174

Generating Societies:
Collective Social Patterns in Humans and Animals

Ivan D. Chase
Department of Sociology
State University of New York at Stony Brook
Stony Brook, New York 11794-4356
USA
ICHASE@CCVM.sunysb.edu

Abstract

In this paper I discuss some principles that order collective social phenomena in human and animal groups. In general I suggest that many types of social organization are self-organizing processes: that small-scale behavioral interactions generate the more global social patterns that we readily observe in our own and animal groups. I further suggest that both humans and animals use a relatively small number of generic, micro-level interactions in producing patterns of social organization. As a consequence, many otherwise dissimilar species use the same type of interactions and have the same kind of global social patterns in their groups. I illustrate these principles using the examples of dominance hierarchy formation and the distribution of material resources through what are known as vacancy chain processes.

INTRODUCTION

One of the themes of this conference and of artificial life studies in general is the discovery of fundamental principles which govern both real and artificial life systems. In this paper I'll discuss my work in trying to discover some of these principles in collective phenomena in both human and animal societies. This work is concerned with social organization--behavioral patterns at the group level--that are often readily apparent in humans and animals and in which we ourselves take part. My research examines such types of social organization as patterns of interaction in small, face-to-face groups, the distribution of material resources, and cooperation and the division of labor. Because a number of other papers at this conference will be covering cooperation and the division of labor, I'll concentrate on interaction in small groups using the example of dominance hierarchies or peck orders and the distribution of material resources using the example of what are known as vacancy chain processes. Most of my work has been observational and experimental, with some modeling; for those people with strong modeling interests, the systems I'll discuss present an almost virgin area with wonderful possibilities for developing new and I think unique types of models.

In general I'm going to suggest--perhaps as no surprise to the attendees at this conference--that many forms of social organization occurring in human and animal groups are types of self-organizing or self-structuring phenomena. The more global patterns of social organization that we observe can best be explained as emerging from typical and characteristic forms of local interaction. While this suggestion may not surprise participants at this conference, I should point out that research on social organization as a type of self-organization has only just begun in a few limited areas, and practically everything yet remains to be investigated. I should also point out, as some of you may know to your sorrow, that an alternative and very strongly held view concerning the correct theoretical approach to social organization is already firmly entrenched in the disciplines that currently study human and animal behavior. Briefly put, that alternative theoretical view is that social organization is not emergent, but rather predetermined by differences in the attributes of individuals in groups. That is, social organization is generated by differences in the characteristics of individuals rather than by interactions among them, while interactions are at best considered as epiphemonena. For example, the rank of individuals on attributes measured before a group forms predicts their ranks in the dominance hierarchy that appears after they are assembled or their later successes or failures in getting material resources. This approach for explaining the form of social organization is much like that of homuncular theorists in the 16th and 17th centuries who explained the growth and development of human infants from conception to birth wasn't really a problem since each sperm cell contained a tiny and already fully formed infant, the homunculus, which just developed to full, baby size in the female womb. In particular, much theoretical work in sociobiology and behavioral ecology implicitly assumes that social organization is prefigured by prior information about individual differences. But even among many of us who see self-organization as a common operational principle in nature, I think that this alternative view unknowingly colors how we think about our own behavior and how we receive research reports from more traditionally-minded biologists and sociologists. Some of my research is directed toward demonstrating the shortcomings of this traditional view and I'll mention it here.

Another thing I'll suggest is that both animals and humans use a relatively small number of generic, micro-level processes in generating patterns of social organization. This of course implies that many species use the same micro-level processes, perhaps even groups that we normally think of as having nothing in common, and further, this implies that many otherwise dissimilar species have similar global patterns of social organization. Here of course is the idea that form is primary and content secondary. For example, I offer evidence below to indicate that chickens, three species of fish, and rhesus monkeys all use the same small-scale behavioral processes in forming their dominance hierarchies and that humans getting new houses, jobs, or cars and hermit crabs looking for new snail shells in which to live, all get their respective resources through the same micro processes.

