intuitive sense of one of the key determinants of longterm success or failure, but what do we mean by robustness, and what specific features of a social process contribute to its robustness or fragility?

In the past few years, the concept of robustness has been the subject of growing interest in the natural and engineering sciences. Building on traditional fields such as stability, reliability, and control theory, the study of robustness has focused on the ability of a system to maintain specified features when subject to assemblages of perturbations either internal or external (see, e.g., [19, 13] and the web site http://discuss.santafe.edu/robustness). The system of interest in robustness is typically not in equilibrium, and the perturbations are typically such that it is unrealistic to attempt estimations of their supports and distributions.

Preliminary progress has been made in the understanding of general principles of robustness especially in the context of evolutionary and developmental biology, ecology, and computer network design (see the next section "Relation to Other Work" for more discussion). The insights have stimulated a rich set of research programs, and, even more importantly, are contributing to new ways of thinking on issues ranging from the architecture of regulatory control, through the relation between performance and flexibility, to the evolution of general-purpose information-processing algorithms in these contexts.

In social contexts, however, the study of robustness has thus far not emerged as an explicit focus of research. Potential interest is enormous however. Examples of the questions that motivate the study of social robustness include:

- Why do some social arrangements—monogamy, religious rituals, forms of property rights, markets, e.g.—persist over long periods and recur repeatedly despite significant adverse conditions, while others pass away quickly even in the absence of any serious challenge?
- How do social norms enhance or degrade the robustness of the socio-ecological-economic systems in which they operate?
- How can individuals and systems employ effective decisionmaking procedures in social situations where choices have unforeseeable consequences?
- What keeps a cultural tradition vital and open to innovation by the individuals participating in that tradition?
- What makes for a robust economy? Why for example did the Soviet system collapse with such speed? And why have the different former Communist countries had such different experiences in recovering?

The above questions signal the core issues of interest: the tension between staying the same and responding to change; opportunities for innovation, and vulnerabilities to collapse,

on multiple scales; effects of interactions among slow variables such as cultural tradition and fast variables such as economic change; and, interwoven throughout, the role of learning.

A Program is proposed here to develop the foundations for an understanding of social robustness. The goal of the Program is to explore the emergence, pathways, and consequences of robustness in social processes. The approach will emphasize phenomenology and the use of case studies as the basis from which to abstract general principles of robustness.

The Program will be inherently transdisciplinary not only in considering case studies and theoretical analyses across the range of social sciences, but also in drawing upon recent advances in the the study of robustness in *non-social* processes in biology, ecology, computer science, and engineering. It is important to note however that while the proposed Program will attempt to survey and to integrate diverse perspectives on robustness, it will in no way seek to unify all such perspectives, or to establish "universality principles" for robustness that would be inconsistent with the patent diversity and distinctiveness of the range of processes to which the concept applies.

The initial research themes for the Program will examine the usefulness of two complementary perspectives on robustness in social processes. The first (inspired in part by ecological studies) views robustness as characterizing a stage in the developmental history of a process. The social process will be analyzed as a set of dynamic interactions with feedback across multiple scales and in multiple dimensions on multiple networks. The question then is the role of these different dynamics in providing flexibility or rigidity in the response of the social process to uncertainty and change, and in leading to any of the future possibilities of innovation, persistence, degradation, or collapse.

The second perspective (inspired in part by engineering and computer science studies) views a social process—whether it be economic exchanges, the functioning of an organization, or an example such as decisionmaking either by individuals or by social systems—as distributed information-processing systems with feedback control. The goal then is to understand the features such as error-correction or buffering that enable the process to perform successfully even with model uncertainty, unforeseeable consequences, conflicting data, and other complexities that could preclude the process from functioning as desired.

A challenge for the Program will be to construct new perspectives that incorporate useful aspects of the ecological and the engineering views described above, but that highlight the uniquely *social* features of social processes. Such features—including the critical role of cognition and learning, intentionality and identity, evolving cultural repertoires, and the extraordinary human capacities for effective behavior including deliberate collective action or the envisioning of alternative realities—impart to social processes their distinctive flavor of complexity, and are clearly key to any study of social robustness.

As an example of one result of these uniquely human capabilities, the deviant behaviors that challenge social system integrity are not accidental and uncorrelated (like mutations in biological models), but necessarily are sometimes intentional and coordinated. Moreover, humans adopt behaviors through cultural transmission processes that can be extraordinarily rapid and characterized by conformist learning (a tendency to adopt behaviors that are common, independently of other influences on learning such as relative payoffs). Study of factors such as the prevalence of conformist learning in social processes, and its implications for the likelihood of cataclysmic collapse or the persistence of multiple distinct outcomes, can be counted on to give rise to a radically new, and fascinatingly social, understanding of robustness.

2 Relation to Other Work

The proposed Program represents a new direction for SFI. There is at present no organizational structure and no funding at SFI for the study of robustness in social contexts. In point of fact, the research descriptions contained in this proposal were generated in most cases by an invitation to researchers throughout the social sciences (most, but certainly not all, of

whom were already affiliated with SFI) to reinterpret their own areas of research from the perspective of robustness. In many cases, this invitation represented for the researchers their first occasion for considering the topic of robustness and its relevance to social processes.

By virtue of a program sponsored by the Packard Foundation, SFI does however have extensive expertise in the study of robustness for natural and engineering systems. A key component of the McDonnell Program will address the relevance of these studies to the robustness of social processes. (The Packard Foundation explicitly precludes support of research in social sciences.) The expectation is that the differences between social and non-social processes will prove as instructive as the commonalities.

As a technical concept, *robustness* up to now has been used only in certain subcommunities in science and engineering, with different interpretations in each of those contexts. Some of the major areas in which robustness is studied are discussed below.

