

COMPLEX MOTIVES IN AGENT SIMULATION:
PROXIMITY ATTRACTORS AND THEIR DESIGN

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Within the growing agent simulation community, there are disagreements as to whether agents necessarily must remain simple, so that the dynamics of agent simulation can be fully comprehended, or whether they should be complex in order to represent the subtlety and dynamism of social processes. It is likely that only years of experimentation and analysis will fully resolve the issue, however, at least part of the answer may arise from the art and science of design. The approach of this paper is to: 1) reinforce the necessity of developing models that reflect the complexity of human intentionality, and 2) introduce a dynamic mechanism, an artificial attractor, that integrates multiple domains and constraints. The promise of this approach is its ability to represent complex agent motives using simple mechanisms.

KEYWORDS: agent simulation, design, attractor, constraint, artificial social process, motivation, utility

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The computational modeling of social processes has grown dramatically in recent years. Increasingly, it is regarded as a third leg of social science, supplementing theory and empirical research.

Agent-based simulation, for example, is increasingly viewed as an alternate method of investigating macro structures and processes. It allows both an experimental approach to complex domains and a means of exploring theoretical generalizations. Agent simulation appears especially appropriate for addressing long-duration or rare events, and may facilitate the study of complex, multilayered social processes in new and promising ways.

To realize this potential, the modeling of social processes must explicitly address design issues. The present paper specifically emphasizes the importance of representing the complex, interacting motives of social agents. An attractor model is proposed as a generic mechanism for simulating complex motives of porous social agents.¹

I. SOCIAL SCIENCES OF THE ARTIFICIAL?

Herbert Simon describes how the natural sciences "almost drove the sciences of the artificial from professional school curricula" (1998, p. 111). Their deprecation reflects the fact that design was not considered to be a scientific activity. But a consequence of this

¹The concept of porous agents, as used in the present discussion, not only implies a hierarchy of interpenetrating levels (such as individual, group, organization, institution, society, civilization, cf., Fararo & Doreian 1984), but at the same time recognizes that agents at these multiple levels share, and co-evolve, common goals and motives. These shared intentional states are dynamic, cascading and

perspective meant that the science of design was unlikely to be taught and as such and, thus, rigorously extended.

Notwithstanding various contributions that social modeling has made since World War II, such as game theory in international relations and economics (Schelling 1960; 1978; Cooper 1999) and the SEIR model in epidemiology (Bartlett 1990), it seems fair to say that the *social sciences of the artificial* are underdeveloped. One reason is that, prior to the exponential increase in computational capabilities, it was unclear what types of artifact would best contribute to the understanding of social dynamics.

Now, however, with dramatic capabilities available, or becoming feasible, the science of design will reward the professional attention of social scientists. One illustration of this *desideratum* is found in the debate on whether it is desirable to restrict agent simulation models to employ only simple agents.

Considering the complexity of historical processes, it seems unlikely that models composed of simple agents can address issues of the greatest interest and urgency. The causes and prevention of war and genocide, the social prerequisites of peace, the sources of economic prosperity, the consequences of various social policies, these and other issues, for example, may be beyond the reach of simple agent models. The requirements and possible architectures of complex social agents are addressed by Carley and Newell (1994).

At the same time, other scholars have argued that models based on cascading complexities seem likely to yield results that are inchoate or cacophonous. Impressive insights have been gained through research

recombining in response to changing circumstances, but they also provide an emergent source of social order.

based upon simple agents (Schelling 1978; Epstein & Axtell 1996; Axelrod 1997; Gaylord & D'Andria 1998).

This analysis focuses upon complex agent motives, and why their interactive representation is essential, exploring one mechanism by which they may be modeled. Implicit in the analysis is the potential of systems modeling as theory in untangling the logic of social complexities.

II. UTILITIES AND PREFERENCES

Neoclassical economics, (evolutionary) game theory and rational choice researchers have built effective models of economic and social behavior based upon relatively simple motivational assumptions and representations. Nonetheless, the nature of intentional models has evolved over time. The representation of intrapersonal utilities has shifted from transferable to non-transferable (Aumann 1989), and from expected to revealed (Binmore 1994, pp. 259-282).

In general, the evolution of intentional models has not addressed the dynamic competition and coordination of multiple motives found in the everyday lifeworld. The most promising approaches to this type of complexity, are found in the effort to model historical settings. Tsebelis (1990), for example, demonstrates, in a variety of settings, that seemingly irrational results are explained by models in which participants play simultaneous games. Analytic narratives, frequently represented in extended game form, model the complex and shifting motives found in diverse historical cases (Bates, *et al.* 1998).

While these efforts move in new, creative directions, their strength, grounding in the complexities of history, also limits their general applicability. A design-centered approach to agent simulation seeks to retain the traditional game theoretic emphasis on the

development of generic models while also representing intentional complexity. Like Carley & Newell's (1994, pp.229-235) cognitive-level agent, a social agent should be designed with the capability of determining new preferences.