THE FORMATION OF DOMINANCE HIERARCHIES

When two animals are placed together, they will often form a "dominance relationship:" a stable pattern in which one animal usually directs aggressive acts at the other which reacts by usually returning submissive acts or fleeing. Taken together, the network of all the dominance relationships in a group composes a dominance hierarchy or peck order. Researchers have described dominance hierarchies in a range of species including some insects, reptiles, and amphibians and many fish, birds, and mammals including human children (Wilson 1975, Savin-Williams 1977, Chase 1985). Once formed, a dominance hierarchy may remain stable for weeks or months. The rank of an individual within a hierarchy is often associated with many important aspects of its life including its probability of mating, ability to raise viable offspring, access to food, physiological reactions to stress, risk of predation, and immune system response (Wilson 1975, Sapolsky and Ray 1989, Chase 1994).

Dominance hierarchies often take one of three types of structural forms: "despotisms", highly linear hierarchies, and hierarchies marked by both ranks and collections of alliances, often shifting. In a despotism one individual dominates all others, but these individuals do not have well worked out relationships among themselves. These hierarchies appear to be more common in "lower" animals such as amphibians (Wilson 1975). A linear hierarchy is a complete transitive order: dominance relationships exist among all pairs in a group with a first individual dominating all others, a second dominating all but the first, and so on down to the last individual who is dominated by all. Highly linear hierarchies appear to be the mostly common of all structural types found in the animal kingdom (Chase 1985). Hierarchies marked by both ranks and coalitions are at present chiefly reported in the higher primates (de Waal 1982).

Highly Linear Hierarchies

In my research I have been intrigued by the strongly linear hierarchies because they are so common in nature and because of their clear mathematical structure. While it may seem perfectly reasonable that hierarchies are often highly linear--this is our commonsense idea of a peck order after all--a much broader range of mathematical possibilities for hierarchy (tournament) structures exists. For example, Table 1A shows a perfectly linear hierarchy for five individuals, Table 1B a hierarchy as far from linearity as mathematically possible, and a variety of structures between these two extremes are possible. Given these possibilities, the question that has motivated my research has been this: How is it that relatively linear hierarchies are so often found in animals?

One possible answer to this question, and this is the one implicit in virtually all traditional approaches to hierarchy behavior, is that a strongly linear hierarchy is simply a reflection of various differences among the individuals that could have been known, certainly in principle, before the animals were introduced to form a group. The idea is that animals vary on attributes such as weight, past aggressive performance, and physiology prior to group formation, and rank on a composite measure of these prior attributes translates into hierarchy rank when the group is assembled. That is, the individual ranking top on the prior attribute score takes the top rank in the hierarchy, the individual ranking second on prior attributes takes the second to the top position in the hierarchy, and so on. If this were true the rank structure for prior attributes would prefigure and thus explain the rank structure of the hierarchy. With this explanation the structural form of hierarchies would not be a mystery to be explained, but rather the mystery would concern issues like what prior attributes are the most predictive and how various attributes should be weighted.

Although this idea that ranking on prior attributes determines rank in hierarchies and thus their pattern of organization is still the predominant view in animal behavior and has a strong commonsense appeal to many people, two sets of research results suggest that this idea has limited explanatory power. The first set of results is mathematical. In earlier work Landau (1951) and I (Chase 1974) explored the mathematical conditions necessary to generate highly linear hierarchies using a variety of mathematical models based upon differences in prior attributes among individuals. We demonstrated that demanding mathematical conditions were required--extremely high correlation coefficients and unlikely probability distributions for winning encounters in tournaments--and that the empirical data available almost never met these demanding conditions.

The second set of results arguing against the prior attribute explanation is experimental. In these experiments researchers assembled groups of animals to form a first hierarchy, separated them for a short period of time sufficient to forget their previous relationships, and then finally reassembled them to form a second hierarchy. The expectation in these experiments was that if prior attributes were good predictors of hierarchy ranks and that if these attributes were reasonably stable over short periods, then the rank of an animal in the first hierarchy would be highly correlated with its position in the second hierarchy. In contrast to these expectations the researchers usually found relatively low to moderate association between animals' ranks in the two hierarchies (Chase 1986). We are currently repeating these experiments in my laboratory and also finding little carryover in rank from one hierarchy to the next, even in quite small groups.