- In engineering applications, robustness of systems is the object of intense effort, so much so that regulatory and control features designed for the explicit purpose of achieving robust performance often outweigh in both complexity and cost the actual functional features. Typically robustness in these contexts is understood to mean reliability of function in the presence of failures with estimable probabilities and supports. Morever, robust design is typically implemented "after the fact"; in other words, functionality comes first, with regulatory controls imposed subsequently to avoid failure modes. The incorporation of robustness as an integral component of the functional design process is a relatively new idea in engineering, and has yet to be realized to any real extent.

- In the context of software engineering, robustness is distinguished from correctness. A program is expected to perform correctly on cases covered by its specifications (which might include faulty data, user error, etc.), but programmers also explicitly design for robustness *outside of* specifications—for example, the program might be expected to fail gracefully in the event of a disk crash.

- Within developmental biology, robustness typically refers to the ability of developmental processes to stay "on track" in the presence of perturbations such as environmental insult or developmental noise or knockout mutations. In recent years, robustness in cell biology has been used to describe the ability of certain metabolic and regulatory processes to perform correctly within a large range of parameters.

- In the context of ecosystems, robustness is often interpreted as what Gunderson and Holling [16] call "ecological resilience;" namely, the capacity of a system to undergo disturbance and still maintain its functions and controls. Note that no concepts of metrics or of equilibrium are implied in this definition of resilience, and the concept differs in this way from traditional notions of stability or other forms of ecosystem resilience [37], where the appropriate measure is the rate at which the system returns to equilibrium following a perturbation.

Examples of phenomena whose robustness has been studied recently from the perspective of complex adaptive systems include the effects of structural mutation on cellular processes of metabolism and growth; directed evolution of enzymes with specified catalytic properties; disturbance regimes and recovery of ecosystems; computer network security systems subject to purposeful attack; and design of Internet protocol systems. Insights that have been achieved in these contexts relate to the:

- relation between robustness and flexibility; in particular the role of robustness in reducing the potential lethality of mutations and increasing an organism's capacity to accumulate nonlethal genotypic and phenotypic variation. One consequence is to reduce the number of mutations needed to produce phenotypically novel traits [23, 34].

- robustness of food web networks that consist of a large number of weak interactions together with a small number of strong interactions. Endogenous and exogenous changes are then more likely to result in local elaboration of new morphologies rather than in a catastrophic failure of global organization [23].

- implications for robustness of what software engineers call "on-line management," namely, the need to maintain current functionality while implementing change or repair. Examples include the separation in protein evolution algorithms of modules governing function and structure so as to permit exploration of new functionality while maintaining necessary structure [48].

- existence of "congruence principles" that translate robustness at one level into robustness at another level. Examples include mutational robustness arising as a correlated response to selection on environmental robustness in RNA evolution [3], and the use of the same molecular mechanisms to realize both learning capabilities and developmental stability in neuronal systems [30].

- existence of conservation principles for robustness implying that systems that have evolved or been designed to withstand specified thresholds of shocks are commensurately susceptible to shocks above those thresholds and to other forms of shocks [13].

- analysis of biological sensory-processing systems that use redundancy of representation as a general-purpose algorithm and thereby gain multiple functionalities, including improved abilities to deal with poor signal-to-noise ratios, and to separate out multiple signal sources [60].

- identification of an extensive repertoire of biological mechanisms that employ diverse strategies that can be characterized as: 1) buffering the organism from effects of an insult; 2) amplifying the insult as to enable the organism to purge it; 3) identifying and repair the damage from the insult.

- establishment in ecosystem management of the need for policies and management that are flexible, adaptive, and experimental at scales compatible with the scales of critical ecosystem function [50, 17, 12], and recognition of the pathways by which fixed rules and rigid management structures lead to systems exhibiting a *loss* of robustness—i.e., that suddenly break down under disturbances that previously could be absorbed [16].

Many of the above points are clearly suggestive of questions that are important for understanding robustness of social processes. The usefulness of pursuing such questions will be a ongoing topic of discussion in the proposed Program.

In addition to the Packard program on robustness in natural and engineering systems, SFI's growing body of research in social systems will be another important building block for the Program on social robustness. Previous work at SFI in social systems has adopted what Arthur et al [4] have characterized as a "process-and-emergence" approach. The approach emphasizes the mechanisms by which social organizations and social institutions change over time, and the emergence of new organizations and new patterns. Characterizing the interactions among agents with diverse expectations, and the role of these interactions in giving rise to new social entities, have received special attention. Specific studies have included analysis of the role of positive feedback and its associated phenomenology of path dependence and lock-in in economic systems [4]; the use of agent-based modeling to study emergence and persistence of social institutions such as community settlement patterns [15]; analysis of the growth and stability of social networks, in particular what are called "small-world" networks [51]; and the emergence of stable cooperative strategies in iterated games, for populations of players, and in high-conflict settings such as civil wars [5, 55].

In the context of general complex adaptive systems, the initiative will share a number of overlapping themes with a new joint SFI/University of Michigan IGERT program sponsored by the NSF to support graduate training in complex systems and institutions (focusing on dynamics, information and learning, interaction structures, diversity/heterogeneity, and emergence), and with a new Program in the Behavioral Sciences to be launched at SFI in 2003. Numerous research projects headed by SFI affiliates will feed into, and draw upon, the Program, including many of the Resilience Alliance projects on natural resource management, the McDonnell Foundation-supported work on social institutions and the resilience of socio-natural systems, and NSF-supported work on coupled human-natural systems and property transformations in postsocialist countries, among many many other examples.

More importantly, the Program, with its emphasis on phenomenology and case studies as the starting point, will look first to the general scientific community (whether interested in questions of robustness or not) for the empirical and analytical understanding of the specific social under study. The phenomena themselves in many cases have been studied extensively, and the cumulative expertise of the scientific community on, say, constitutions or cultural traditions is of course profound. The goal of the Program is to bring a new perspective to bear on these areas, and to draw upon existing expertise as much as possible in identifying fundamental questions and insights that will contribute to the understanding of robustness.