It will be useful to examine some ambiguities on the periphery of economic applications of game theory. In recent years a series of case studies of economic innovation have suggested that market processes are characterized by a greater amount of idiosyncrasy and sub-optimal performance than neoclassical theory would imply. The issue is framed by a series of innovations in which an evidently inferior technology prevails against a superior competitor, such as QWERTY over Dworak keyboards (David 1985), VHS over Betamax videotape recorders (Arthur 1988), AC over DC power distribution (David 1990; 1992).²

While such cases are sometimes viewed as departures from a utility function based on profitability, technical innovation is a distinct objective that interacts with profitability in potentially complex ways. In actuality there are a number of types of innovation, with diverse potential, risks and impacts on the bottom line. An attractor model provides one generic way to model these complexities.³

A second example is provided by the neoclassical view of a state or ruler. For North, a state with a utility maximizing ruler has three characteristics (1981, p.23): 1) a set of services (e.g., protection and justice) that are traded for revenue, 2) a classification of

² Commonly cited sources of path dependency in economic innovation are summarized as 1) sunk costs, 2) winner-take-all competition, 3) political obstacles and 4) the mutual unintelligibility of technical paradigms (Sabel 1995).

³ Another utility frequently blurred with profitability is economic growth. Specifically, the latter is seen as a direct outgrowth of the freedom to pursue profit that arises from a market-based economic

constituents, the distinctive property rights of which are assigned so as to maximize revenue, and 3) the opportunity costs inherent in the prospect of constituent groups providing support for an alternate ruler, whether internal or external. Each characteristic serves to constrain the feasible set of policies available to the ruler.

Margaret Levi (1988) recognizes the constraint implicit in North's third characteristic as a form of bargaining power available to the ruler, and also observes other factors that influence ruler objectives and strategies. The cost of creating, monitoring, measuring and enforcing compliance (transaction costs), and the relative value (and probability) of present versus future utilities (discount rate) form additional constraints on a ruler's feasible set of actions.

Nye (1997) adds productivity as an important factor that includes both the productivity of available technology, especially military capabilities, and economic productivity. In many eras, the latter includes the relative productivity of free versus bound labor.

The actual and potential role of force is present in many of these considerations. Levi (1988, p. 11) observes, . . . when the state itself is the enemy from whom people are buying protection, the state resembles a protection racket rather than an institution that engages in productive activity." However, diverse types of state may nonetheless be integrated into the same theoretical framework. North observes that contractual and predatory views of the state are reconciled by the concept of "violence potential". The former assumes a wide distribution of violence potential, while the latter posits a distribution that is sharply polarized.

system. However, the two utilities clearly reside at different levels of analysis, a topic addressed in a subsequent section of the paper.

Nor do neoclassical considerations exhaust the possible motive structures of the state. Classical social theorists such as Pareto, Durkheim, Weber and Mosca have models of state dynamics into which the neoclassical models may be incorporated. Attractor systems can also provide a flexible mechanism for such integration (Sallach 2000). Before this representation can be assessed, however, several more forms of intentional complexity must be considered.

III. BOUNDED RATIONALITY AND EMOTIONAL HEURISTICS

Historically, in game theory and in neoclassical economics, players have full knowledge of the rules of the game, and the strategies and available payoffs of competitors. In a step toward verisimilitude, Simon (1985) introduced the concept of bounded rationality. However, the utility of economic models that incorporate bounded rationality has yet to be established. As Rubinstein (1998, p. 3) recently observed, “. . . many of us feel that attempts to model bounded rationality have yet to find the right track.” While an in-depth model of bounded rationality is beyond the scope of the present discussion, two points seem worth considering. First, a more adequate representation of the role of memory may well provide a clue to the effective representation of bounded rationality. Second, an artificial attractor is sufficiently flexible to incorporate that representation.

For Carley and Newell (1994), the definition of social agents is best conceptualized as a *contraction* of the knowledge and capabilities available to an omnipotent agent.⁴ No longer omniscient with respect to the task environment, the boundedly rational agent knows less and has

more limited processing capabilities. The authors describe emotions as unable to contribute to human reasoning abilities; rather, they can only degrade or limit those capabilities (p. 225).

However, agents whose rationality is bounded are likely to have, not only limited processing capabilities, but also positive compensations that are likely to accompany those limitations. Indeed, it may be hypothesized that the effective integration of emotion with memory and strategic inference plays an important role in the activity of such a compensatory effect.