The Jigsaw Puzzle Model

Given these mathematical and experimental results, some years ago I began to wonder how highly linear hierarchies were being generated, if not by prior differences in individual attributes. It seemed to me that the answer might lie in understanding interactional processes: what happened when the animals were assembled, how they went from not knowing one another to having a stable hierarchy a few days later. Earlier research had almost totally ignored the study of these interactional processes, and so I began a series of experiments to see if something of importance was found there. Through these experiments I developed what I have called the jigsaw puzzle model of hierarchy formation. In a jigsaw puzzle the scene is revealed when the little pieces composing the puzzle are assembled in the correct way. Similarly, my idea about hierarchy formation was that when the "right" components of small-scale interaction were put together in the right way, relatively linear hierarchies would result. If the "wrong" interactions were used, a hierarchy that was not linear would result.

The components of small-scale interaction that became of special interest to me were behavioral sequences in triads, groups of three individuals. I wanted to know if an earlier interaction among two members of a triad influenced what either of them did later with the third member. There are only four possible sequences by which an initial interaction might influence the second one in a triad , and these are shown in Figure 1. In this figure the interactions are considered to be dominance relationships, and by convention A is dominant in the first relationship, B subordinate, and C the "bystander" who will be involved in the second relationship. After A dominates B, A can be involved with C in the second relationship and either can win for two possible sequences (Double Dominance or Bystander Dominates

Initial Dominant), or B and C can be involved, again with two possible outcomes (Double Subordinance or Initial Subordinate Dominates Bystander). Eventually, the third relationship will fill in, but for reasons to be explained shortly, the sequence of the first two relationships is crucial to the generation of linear hierarchies.

I used triads of chickens, the classic dominance animal, in my first experiment examining the use of these sequences. If relationships formed randomly, each of the four sequences would occur equally often, about 25% of the time, in a group of triads observed. Instead I (Chase 1982) found that Double Dominance and Double Subordinance were very common, together occurring in 91% of 23 triads observed and that the two other sequences were rare (9% together). Intuitively these results indicated that winners won again in their next encounters, losers lost, and bystanders were more successful against previous losers than winners. More mathematically these results have a crucial implication for the formation of linear hierarchies. The two most common sequences, Double Dominance and Double Subordinance, guarantee that a triad will have a transitive dominance relationship regardless of the direction in which the third relationship later forms. In a transitive dominance relationship X dominates Y, Y dominates Z, and X also dominates Z. If all the possible component triads in a larger group have transitive dominance relationships, then by definition the hierarchy will be a linear one. The two rare sequences can give rise to either transitive or intransitive relationships, depending upon the direction of the third relationship. In an intransitive dominance relationship X dominates Y, Y dominates Z, but Z dominates X. If a larger group has an intransitive relationship in one component triad, it is by definition non-linear, and the more triads with intransitive relationships, the further from linearity.

These experimental results suggested that the jigsaw puzzle approach might be a good description of hierarchy formation: that linear hierarchies might arise because the "right" small-scale interactions (Double Dominance and Double Subordinance) were occurring in component triads of larger groups, and the "wrong" ones (Bystander Dominates Initial Dominant and Initial Subordinates Dominates Bystander) were being avoided. Several other researchers and I have gone on to investigate the application of the jigsaw puzzle approach in larger groups and in other species. We have found that the two sequences guaranteeing transitivity, Double Dominance and Double Subordinance, occur in a broad range of species including chickens, fish, sparrows, and rhesus monkeys (Chase 1982, Mendoza and Barchas 1983, Chase and Rohwer 1987, Chase and Beacham 1993). Other researchers and I have also investigated interactional sequences involving just single attacks instead of dominance relationships, and here again we have found the same behaviors among diverse species (Chase 1985, Barchas and Mendoza 1984, Nelissen 1985). In spite of their great differences in phylogeny, ecology, and other aspects of behavior, all these species use the same micro-level forms of interaction in establishing their hierarchies.