3 Research Themes

The McDonnell Program will organize a range of activities—including workshop, visitor, postdoctoral fellowship, and student programs—around a limited number of research themes. Within each research theme, a range of case studies will be discussed with the objective of identifying specific phenomenology relating to the emergence, mechanisms, and consequences of social robustness.

Note that the research themes are **not** chosen for any of the usual reasons; in particular, they are not chosen on the basis of inherent interest (compelling though they may be), or for their usefulness in spanning the set of diverse social processes, or for any intellectual coherence they provide in their own right. Rather the choice of themes reflects an assessment of the likelihood of Program participants being able to identify case studies within the themes that will contribute to understanding principles of robustness in social processes. Two points are critical here: the themes are expected to contribute to the understanding of *robustness* (and only secondarily to the advancement of, say, economics or sociology); and they are expected to illuminate aspects of robustness that are special to *social* (as opposed to biological or engineering) processes.

There is obviously a fine line being drawn here. Robustness will be adopted by the general community as a useful perspective only to the extent that **it provides some fundamental insight into a social process,** and therefore it may seem peculiar to emphasize the feature of robustness rather than the social process itself. The Program's philosophy however is that 1) the participants' commitment to the details and specificity of their specific phenomena of interest is a given, and 2) robustness is an important and little-understood aspect of those phenomena. The conclusion is that there can only be scientific gain from imposing a strict requirement that, in the context of this particular Program, those phenomena be studied from the perspective of robustness.

One consequence of the Program's philosophy is that *the research themes will evolve with the Program* as they turn out to be more or less instructive in contributing to the robustness effort. The expectation is that as the Program takes shape, some of the themes will launch themselves as active areas of collaboration, some will morph into related topics, and others may well evaporate and be replaced by new areas of interest. The ebb and flow will in large part depend on the success of the Program participants in identifying case studies within the research theme with the appropriate mix of richness and tractability.

The six research themes are listed below together with the main rationale for their being selected as initial foci for the Program.

- The Robust Decisionmaking research theme will focus on the robustness of **choice with unforeseeable consequences**. Discussions will highlight the importance of issues including intentionality and the cognitive ability of social agents to observe outcomes, infer the reasons for those outcomes, and change their behavior accordingly.
- The Robustness of Business Organizational Structures theme will focus on the role of **network structure** in facilitating the dynamics leading to phenomena such as innovation or collapse in a social organization. Specifically, the research will explore the consequences for robustness of the ability of social agents functioning within a hierarchical structure to form social ties across all scales of the organization.
- Robustness of Political Agreements, States, and Regimes will address the robustness of **negotiated agreements** that define a social structure such as a nation-state, and in particular the dynamics that enable some such agreements to survive internal or external shocks—such as events that challenge the beliefs of the involved parties, or shifts in interpretations of the agreements, or organized attempts to disrupt those agreements—while others collapse into conflict.
- The Robust Institutions theme will examine the **social dynamics** that contribute to robustness or fragility of institutions. One set of issues to be explored is the role of competition between groups in favoring those with more robust institutions, and the within-group processes of collective action that can serve to create the range of novel institutional forms on which between-group selection can act.
- Robust Economies will consider issues of **scale and levels** in robust social processes. Included will be interactions between the slow variables of cultural patterns and the fast variables of economic change; the transferrence of robustness from one level to another; and mechanisms of robustness in organizations that are so large as to compromise the effectiveness of social norms.
- The case studies to be discussed in the Robustness of Cultural Traditions theme will be instructive for the question of **inference from the historical record.** The discussions will attempt to disentangle the two aspects of "staying the same" versus "responding to change" that characterize robustness, with the goal of developing a methodology for examining the history of environmental or internal change, and the response of a social process to this change.

Integration of the insights from the various research themes—with careful attention to differences as well as commonalities of the case studies—will be achieved in several ways. First, group meetings will be held to discuss results emerging from the different themes. Second, individuals typically will participate in multiple themes. Third, and most importantly, several of the specific case studies and conceptual issues are expected to cut across multiple themes. An analysis of unforeseeable consequences for example, will interweave the themes on "Robust Decisionmaking" and "Robustness of Political Agreements." The role of robustness in positioning a social process for innovation versus collapse will be key to the "Robustness of Business Organizational Structures," "Robustness of Cultural Traditions," and "Robust Institutions." The dynamics of belief structures will be central to research not only in "Robustness of Political Agreements," but also in "Robust Institutions" and "Robustness of Cultural Traditions." And issues such as the potential and limitations of collective action will be discussed in "Robust Institutions" and "Robust Economies," as well as in "Robust Political Agreements."

Finally it should be noted that a number of strong research interests of Program participants relating to robustness of social processes are not explicitly listed above. Examples include the robustness of technical traditions, the robustness of diffusion of innovation and related issues in network contagion and social learning, and the role of diversity and redundancy in enabling robustness in political and economic contexts. In these and other cases,

Program participants recognize the importance of the topics but as yet have not identified candidate case studies on which to base a coordinated research theme. The areas will be regarded as "Exploratory Research Topics," and the hope is to develop an approach for their study as the Program proceeds.

The six initial research themes are described below.

Robust Decisionmaking

Social systems can be distinguished from biological and physical systems by the intentionality of their agents. Social actors have the capacity to change their behaviors in response to their understanding of the system in order to achieve more preferred outcomes. This difference heightens the salience of *design*. Biological systems are "designed" by natural selection, but in social systems it is natural to ask, for example why do these actors do this thing which gives them such a bad outcome? Why does a given social norm persist? The robustness of many social systems reflects robust decisionmaking by the individuals whose choices ultimately constitute the system's behavior.