One basis for this hypothesis is the study of mass belief systems. Brady and Sniderman (1985) observe that, notwithstanding their possession of a low level of abstraction and little specific information, members of mass publics can accurately estimate the political beliefs of strategic groups, as well as the policy positions group members are likely to take on salient issues. The seeming mystery appears to be based upon the use of an affectivity heuristic in which respondents combine their beliefs with an emotional response to the target group. The response may arise from personal experience, a shared generalization, or some other social basis. The affectivity heuristic thus serves as an intellectual shortcut. Similarly, Dawson (1994) documents how an overdetermination of life chances leads to the development of a black utility heuristic, in which the perception of group interest become a proxy for the interests of its members.

There is nothing to suggest that the cognitive process on which these effects are based form a special-purpose heuristic only applicable to public belief. Rather, there may be a generic effect

⁴ With a correlative symmetry, Nilsson (1998) provides an innovative artificial intelligence text that proceeds in the opposite order: from

that helps compensate for human limitations in knowledge and reasoning capacity. On this basis, it has been proposed that an affectivity calculus may provide a useful component for computational models of social mind (Sallach 1988, pp. 712-713). If the heuristic is conceived as identification with, or alienation from, particular political groups, this defines a prototypical form of an attractor system.

An affectivity heuristic might serve other representational purpose as well. Harsanyi (1993), for example, distinguishes between outcome and process utilities, in which the former constitute the results typically studied in game theory, while the latter involves attachment to the process of participating in a game. Although Harsanyi applies the distinction only to the activity of gambling, where one may be motivated either by the potential payoffs or by the risk and excitement of gambling as an activity, the insight seems to have broader applicability. There are numerous types of games, and most appear to have some potential to elicit participant attachment to their process of activity.

Process utilities are not new to social theory. Robert Merton (1957) identifies a "ritualist" as a social type in whom the means of achieving an end is elevated into the effective focus of activity. Thus, for Merton's ritualist, the means becomes the end; the process of participation becomes a goal in its own right.

Social processes with which a social agent may identify are numerous, including a game, a role, a tradition, a technique or a lifestyle. However, whether the outcome or the process motivates the player's choices, the dynamic can be effectively represented by an attractor. It is to this topic that we now turn.

simple to complex agents.

IV. BASINS OF ATTRACTION

Having framed a challenging set of issues that artificial attractors are designed to address, attention turns to the solutions that the mechanism makes available. A hyperdomain binds a set of dimensions that are interrelated by potential interaction (non-decomposability). A hyperdomain associated with an entity or an environment may contain one or more attractors that can act upon associated entities. In a spatial context, the prototypical effect of such attraction might be to change the location of the entity within the hyperdomain.

An attractor must be defined in terms of at least one dimension, and may be defined on multiple dimensions, with the caveat that each dimension be part of the same hyperdomain. Agents must be defined in terms of: 1) the hyperdomains with which they have a composition relationship, and 2) the attractors that may affect them, and 3) the hyperdomains within which those attractors are defined. The effect of a given attractor may vary by agent type.

Consider a simple spatial framework. A small set of (minimally) ordinal, and typically orthogonal, dimensions is aggregated into a hyperdomain. These dimensions afford the possibility of movement (Gibson 1986), and thus introduce a "degree" of freedom for entities associated with the hyperdomain, although that degree may be uneven or idiosyncratic.

Points of attraction (repulsion) within a hyperdomain are defined upon one or more of the participating dimensions, and may manifest

linear, cyclical, or fractal (or other nonlinear) forms of relations.⁵ These attractors may have divergent effects based upon the entity type or the value region of the dimension, or both. Attractors may be defined on multiple participating dimensions, and there may be interaction effects between (among) those dimensions.

An example is provided by WaTor, a predator-prey model used to explore load balancing issues in parallel implementations of simulations (Hanxleden & Scott 1991; 1992). A virtual ocean, modeled as a torus, is inhabited by sharks and herring. Sharks eat herring, and die if too many ticks pass without doing so. Let us also posit an implementation in which sharks also mate and reproduce.

Each fish maintains state variables indicating its AgentType, including gender. A sophisticated implementation might indicate a multiple inheritance regimen (cf., Kiczales, des Rivieres & Bobrow 1996, pp. 78-82). Each shark also maintains a state vector indicating the number of ticks since eating, the number of ticks since mating and, if female, the number of ticks since giving birth. Each shark can perceive a specified distance (e.g., a Moore region) and, is aware of the location of shark and herring neighbors thus perceived.

Three pieces of complex data are passed to the attractor, an AgentType, a StateVector and a perception of the agent's Neighbors. These data are then employed by an attractor to apply situated rules. In this example, such rules might include the number of ticks subsequent to eating and mating after which shark hunger and libido, respectively, reemerge. It also represents rule interaction, such as the possibility that extreme hunger may block the desire to mate.

⁵ For a mathematical description of attractor systems see Hurley (1982) and Alligood & Yorke (1989). For a qualitative analysis of their

Moreover, this type of effect might take place at a higher level of generality than sharks, applying to all fish, or to all animals.