Future Models

In spite of the apparent success of the jigsaw puzzle approach in showing how small-scale interactions can generate more global hierarchy structures, I think that this idea has certain limitations and that more insightful models can be developed. This is a future line of research for me. Although the jigsaw puzzle model represents a new view of dominance hierarchy formation, it is still subtly influenced by the prior attribute approach. The jigsaw puzzle approach attempts to explain a static hierarchy structure by small-scale interaction processes, and a static hierarchy structure is a conception rooted in the more traditional approach. The raw data that researchers gather in examining hierarchies is ongoing streams of aggressive interactions among group members that continue, of course, even after the researchers have abstracted this data to say that relationships have become stable and various ranks achieved. I think that the next generation of models should concentrate on these ongoing streams of behavior. Models of the sort developed by Hogeweg and Hesper (Hogeweg 1989) might be particularly appropriate. In these models the outcome of small-scale interactions between individuals would be generated by rules involving both prior attributes and the results of immediately prior interactions since research demonstrates that both winning and losing earlier contests influences the results of later contests. These interactions would take place as animals moved about a prescribed physical space and would follow "local" timing according to their own movements and previous interactions rather than a more global or fixed schedule.

THE DISTRIBUTION OF MATERIAL RESOURCES

Many kinds of processes for the distribution of material resources in humans and animals are, I think, self-organizing phenomena, and I'll now discuss one example on which I have worked, that of vacancy chains. Like the man who finally realized that he'd been writing prose, many of us have been involved in these chains without perhaps knowing it. In a vacancy chain, an initially occurring, vacant resource unit, one without an incumbent, is taken by a first individual who leaves his or her old resource unit behind, the first individual's old unit is later taken by a second individual who leaves his or her unit behind in turn, and so on. A familiar example is provided by hirings in a corporation: the president of the company dies or retires, her position is taken by a vice-president, his old position by the chief of sales, and so on as the chain proceeds down the corporate ladder and finally ends when a new recruit from outside the company is hired to fill the last vacant position. The vacancy, initially appearing in the president's position, initiates a chain reaction allowing several people to advance to new and presumably better paying positions, as it travels down the corporate hierarchy. Here, unlike many other types of resource distribution, several individuals advance together, and the success of one individual is contingent upon the earlier successes of others.

Researchers have demonstrated that a variety of important human resources are distributed through vacancy chain processes: houses and apartments (Lansing et al. 1969, Sands and Bower 1976, Marullo 1985), automobiles (Smith 1941), and jobs in bureaucratic organizations including those for clergy (White 1970), state police officers (Stewman 1975), and athletic coaches (Smith and Abbott 1983). Recently, my colleagues and I made the first discovery of vacancy chains in a non-human species (Chase and DeWitt 1988, Chase et al. 1988). We found that the hermit crab *Pagurus longicarpus*, common to the eastern coast of the United States, gets the snail shells in which it lives through this process. Unlike other crabs, hermit crabs are not completely covered by a hard exoskeleton and as a consequence, for protection against predators and physiological stresses, they live in and continually carry around empty snail shells as portable shelters. Because hermit crabs grow larger throughout their lives, they periodically need bigger shells, and having a shell well-matched to its body size provides better protection against predators and insures maximal somatic growth (Chase et al. 1988).

A vacancy chain begins when a resource unit new to a population is introduced--e.g., a new house or car is built, a new job created, or a snail is killed by a predator or disease leaving its shell intact--or when an already-occupied resource unit is vacated by an individual leaving the system of concern: an employee dies or retires, a home owner goes to a nursing facility, or a hermit crab dies without its shell being crushed. Chains eventually end, when the last, vacant unit is taken or destroyed and this can happen in a number of ways. Perhaps most common is for a new recruit, an individual without a unit, to move into the system, e.g., a person buys his or her first house or car, or a very young hermit crab takes its first shell. Chains can also end when the last unit is abandoned, merged with an existing unit, or abolished, e.g., when the last shell in a chain is of such poor quality that no crab takes it before it is swept away by the tide, the duties of the last job are given to someone already in a company, or the last house is burned or demolished.

Researchers usually trace human vacancy chains through a series of linked interviews with former and later holders of resource units (e.g., Lansing, et al 1969) or thorough examination of organizational records (e.g., White 1970). In hermit crabs we observed them directly as they occurred at a local beach: we dropped an empty snail shell into a tidal pool, and watched the ensuing series of events for 45 minutes (Chase et al. 1988).