Decision theory for particular types of uncertainty is a standard tool in economics. However there are forms of uncertainty whose implications for decisionmaking have yet to be explored. Decision theory divides unknown phenomena into two classes: *objective uncertainty*, or *risk*, which has to do with those random perturbations whose probabilities can be assessed, and *subjective uncertainty*, or simply *uncertainty*, whose (frequentist) probabilistic assessments cannot be made. Expected utility decision theories address known risk, and uncertain events governed by subjective beliefs which are prepresentable by probability distributions. Bets on the outcome of a horse race, or a presidential election, are examples of this kind of risk. But within the class of subjectively uncertain perturbations are those which are *unforeseeable*, and so even subjective quantification is impossible.

Unforeseeability is an important consideration in constructing a positive theory of robust individual decisionmaking. In many contexts there are deep identification problems which prevent an individual from fully learning about various important parameters based on observational data. For example, the payoffs to educational investment may not be observable to an individual who grows up in a community where such investments are rare. Manski [27] describes how identification problems of this type lead to interesting indeterminacies in the course of individual and group behaviors. An outstanding research question is whether various behaviors that appear to be anomalies from standard formulations of rational choice models may be interpreted as robust behaviors in uncertain environments. Another important question is whether "robust" forms of behavior evolve in environments characterized by some degree of unforeseeability. Both questions call not only for the development of new theoretical frameworks, but also for the design of careful experimental studies that would illuminate behavioral and cognitive aspects of decisionmaking under this form of uncertainty. For example, one possibility is to carry out experiments to observe the evolution of individual strategies for simple games in which certain aspects of the payoff structure exhibit Knightian uncertainty.

Unforeseeability is also relevant for normative aspects of policy analysis—i.e., the evaluation of alternative government policies—in the presence of uncertainty about the structural determinants of the economy or society in which the decision will be made. In many contexts social scientists at best possess a class of possible theories to explain a given phenomena rather than a single theory. Most policy analysis is done within a given model, which is to say that the possibility that the model is incorrect is not foreseen by the analysis.

A number of new areas for policy evaluation will be explored. One area concerns the consequences of model uncertainty in the context of monetary policy rules. With macroeconomics, a range of alternative business cycle models has been developed, each of which assumes a different relationship between aggregate levels of unemployment and per capita output. While the policy predictions of these models may dramatically differ, there is no *a priori* basis for accepting one model versus the other as the "true" description of the economy, nor can model selection be plausibly based on relative goodness of fit given aggregate

macroeconomic data. Model uncertainty of this sort should be an integral part of policy analysis: A policymaker should be concerned about the robustness of the proposed policy to the uncertainty in knowing which theory actually describes the macroeconomy at a given point, and even the possibility that no extant theory is accurate.

Participants in this research theme will include Larry Blume (economics, Cornell), William Brock (economics, Wisconsin), Dan McFadden (economics, Stanford), Steven Durlauf (economics, Wisconsin), Buzz Holling (ecology, Florida), Charles Manski (economics, Minnesota), John Miller (economics, Carnegie Mellon), Elinor Ostrom (political science, Indiana), Scott Page (political science, Michigan), Sander van der Leeuw (archaeology, Paris), and Brian Walker (ecology, Resilience Alliance).

Robustness of Business Organizational Structures

Business organizations today face the challenge of adapting to a transforming global economy: enterprises must increasingly cope with market volatility and the extraordinarily rapid pace of technological change. In attempts to cope with uncertainty, firms create hybrid organizational forms and build networks of strategic alliances (e.g., [38, 45, 43]). Are there general principles that determine success or failure of strategies during such periods? What is the role of path dependencies [4] in which organizations lock-in to practices that were once successful but that prove less effective when conditions change? How do distinct organizational forms respond to change?

A representative project in this research theme will focus on hierarchical but decentralized network structures that facilitate robustness and innovation in modern business organizations. The objective is to design the structure to enable the business not only to perform distributed production, but also to enable continuous repartitioning of production tasks to keep pace with a changing environment. The extreme form of this challenge is the design of a robust structure that deals successfully with potentially catastrophic change such as the loss of existing capabilities or the obsolescence of existing technology.

The design of a robust network structure must take into account that the dynamics of an organization operates on and between all levels, with units at each level following their own spatio-temporal scales and engaging in their own dynamics, as well as communicating with other units at the same and different levels. The distributed and diverse nature of dynamics permits a range of phenomena which, under stress, may result in system malfunctions (e.g. Rappaport 1972; Flannery 1972). Examples include information-flow problems that cause faulty feedback to regulatory mechanisms; over-segregation or over-centralization; over-dependency among different entities in a system; and usurpation that occurs when subsets of entities come to dominate overall behavior.

The work will build upon two very different lines of research: (i) studies by Radner and others [41, 9, 59] in developing models that describe the information burdens of distributed organizations, and (ii) work by Watts, Barabasi, and others [51, 6] in the analysis of *small-world* and *scale-free* networks—two classes of generic networks that have attracted attention recently in large part because of their applicability to social dynamics. Both these approaches will be significantly modified in order to address the question of robust network structure. First, the models proposed by Radner et al will be modified to address the problem of information congestion arising from problem-solving and regulatory activities. Second, the small-world and scale-free network analyses will be modified to incorporate an underlying hierarchy together with rules by which individuals construct ties across different scales of organization (the team, the department, the firm, the district, the industry as a whole, and the entire economy).

The models will be used to generate predictions about the reconfiguration of network structure, and consequent effect on information congestion, during times of stasis versus change. One particular interest is using the models to determine the organizational unit at which innovation, problem solving, and recovery from breakdown occurs. The models' predictions will be tested against a variety of data sets from sources including instant messaging and email logs at large firms, infrastructure networks such as the Internet, and social

networks of peers.

Participants in this research theme will tentatively include Peter Dodds (physics, Columbia), John Padgett (political science, Chicago), Woody Powell (sociology, Stanford), David Stark (sociology, Columbia), Steve Strogatz (applied math, Cornell), Sander van der Leeuw (archaeology, Paris), Duncan Watts (applied math, Columbia), and Doug White (anthropology, UC Irvine).