Formalizing a simple attractor for this example in terms of category theory (Mac Lane 1971; Asperti & Longo 1991), could produce the following morphisms:

$$H_A \circ L_A \circ I \circ A$$

where H_A is Hunger attraction, L_A is Libido attraction, I is motive Interaction, \circ denotes the operation of composition of adjacent morphisms (or arrows), and A is the action to be taken on the next tick.

Since the specific effects of any single attractor mechanism might be produced by program code using a nested case statement, its primary advantage is not inimitability. Advantages are found in the fact that rules are not isolated from each other. Rule interaction is supported without deep procedural nesting, facilitating situated reactions (Muller 1991, pp. 25-31). In addition, the ability to support declarative rule specification allows research to focus upon models, including model revision, rather than upon implementation techniques. Finally, the attractor model provides the ability to carry these virtues over to successively more complex models.

An attractor system would not be limited to spatial domains. A hyperdomain that integrates generic dependencies might be quite useful to modelers. A representation combining requirements for food, water, shelter and reproduction, for example, could not only capture the dynamic interplay of agent needs, including the emergence of overriding priorities, it would also allow a strategy function to plan the joint satisfactions of multiple needs. Similarly, a belief attractor

application to social systems, see Sallach (2000).

combining various forms of affirmative knowledge with an affectivity heuristic might be applicable in many domains.

As cases move away from simplicity, participating dimensions may be binary (true/false; male/female), tripartite (true/false/unknown; solid/liquid/gas), nominal or fractal. The associated attractor structure would become correspondingly more complex.

Agent architectures composed of layers are consistent with prevailing standards of agent design (Muller 1996). Implementing layers as hyperdomains with embedded attractors provides equivalent clarity of design. They allow, for example, interleaving communicative and inferential functionalities between reactive and motor layers. However, this form of implementation also allows for one, or several, layers to create contextual effects that alter the attractor basin of other layers.

Consider an attractor model of social stratification. One hyperdomain might aggregate indicators of wealth, income, status and power. Agents would carry an internal state vector associated with each dimension representing their individual motivational structure. For various research purposes, an internal state may be treated as fixed (genetic), defined by early life experience (nurture) and/or dynamic (situational). In this case, the interaction of multiple attractors would define agent efforts.

Complex interactions, such as an agent preferring wealth, except when the mode of generating it reduces her status in a particular community, can be represented and implemented as a straight-forward extension of the attractor mechanisms indicated in the simple WaTor simulation described above. The preference for avoiding forms of wealth generation that would reduce one's status within a designated

community, for example, is an interaction effect that is structurally similar to the effect of starvation upon sexual desire.

As a further illustration, consider the motivation structure of the previously described neoclassical ruler. A ruler would carry a dynamic state vector (or more complex data structure) representing the set of Services available to be traded for revenue. (To the extent that autonomous agents deliver such services, greater complexity is introduced.) A ruler would also maintain a classification of Constituent groups, as well as their associated property rights, an estimate of their opportunity costs, and a history of actions relevant to the regime. Since constituents would be classified on many dimensions, the Constituent data structure would be dynamic, and the effects of ruler's classification algorithm would be a topic of research.

Threatening actions by a previously unidentified subgroup might cause a total reorganization of the ruler's estimate of Constituent opportunity costs and/or affectivity heuristic and, thus, in her Constituent classification. Simulated shifts in transaction costs, military effectiveness and/or labor productivity would be likely to interact so as to restructure the representation of dependency and belief spaces, resulting in nonlinear changes in strategy or behavior.

Implementations of an attractor model can be structured in a variety of ways, and such differences constitute a natural subject of investigation. The general approach, however, supports declarative conceptualization, representation of high dimensional problem spaces, and a design strategy based upon the decomposition of complexity. Accordingly, attractor models may help resolve representational tensions between the simple and the complex.

V. CONCLUSION

The immediate focus of the present paper has been upon complex agent motives, why their representation is advantageous, and how an artificial attractor model can combine model complexity with cogency of interpretation. As a design concept, the attractor system provides a potentially versatile building block, with the ability to represent contingencies, historical variations and shifting context. Evolving basins of attraction not only can represent dynamic processes, their definition provides an extensible approach that facilitates the move toward ever more generic levels of abstraction.

The result combines complex representation with a potentially simple mechanism. The simplicity is only potential. However, if attractor models are not guaranteed to be simple, they do appear to provide a data structure that, as growing insight permits, is capable of recursive simplification. There is a tension between simple clarity and the need to model complex processes, and it is in the resolution of this tension that artificial attractor systems may contribute most effectively.

Finally, this discussion concludes as it began by asserting that, in the twenty-first century, and especially in the study of artificial social processes, the science of design will be essential to the advancement of social science.

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