Comparison of Patterns of Social Organization in Vacancy Chain Systems

When I was discussing dominance hierarchies I mentioned that the question of concern was: How is it that strongly linear hierarchies are so often found in nature? This was a question about global structures, and in my answer I suggested that they were generated by similar micro interaction processes occurring in many species. Here the question is the other way around: Does the fact that many groups get resources through the micro process of vacancy chains imply that they all have similar, more global forms of social organization? My hypothesis is that they do, but more empirical observation and modeling need to be done in order to support this hypothesis. I'll sketch out some of the information we presently have about patterns of social organization in different vacancy chain systems, and some of my speculations about future comparisons.

In order to visualize a vacancy chain system, it's helpful to think about the set of resource units occupied by incumbents in a particular system of concern. In most cases this probably looks like a typical pyramid structure for a human corporation: a relatively small proportion of units of the largest size or highest status, a larger proportion of units of intermediate size or status, and a yet larger proportion of units of the smallest size or lowest status. As vacant units new to the system enter it, or as incumbents already in the system leave it, vacating their old units, vacancy chains begin and generally work downward through the resource pyramid. The number of vacancy chains and their entry point in a pyramid, caused by these new units and vacating incumbents, dictate the patterns by which individuals move through their systems. More chains starting at higher levels provide more mobility opportunities and an increased speed of movement for individuals throughout the system. However, if chains mostly begin at lower levels, only those at yet lower levels will experience much mobility and those at higher levels will languish in their present positions.

Average Vacancy Chain Length

The length of a vacancy chain is defined as the number of moves that a vacancy makes starting with the move from the initial, vacant resource unit and ending with its final move outside the system that ends the chain. White (1970) called this the multiplier effect, borrowing a term from input-output economics (one vacancy has multiple moves and consequently provides multiple mobility opportunities). I have found that multiplier effects are remarkably similar across those systems for which we have good data on complete chains. For chains in systems as ostensibly different as those for people getting bureaucratic jobs or buying houses or cars and for hermit crabs obtaining snail shells the average length is about 3.0, and for chains begun by elite units--ones of large size or status--average length varies from a little less than 4.0 to nearly 5.0 (Chase 1991). This comparability in vacancy chain lengths suggest some overall similarity in the structure of resource pyramids (their numbers of levels and ratios of incumbents at various levels), rates and levels at which new units enter the pyramids or incumbents vacate, and demography of the participants and life spans of their resource units.

Short-Term Mobility Patterns

Researchers investigating vacancy chain systems often use transition probability matrices to show the probabilities that a vacancy in one size of resource unit has of moving to units of other sizes or out of the system (terminating a chain). These matrices traditionally show movements of vacancies rather than individuals since vacancies are considered primary in the systems: a vacancy must exist first before an individual can move. However, these matrices give the movement of individuals indirectly since every time a vacancy moves from a unit in status X to a unit in status Y, an individual makes the opposite move from Y to X. So these matrices can be used to give a picture of short-term mobility patterns--from one status to another--for individuals in vacancy chain systems.

Table 2 shows the transition probability matrices for three different vacancy chain systems: Methodist clergy in the early part of this century, people getting new houses recently, and hermit crabs in our study. I find the short-term mobility patterns indicated by all these matrices and other matrices I have reviewed to be similar: vacancies usually move laterally to other resource units in the same status or downward one or two jumps in status, they rarely move upward to higher ranking classes, and they are most likely to leave the system from lower-ranking statuses. In other words, individuals, in all these systems, are usually mobile in small to moderate jumps of resource unit size, or laterally mobile to new units within the same class as their old ones, and they rarely experience downward mobility to smaller units.

I suggest that the similarity among short-term mobility patterns arises because of analogous constraints in all vacancy chain systems. In all these systems individuals are constrained in their movements by the previous movements of other individuals and by what might be considered broadly as their personal "worth". For example, crabs can't move upward too many jumps in shell size because they probably can't bear a greatly increased cost of shell transportation, and car and house buyers similarly usually don't have the financial means to make large jumps in resource unit cost.