Robustness of Political Agreements, States, and Regimes

What explains the robustness of political agreements as a form of political organization? This is something of a puzzle, as its integrity—for example, its monopoly on the legitimate use of violence—requires the cooperation of vast numbers of individuals, each seeking their own ends. The political agreements—ranging from constitutions to handshakes—on which the national state is based must therefore be self-enforcing.

Why is individual compliance with these agreements and the other requirements of the integrity of the national state a mutual best response [40] for most of those involved?

What explains its occasional failure, as when nation-states disintegrate through the secession of ethnically distinct member nations or when states collapse due to internal conflict, as occurred during the 1990s when the former Soviet Union fractured into over a dozen new nation-states?

Why are some fractured political entities—East and West Germany, South Africa during the revolt against apartheid, Costa Rica during the civil war of the mid-20th century—reunited through robust settlements, while in other cases, a division becomes permanent—as in the dissolution of the Union of Norway and Sweden and their emergence as separate states in 1905?

In particular, what distinguishes robust from non-robust political agreements that define the nation-state such as constitutions or peace treaties? What are the dynamics that enable some such agreements to survive internal or external shocks while others collapse into conflict? Two representative research projects to be included in the research theme will be the restoration of a pre-existing political entity through robust settlements of civil wars, and the resilience of democratic constitutions.

Negotiated resolutions to civil war were attempted in the majority of cases of civil wars since World War II. Negotiations resulted in a comprehensive peace agreement in approximately a third of civil wars between 1940 and 1992, yet those agreements were successfully implemented in only about a fifth of the civil wars [49]. Some peace processes such as those in El Salvador and South Africa were robust to substantial internal and external shocks, including political violence, assassinations, and significant violations of the terms of the agreement. Seemingly well-crafted agreements in other cases , such as those in the Middle East and Colombia, collapsed.

This project will involve modeling robust settlements to civil conflicts in light of the empirical experience in a set of case studies, including Colombia, the Middle East, El Salvador, South Africa, Sri Lanka and Angola. Drawing on recent models of transitions between conventions [57], the models being developed by Wood [55] will explore the robustness of civil war settlements in a framework of volatile beliefs. The models analyze the conditions under which such agreements are self-enforcing, identifying the distributional terms of robust settlements, that is, settlements which will not unravel despite substantial perturbation in the beliefs of the relevant parties concerning such things as the post-settlement distribution of power and the likelihood that the other will compromise. An outstanding question is to address how distinct forms of political violence may render agreements more or less robust.

The second research project will address the robustness of democratic constitutions which have a core function of establishing a balance between governmental responsiveness to majority will and protection of individual rights. To employ a biological metaphor, constitutions may be robust genetically: that is, their core function may be aided by complementary constitutional clauses or made impossible due to inconsistent clauses. They may also be robust phenotypically: the government that they create may fare better or worse at coping with

challenges because of the institutional structure created by the constitution.

How does one allow enough flexibility in a constitution to ensure that it continues to generate a responsive government while at the same time maintaining the core principles? Constitutions possess differing degrees of structural flexibility, for example, that permit the constitution to be changed, either formally, through amendment, or informally, through doctrinal or interpretive shifts. Structural flexibility aids adaptation to new circumstances, but inconsistency destroys the constitution's force by eroding its legitimacy. Likewise, changes in the power structure of the government, from partisan power shifts to alterations in the organization of government to the invocation of emergency powers on the part of the executive [26], affect its dedication to the founding principles in the face of unexpected challenges.

A specific case study to be studied in this context is a comparison between the U.S. Constitution and the constitution of Argentina that borrowed heavily from both the U.S. and Switzerland. For example, the Guarantee Clause (Art. 4, Sec.4), in which the U.S. federal government guarantees to the citizens of each state a republican (representative democracy) form of government within the state, appears verbatim in the Argentine constitution. Whereas in the U.S., the clause was intended to preclude monarchies in states, the Argentine federal government has interpreted the same wording to give itself broad powers to intervene in the political affairs of the provinces by governing the province directly. During an intervention, the President substitutes his own manager for the democratically-elected governor, and often dismisses the entire legislature and judiciary as well. These interventions have affected the balance of power between federal and provincial governments and appear to be important to the economic health of Argentina. They also may help explain the curious pattern this century of flourishing, competitive democracy and military coup.

Additional studies of constitutional agreements at multiple levels—ranging from international agreements down to self-organized resource user groups will be encouraged.

Participants in this research theme will tentatively include Jenna Bednar (political science, Michigan), Lars-Erik Cederman (government, Harvard), Elizabeth Cousens (SSRC), Russell Hardin (political science, Stanford and NYU), Stathis Kalyvas (political science, Chicago), Karl Moene (economics, Oslo), Elinor Ostrom (political science, Indiana), James Ron (sociology, McGill), Stephen Stedman (international relations, Stanford), Barbara Walter(political science, UCSD), Elisabeth Wood (political science, NYU), and Peyton Young economics, Johns Hopkins).

Robust Institutions

Some types of social institutions—markets, states, monogamy, private property, worshiping supernatural beings, social ranking, and sharing the necessities of life among non-kin, for example—have persisted over long periods of human history and have emerged and proliferated in highly varied environments. Others have been of passing importance, generally occupying limited ecological niches, and proving vulnerable to environmental and other shocks. Over long periods of history, politically hierarchical and economically unequal structures have proven persistent, while at other times more consensual and egalitarian institutions have endured. What accounts for the persistence of some and the ephemeral nature of other institutions?

A key innovation in this area will be to model the idiosyncratic behavior inducing tipping events not as the game theorist's "trembles" or the population biologist's mutations, but rather as intentional behaviors, often taking the form of collective action. The second process is a between-group dynamic, where institutions persist to the extent that they favor the groups adopting them in inter-group conflicts and in surviving adverse environmental shocks.