Other Patterns

I don't have the space to discuss it here, but I also suggest that several other global patterns of social organization are similar across all vacancy chain systems--whether human or animal. I explore these comparisons further in a book I'll soon be completing (Chase 1994). These other patterns include career trajectories, aggregate costs and benefits for individuals moving through vacancy chains, and aggregate costs and benefits for individuals and institutions associated with those individuals moving through chains. One example of associated individuals is the epibiont community of plants and animals residing on the shells occupied by hermit crabs. Elsewhere I have suggested that their evolution of competitive tactics and life histories has been strongly influenced by the typical dynamics of hermit crab vacancy chain systems (Chase and DeWitt 1988, Chase 1994).

Abstract Qualities of Resource Units

I suggest that many of the resources used by humans and animals can be divided into a relatively small number of types depending upon their abstract qualities, that resources with the same abstract qualities are distributed through the same small-scale processes, and that similar small-scale processes produce analogous global patterns of social organization in otherwise quite different groups. I discuss the abstract qualities needed for distribution through vacancy chains in more detail elsewhere, but, some of the qualities needed are, for example, that resource units be reusable and occupied by only one individual or group at a time, that users must need or want new units periodically, and that the number of vacant units available at any one time must be small compared to the number of individuals ready to move (Chase 1991). Based upon their abstract qualities, a variety of other human and non-human resources probably move through vacancy chains including major consumer goods like private airplanes and boats, expensive pieces of industrial equipment, rock shelters for lobsters, and holes in coral reefs for small fish such as blennies (Chase 1991). Elsewhere I also describe some of the other types of abstractly defined resources and the small-scale processes used in their distribution (Chase 1994).

Future Models

Much of the present modeling of vacancy chain systems uses stochastic techniques, e.g., Markov chain models, to predict things like vacancy chain length or flows of individuals among various classes of resource units (Weissburg et al. 1991, Chase 1991). These models become unwieldy, if not intractable, when asked to give predictions about how vacancy chain systems develop over time, e.g., about the career trajectories of individuals. So, here again, as in the case of the development of dominance hierarchies, I think that models of the sort that people at this conference are developing would be more profitably employed. These models would, it seems to me, generate vacancy chains through simple rules concerning the taking of new resource units (e.g., units have to be vacant and sufficiently better than an individual's present one but not too much bigger) and assumptions about individual's probabilities of encountering vacant units. And hopefully, the specification of the local behaviors of individuals would generate the larger-scale patterns of social organization like vacancy chain length, short-term mobility, and career trajectories that I suggest are comparable across many different vacancy chain systems.

REFERENCES

Barchas, P. R. and Mendoza, S. D. 1984. Emergent hierarchical relationships in rhesus macaques: an application of Chase's model. In: Social Hierarchies: Essays Toward a Sociophysiological Perspective. Barchas, P.R. (ed.), pp.23-44. Westport, Connecticut: Greenwood Press.

Chase, I.D. 1974. Models of hierarchy formation in animal societies. *Behav. Sci.* 19:374-382.

Chase, I.D. 1982. Dynamics of hierarchy formation: the sequential development of dominance relationships. *Behaviour* 80:218-240.

Chase, I. D. 1985. The sequential analysis of aggressive acts during hierarchy formation: an application of the 'jigsaw puzzle' approach. *Anim. Behav.* 33, 86- 100.

Chase, I.D. 1986. Explanations of hierarchy structure. *Anim. Behav.* 34:1265- 67.

Chase, I.D. 1991. Vacancy chains. *Ann. Rev. Sociol.*, 17, 133-54.

Chase, I.D. 1994. Generating societies: Social organization in humans, animals, and machines. Cambridge, Mass: Harvard University Press, forthcoming.

Chase, I.D. and Rohwer, S. 1987. Two methods for quantifying the development of dominance hierarchies in large groups with applications to Harris' sparrows. *Anim. Behav.*, 35, 1113-1128.

Chase, I.D. and DeWitt, T.H. 1988. Vacancy chains: A process of mobility to new resources in humans and other animals. *Soc. Sci. Info.* 27:81-96.

Chase, I.D., Weissburg, M., DeWitt, T.H. 1988. The vacancy chain process: A new mechanism of resource allocation in animals with application to hermit crabs. *Anim. Behav.* 36:1265-74.

Chase, I.D. and Beacham, J.L. 1993. Hierarchy formation in two species of fish. Unpublished ms., in preparation.

Hogeweg, P. 1989. Mirror beyond mirror: puddles of life. In: Artificial Life. Langton, C.G. (ed.), Redwood City, CA: Addison Wesley

Landau, H.G. 1951. On dominance relations and the structure of animal societies: I. Effect of inherent characteristics. *Bull. Math. Biophys.* 13:1- 19.

Lansing, J.B., Clifton, C.W., Morgan, J.N. 1969. New Homes and Poor People. Ann Arbor, Michigan: Mich. Inst. Soc. Res.

Marullo, S. 1985. Housing opportunities and vacancy chains. *Urban Affairs Q.* 20:364-88.

Mendoza, S.D. and Barchas, P.R. 1983. Behavioural processes leading to linear status hierarchies following group formation in rhesus macaques. *J. Hum. Evol.* 12:185-192.

Nelissen, M. H. J. 1985. Structure of the dominance hierarchy and dominance determining "group factors" in Melanchromis auratus (Pisces, Cichlidae). *Behaviour* 94:85-107.

Sands, G. and Bower, L.L. 1976. Housing Turnover and Housing Policy: Case Studies of Vacancy Chains in New York State. New York: Praeger.

Sapolsky, R. and Ray, J.C. 1989. Styles of dominance and their endocrine correlates among wild olive baboons (Papio anubis). *Am. J. Primat.* 18-1-13. Savin-Williams, R.C. 1977. Dominance in a human adolescent group. *Anim. Behav.* 25:400-406.

Smith, T.H. 1941. The Marketing of Used Automobiles. Columbus, OH: Ohio State Univ. Bur. Bus. Res.

Smith, D.R. and Abbott, A. 1983. A labor market perspective on the mobility of college football coaches. *Social Forces* 61:1147-67.

Stewman, S. 1975. An application of job vacancy chain model to a civil service internal labor market. *J. Math. Sociol.* 4:37-59.

de Waal, F.B.M. 1982. Chimpanzee Politics. New York: Harper and Row.

Weissburg, M., Roseman, L., Chase, I.D. 1991. Chains of opportunity: a Markov model for acquisition of reusable resources. *Evol. Ecol.* 5, 105-117.

White, H.C. 1970. Chains of Opportunity: System Models of Mobility in Organizations. Cambridge, Mass: Harvard University Press.

Wilson, E.O. 1975. Sociobiology. Cambridge, Massachusetts: Belknap Press of Harvard University.

Table 1A. Linear dominance hierarchy for a group of five individuals. A 1 in a cell indicates that the animal labeled by the row dominates the animal labeled by the column.

Dominant animal	Dominated animal					Number dominated
	A	B	C	D	E	
A	-	1	1	1	1	4
B	0	-	1	1	1	3
C	0	0	-	1	1	2
D	0	0	0	-	1	1
E	0	0	0	0	-	0

Table 1B. Dominance hierarchy with a structure as non-linear as possible for a group of five individuals. A 1 in a cell indicates that the animal labeled by the row dominates the animal labeled by the column.

Dominant animal	Dominated animal					Number dominated
	A	B	C	D	E	
A	-	1	1	0	0	2
B	0	-	1	1	0	2
C	0	0	-	1	1	2
D	1	0	0	-	1	2
E	1	1	0	0	-	2

Table 2A **Transition probability matrix for vacancy moves in snail shells taken by hermit crabs from Weissburg et al (1991). State 1 shells are the largest, and state 5 shells the smallest. The "naked" destination state indicates the termination of a chain by a crab without a shell, and the abandoned state indicates termination by a shell not taken during the observation period.**

	Destination state						
Origin state	1	2	3	4	5	naked	abandoned
1	.10	.33	.43	.10	.00	.00	.05
2	.00	.07	.45	.40	.02	.00	.05
3	.00	.03	.29	.16	.14	.06	.33
4	.00	.00	.11	.28	.28	.07	.26
5	.00	.00	.00	.08	.37	.03	.51

Table 2B **Transition probability matrix for vacancy moves in the Methodist church 1922-1937 from White (1970:125)**[a]

	Destination state			
Origin state	Big	Medium	Small	Outside[b]
Big	.46	.33	.05	.16
Medium	.11	.41	.12	.36
Small	.02	.16	.24	.58