Extensive use of agent-based simulations will be necessary given the complex nature of the interactions under investigation.

To ground our theoretical investigations in the real-world problems we seek to understand, and to discipline the theory-building process, the project will identify some challenging case studies of institutional fragility and robustness. One episode of persistence and fragility that we will study is "the first property rights revolution" [10]. This the process, witnessed

over the centuries as farmers have encroached on foragers, has unraveled long-enduring conventions defining the foraging way of life, often in the course of less than a generation of. Both the durability of the foraging institutions—which appear to have persisted over 50,000 years at least – and their rapid eclipse by an entirely new set of property rights will be studied. Another possible example of property rights fragility will be the current challenge to conventionally-defined intellectual and cultural property rights represented by the drastic reduction in the cost of copying and distributing information.

Another approach will be to use careful experimental designs to examine how the same set of rules operate under diverse conditions. How robust are particular rule configurations as social factors change, such as: the size of a group, the capacity of those in a group to know one another in general or to recognize the specific individuals with whom they are interacting, the number of ethnic groups or other identifiable groups, etc. Some of these experiments should be conducted in computer based labs and some in the field where parallel case studies can be conducted that provide knowledge about the rules participants use in their everyday activities similar to the experiment. Under these conditions, it is possible to know how familiar or strange a particular institution is given the experience of those participating [35, 18].

Participants in the research theme will tentatively include, among others, Christopher Boehm (anthropology, USC), Sam Bowles (economics, SFI), Rob Boyd (anthropology, UCLA), Jessica Flack (anthropology, Emory), Peter Hammerstein (biology, ITB Berlin), Suzanne Lohmann (political science, UCLA), and Elinor Ostrom (political science, Indiana).

Robust Economies

In economic systems, the concept of robustness raises a large number of empirical and theoretical questions. Indeed, there are conceptual questions: what is meant by robustness and to what extent is it in fact desirable?

Rather than state some broad concepts and generalizations, which should instead be the outcome of the study, some questions will be put forward here relating to robustness and economic performance.

Is capitalism (the free-market system) robust? Its history has consistently been one of fluctuations in economic activity and in its barometers, the markets for assets such as securities and land. Some of these fluctuations have been very severe and costly indeed, most notably, the Great Depression of 1929-1940. On a a lesser scale, the Japanese economy for the last decade has shown prolonged stagnation after thirty years of unprecedented growth. It cannot be said that any convincing explanation has yet been advanced.

Yet in a longer-term sense capitalism in advanced countries has shown a kind of robustness. After each shock, whether internal as in the cases above, or external, due to war or revolution, the system has recovered. The post-World War II period replaced the Great Depression and war with the most unprecedented rate of economic growth. Most striking was the rapid recovery of Japan and Germany from incredible devastation. However, they did not merely recover; they adapted and changed. Their characteristic institutions partly remained but were partly transformed. In some aspects, there was robustness in the sense of the continuation of productive methods and commercial relations. But in other aspects, there was great alteration, particularly an opening to world commerce and to domestic competition. The differences were both quantitative and qualitative.

A related question is the persistence of cultural patterns. Many economists are skeptical of the role of culture in economic development, but others take it very seriously. The economic history of Latin America is illustrative; every period of economic progress seems to come to an end. It is an old argument that cultural patterns, which may have been highly adaptive at one period, have a robustness which causes them to persist into a period where they become an obstacle (Thorstein Veblen, Max Weber). Of course, as is usual in history, other historical examples (most notably, East Asia in the last fifty years) seem to work in the opposite direction.

Note that robustness in some cases may be the same as rigidity, and its presence at one

level may lead to non-robust behavior at a higher level. Economists frequently argue that rigidities in markets (e.g., fixed wages) lead to instability in the economy (e.g., unemployment). On the other hand, completely fluid relations have problems of their own (creating individual uncertainty which may well be counterproductive).

The issue of individual uncertainty then leads to the question of social norms. In traditional societies, with face-to-face relations, these clearly have a strong regulatory effect on economic activity and serve to make the system robust to changes [11, 21, 20]. The evolution of social norms has been much studied in recent years, usually with a game-theory flavor (see, e.g., [8, 22, 58]). There are equilibrium models based on repeated interaction, in which mutually beneficial relations can be maintained; unfortunately, these models usually have many equilibria, of which the cooperative solution is only one. Population game models in which adaptation to the behavior of others is modeled by a stochastic process tend to show that cooperative solutions are more stable. But these models are very simple; in particular, unlike ecological models, they do not admit external shocks to the system. It is robustness to external shocks that has been studied most intensely by ecologists [31, 32].

What is most needed is the study of the role of social norms in large economies. It seems to be clear that norms (e.g., trust in others and in enforcement institutions) play a role in the most advanced economies, even though the role of personal relations is minimized, and anonymity is the norm in economic relations. The failure of norms to emerge has been argued to be a cause of the relative failure of transition from communism in the former Soviet Union and Eastern Europe. While neither the empirical evidence nor the theoretical reasoning is clear, there are many arguments for the coordinating and enabling role of socially-based expectations (see, e.g., [36, 2, 42, 39]). These need not, of course, always operate to facilitate economic growth; neighborhood effects have also been responsible for crime and other deviant and socially damaging behavior.

This theme will bring economists with other social scientists to explore the signatures of robustness in economic processes, the issues of robustness on different levels of a social system, and to the interplay among economies, cultural patterns, and social norms especially in large societies. Participants will tentatively include Ken Arrow (economics, Stanford), Larry Blume (economics, Cornell), Sam Bowles (economics, SFI), Suzanne Lohmann (political science, UCLA), Paul diMaggio (sociology, Princeton), John Padgett (political science, Chicago), and Woody Powell (sociology, Stanford).

Robustness of Cultural Traditions

The only cultural phenomena available to study are those created by the human species through such symbolically-based means as human language, graphics, or mathematics. These media motivate observers to view the cultural systems in which they participate (and which they study) as stable and structured arrangements of roles, groups, institutions, norms, etc. A perceived environment of fixed entities and relations is comfortable, but it may be misleading. Such perceptions make it difficult to define processes of change fundamental to explanations of cultural transformations. Symbolized entities, however important they seem, may be epiphenomenal to the processes which explain cultural change.

Imagine instead that cultural phenomena are in constant flux, that they can be envisioned as inter-related flows in space through time of material, labor, and messages articulated by individual actors moving by defined pathways or channels. The definitions of channels through which such flows move, and the mechanisms by which channels are changed, are key research issues. The points where flows interact may be thought of as places, groups, institutions and the like, but they cannot be explained without reference to the flows. The goal then is to study the robustness of flows through time and under changing environmental conditions.

Assessing robustness in changing cultural systems would be difficult to do for the modern world system, whose history is brief and whose internal relations are very complicated. Perhaps even more frustrating, there is only one example. One could avoid these problems by studying the world's hunter-gatherers, whose internal relations are less complicated, and

of which there are a great many largely independent local traditions often with very long histories. However, geological processes insure that most evidence of these histories has been erased, and the constant mobility of these simple foragers compromises the ability to map past relations and flows.

The trajectories of the early civilizations from village to empire, of which there were about ten examples, provide a series of essentially independent cases whose changing regional settlement configurations provide ways to monitor changing patterns of flow, and changing arrangements of places and people.

Since 1950, archeological anthropologists have developed a method termed "intensive regional survey" which provides potentially comparable documentation of the trajectories of human societies. Five early civilizations with long-term records have been documented with increasing comprehensiveness. As of the first decade of the 21st century, changing settlement structures have been broadly documented in many component areas of Mesopotamia (e.g., [1, 52]), Andean American (e.g., [53, 54] and Mesoamerica (e.g., [29, 44] and work is progressing rapidly in South Asia (e.g., [33] and China (e.g., [25, 46]). It is now possible to comparably define the changing networks through which messages, labor and materials have moved in a sample of component areas of these five early traditions of complex cultural development.

How can robustness be recognized and measured in the histories of the archaeologically documented early civilizations? The data permits inference of certain measures or proxies for the flows through time, including changes in population mass, food production, or the movement of traded materials. These measures of flows show a significant amount of variability; in particular, there are periods of increase and decrease leading to the integration and disintegration of spatial units [28, 56]. As a first approximation, robustness can be taken to be indexed by two factors: the time-spans of period of little change, and the number of times reintegration occurs after a period of disintegration. An obvious question is whether traditions that show more resistance to change, will show less ability in the long term to reintegrate after disintegration. Another question is whether there the historical flows provide evidence of learning or evolution, such that successive periods of integration are more able to respond to change.

A second example following a similar approach of evaluating multiple traditions will be the analysis of the robustness of technical traditions. "Know-how" constitutes the interface between the human and the non-human resources upon which a social system depends to process energy and matter drawn from its environment. Examples will be studied not only of know-how traditions organized to survive continual perturbations, but also of know-how dynamics that on occasion generate opportunities for inventions to "take off." Historical, anthropological, archaeological, and modern case studies will be included (see, e.g., [14, 24, 47, 7]). The advantage of focusing on robustness in this area is that the study of materials and specific techniques facilitates testing of the dynamics involved.

Participants in this theme will tentatively include Homayoun Bagheri (evolutionary biology, SFI), George Gumerman (archaeology, SFI), Steve Lansing (anthropology, Arizona), Sander van der Leeuw (archaeology, Paris), Doug White (anthropology, UC Irvine), and Henry Wright (archaeology, Michigan).

4 Program Mode of Operation

The emphasis of the McDonnell Program will be on building research interactions that lead to understanding some general principles of robustness in social processes. The crux of the Program will therefore be the bringing together of researchers to share insights, build a common language, and attempt to consolidate what is known across a wide range of disciplines and topics about robust processes.

To achieve its goals, the Program will support not only research on specific topics, but also, and more importantly, interactions across topics coupled with outreach efforts to dis-

seminate research results of general interest to the broadly defined scientific community.

Research efforts supported by the Program will bring together multigenerational teams—students and postdoctoral fellows together with senior researchers—from widely disparate scientific communities. The researchers will interact both with each other and with the broad-based community of researchers at SFI interested in complex adaptive systems. Research activities will include visitor programs, postdoctoral fellow and graduate student programs, working groups, and workshops on specific topics, as well as group meetings convened expressly to identify and to discuss cross-cutting conceptual issues.

The current set of confirmed and tentative participants constitutes a social network that is only sparsely connected. Within that network there are perhaps seven (in some cases overlapping) strongly connected subgroups—ranging in size from two or three in most cases to six in one case—of researchers who have had close interaction with each other in the past (although not on topics relating to robustness). Among the other participants, the linkages are either weak or nonexistent. In the vast majority of the cases, the researchers have never collaborated together, and may well be unaware of each other's work.

The Program recognize that many individuals and research communities, especially from the empirical side of social science, that represent important sources of expertise for the study of robustness are not currently affiliated with the Institute. The Program organizers are committed to identifying and recruiting the best of those individuals and communities into the research activities. Participation in working groups is therefore expected to evolve over time, and suggestions for exploratory research topics and new working groups will be solicited from the general scientific community on an ongoing basis.

In particular the degree of participants from outside the social sciences is expected to wax and wane depending on the specificity and applicability of Program activities. Initial Program meetings will include biologists, ecologists, computer scientists and representatives from other non-social sciences to encourage identification of commonalities and overlapping themes. As the Program evolves, these early participants will assist in identifying other non-social scientists as appropriate future participants. Exactly which non-social scientists become active Program participants will depend on the particular commonalities to be pursued, and on the topics for which Program participants find it useful to develop prototypical models of robustness with applicability outside of the social sciences.