[a] Reproduced with permission from Harvard University Press

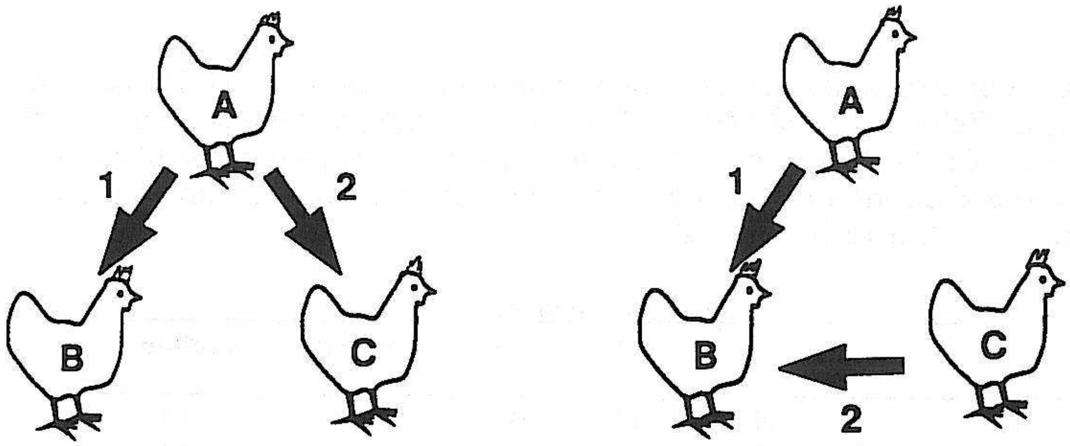
[b] Indicates probability of absorption by all ways of terminating chains combined

Table 2C Transition probability matrix for vacancy moves in owned housing units, 1976-1977, from Marullo (1985:371)[a]

	Destination state			
Origin state	High	Medium	Low	Outside[b]
High ($50,000 plus)	.45	.38	.09	.08
Medium ($30,000-49,999)	.08	.39	.35	.19
Low ($0-29,999)	.01	.09	.39	.52

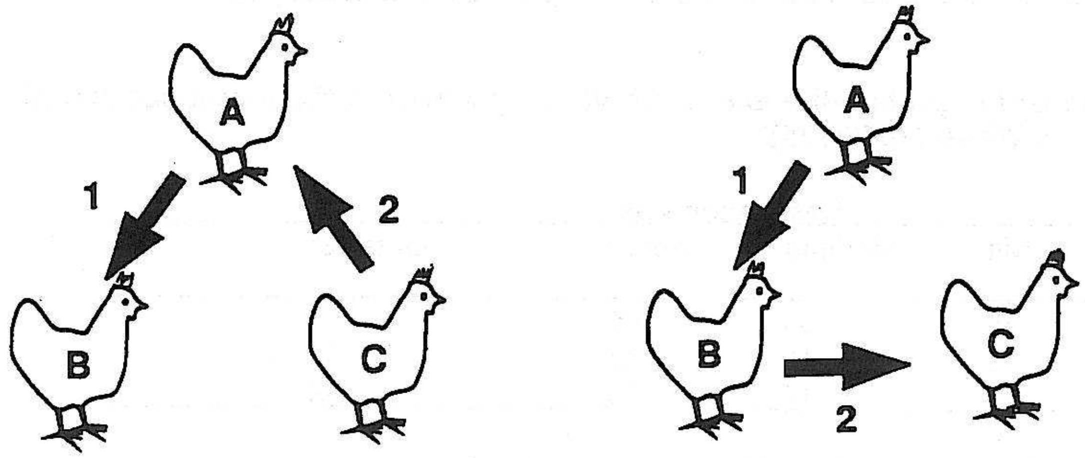
[a] *Urban Affairs Quarterly*, volume 20, issue number 3, page 371, copyright 1985 by Sage Publications, Inc. Reprinted by permission of Sage Publications, Inc.

[b] Indicates probability of absorption by all ways of terminating chains combined.



Double Dominance

Double Subordinance



Bystander Dominates Initial Dominant

Initial Subordinant Dominates Bystander

Figure 1. The four possible sequences for the first two dominance relationships in a triad.