Opportunities to participate in the Program will be advertised electronically, in particular on a web site to be established for the McDonnell Program on Robustness. Research results generated by the Program activities will be summarized on the web site, as well as in a series of publications that address both specific topics and general themes.

Other information dissemination campaigns will target the topic of robustness in the extensive array of SFI educational and outreach programs. Researchers with expertise in robustness will be invited to lecture at the annual Complex Systems Summer School attended by over 50 top graduate students and postdoctoral fellows from around the world, as well as by members of the SFI Business Network. Robustness will be highlighted in recruitment of SFI undergraduates, graduate students, and postdoctoral fellows. Robustness will also be highlighted as an exploratory theme in meetings convened to inform the SFI Business Network of new developments in complex adaptive systems.

The proposal is for a five-year Program. Years One and Two will be devoted primarily to establishing a common language and a common perspective on the questions driving the research. The primary focus of activities in these two years will be on thematic workshops that attempt to establish commonality together with sponsorship of postdoctoral fellows working on specific case studies. The workshops will typically also provide an overview of robustness research in non-social contexts so as to identify constructive linkages.

Year Three of the Program will shift the emphasis toward bringing the perspective shaped by the preceding two years to bear on more topically defined workshops. These workshops are expected in Year Four to generate a number of exploratory collaborative research projects among Program participants. Year Five will focus on integration of insights from these projects, with activities including a summary conference and publication of a review volume.

The hope is that a five-year Program structured in this way will stimulate a cascade of activity and research by the general scientific community on the issues of social robustness.

5 Management Plan

The management plan of the proposed Program is designed to ensure research distinguished by both excellence and value to the general scientific community. The basic structure of the Program management will include a Program Director and an Coordinating Committee working in conjunction with the SFI Science Steering Committee.

The Program Director will be a social scientist who will be in residence at SFI, and who will be responsible for overall coordination and scientific management of the Program. Specific administrative responsibilities will include liaison with the Coordinating Committee; recruitment and selection of postdoctoral fellows and graduate students; recruitment and hosting of visitors; development of workshop and working group proposals; approval (with advice from the Coordinating Committee) of workshop and working group proposals; organization of annual Coordinating Committee meetings; preparation of progress reports; oversight of web site development; and preparation of publications and outreach material for the Program. Scientific management responsibilities include assignment of priorities (with advice from the Coordinating Committee) among the research themes; setting the balance (with advice from the Coordinating Committee) within and across the research themes among thematic, topical, and integrative meetings; scientific interaction with visitors and workshop/working group participants; identification of new research themes; and evaluation of Program progress. The Program Director will also be expected to lead a research program on a specific topic germane to the social robustness Program.

The Program Coordinating Committee will be responsible for selection of the Program Director. The major requirement will be a commitment to both content and process; i.e., commitment to the overall scientific vision of the Program, enthusiasm for exploring new ideas regardless of their disciplinary source, and openness to new ways of doing new business. It is expected that the position will be appointed on a two-year basis. There is a possibility that the responsibilities may be shared among two individuals.

The Coordinating Committee will meet yearly with the Program participants. It will be responsible for advising on research directions and specific research projects, for suggesting individuals and institutions with whom collaboration will be beneficial, and for acting as advocates for the Program with the general scientific community.

Individuals who have agreed to serve on the Coordinating Committee thus far include: Ken Arrow (economics, Stanford), John Holland (computer science, Michigan), Erica Jen (mathematics, SFI), Steve Lansing (anthropology, Arizona), Elinor Ostrom (political science, Indiana), and Sander van der Leeuw (archaeology, Paris).

Program participants will be responsible for: 1) coordinating visitor and working group activities, 2) maintaining an involvement in research activities in other themes; and 3) suggesting and organizing activities that cut across research themes.

On the basis of input from the Coordinating Committee and the theme coordinators, the Program Director and the SFI Science Steering Committee will provide oversight for all activities of the Program, including selection of the theme coordinators, long-term and short-term visitors, postdoctoral fellows, students, research programs, workshops, and educational outreach. The SFI management will oversee the Program budget and the activities of the support staff associated with the Program.

SFI welcomes the opportunity to work with the McDonnell Foundation in supporting innovative science that exploits the power of collaborative research. We believe the proposed Program will establish the foundations for a general theory of social robustness, and demonstrate its usefulness in understanding fundamental issues of success and survival in a complex and uncertain world.

Confirmed Program Participants:

Ken Arrow (economics, Stanford)
Homayoun Bagheri (biology, SFI)
Jenna Bednar (political science, Michigan)
Larry Blume (economics, Cornell)
Eric Bonabeau (entomology, Icosystem)
Sam Bowles (economics, U Mass)
Paul diMaggio (sociology, Princeton)
Steven Durlauf (economics, Wisconsin)
Doyne Farmer (physics, SFI)
Jessica Flack (psychology, Emory)
Walter Fontana (chemistry, SFI)
Michelle Garvin (physics, Cornell)
George Gumerman (archaeology, SFI)
Peter Hammerstein (biology, ITB Berlin)
John Holland (computer science, Michigan)
Buzz Holling (ecology, Florida)
Ed Hutchins (cognitive science, San Diego)
Erica Jen (mathematics, SFI)
David Krakauer (biology, SFI)
Steve Lansing (anthropology, Arizona)
Simon Levin (ecology, Princeton)
John Miller (economics, Carnegie Mellon)
Elinor Ostrom (political science, Indiana)
John Padgett (political science, Chicago)
Scott Page (political science, Michigan)
Woody Powell (sociology, Stanford)
David Stark (sociology, Columbia)
Sander van der Leeuw (archaeology, Paris)
Brian Walker (ecology, Resilience Alliance)
Duncan Watts (applied math, Columbia)
Doug White (anthropology, UC Irvine)
Elisabeth Wood (political science, NYU)
Henry Wright (archaeology, Michigan)
Peyton Young (economics, Johns Hopkins)

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