Multi-Scale Resolution of Human Social Systems: A Synergistic Paradigm for Simulating Minds and Society

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1 Introduction

Recently, we put forth an initial sketch of what we call the *Resolution Thesis*[22]. The thesis holds that 1) models of cognition will be improved given constraints from the structure and dynamics of the social systems in which they are embedded, and 2) the resolution of social simulations of agents will be improved given constraints from cognitive first principles[1]. This thesis reflects a variety of motivations, the most obvious being the observation that there is little overlap between the cognitive sciences and the generative social science approach, both of which rely heavily on computer simulation to understand aspects of human systems, albeit at different levels of scale. The former focuses almost exclusively on the mind as a scientific object of study for which the lion's share of simulation efforts reflect methods that represent a generalizable conception of the mind and the latter emphasizes multiple aspects of social systems, the mind being only one of these aspects. Thus we have a trade-off: the details of one level of scale result in the potential oversimplification at the other level of scale. We posit, by the resolution thesis, that an interdependence between cognitive science and generative social science could be leveraged for the purposes of improving our understanding of important phenomena studied by both.

The Resolution Thesis can be understood from multiple perspectives. From the generative social science perspective, the Resolution Thesis means that the representations of agents in social simulations should be informed closely by cognitive science and relevant neurophysiological considerations. This runs somewhat counter to the principled adherence to simplification of the internal processing of simulated agents found in this literature, a simplification that served to show that complex social dynamics can be driven by simple behavioral rules of agents.

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[1]Cognition considered as theoretical models of human perception, thought and action that includes, broadly, explanations of emotion, motivation, and affect in addition to more tradtional domains of cognitive psychology and cognitive science; one could arguably use the term *psychological first principles* as equivalent

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More recently, there have been efforts in the generative social sciences that acknowledged that closer ties to the psychological and neurophysiological underpinnings of human behavior may yield benefit in terms of modeling social phenomena. Epstein's neurocognitive approach is a notable effort in this vein[8]; there are other related approaches (e.g. [6, 27, 15]). However, there still remains a large gap between these recent efforts and the implementation of models from cognitive science and psychology, not necessarily in principle, but in practice. It is worth noting that there are some threads in cognitive science that approach social modeling from the perspective of cognitive science. In particular, Ron Sun's push for multi-agent systems based on cognitive first principles[30]; other work in this vein exists[4, 14, 13, 24, 25, 26, 10, 9, 12, 33, 34] **flag: check these refs**. The relatively new field of computational social psychology is clearly relevant[31] as well as the computational organizational theory approach[23].

From the view of cognitive science, the *Resolution Thesis* means that patterns of organization (e.g., information flow on the internet, clustering of behaviors in a community) at the social and organizational level should inform cognitive models when appropriate[2]. In other words, these patterns should be included as convergent evidence for a theory or model of cognition. At first consideration this notion may seem hard to fathom because the implications of cognition for the structure and dynamics of social systems are little understood from the cognitive science perspective[3]. Without an explanatory scheme that links facets of the cognitive model to aspects of social organization, how do we interpret the convergent evidence from social systems? The work mentioned above w.r.t. the cognitive first principles within the generative social science approach [30, 4, 14, 13, 24, 25, 26, 10, 9, 12, 33, 34] begins to put in place a better understanding of the implications of cognition on social systems, but does not generally consider simulation output as part of the convergent evidence for theory at the cognitive level of scale. This is a subtle but critical point, so let us put it differently. From the congitive perspective, simulation of social systems with agents grouded deeply in cognitive first principles does not imply the Resolution Thesis unless the simulation results are used to judge the quality of the cognitive first principles that ground the agents.

A third and more general view is that the Resolution Thesis is about human social systems. An understanding of any of these levels of scale is dependent, to some degree, on an understanding of the others. In effect, the notion of convergent evidence as originating, in part, from other levels of scale, applies to all levels of scale. The implication is that we should leverage information across scale in an iterative and synergistic way.

The Resolution Thesis, despite sounding somewhat reasonable at face value, is opposed, to some degree, from both the cognitive science and generative social science perspectives. Simon's notion of nearly decomposable systems– that the temporal dynamics of adjacent levels of scale, in most systems, are

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[2]The appropriateness may not be easily determined; for social cognition it may be obvious, but for other domains, e.g., visual categorization, it is not obvious but also highly possible

[3]Anderson's Relevance Thesis[1], a rare exception, reasons about how cognition may have implications for social organization.

little correlated–suggests that we can understand well the dynamics at each level of scale independently of the others[29](see [2], for similar arguments in physical systems). The KISS principle (keep it simple, stupid) used heavily in the generative social sciences, is clearly akin to Simon's notion, and is bolstered by its early wins in understanding the behavior of social systems using simple, non-cognitive agents[28, 3, 7]. In cognitive science, Newell, in considering the time scale of human behavior, suggested that the social band ($> 10^4$ seconds, representing social systems and organizational behavior) is characterized to be weak in strength in the sense that it may not reflect computations in a systematic purposeful way relative to lower temporal bands, e.g., cognitive and neural processes[18].

These counter arguments notwithstanding, our working assumption is that the degree to which the *Resolution Thesis* is useful is an empirical issue. The state of the art in technology and computing and the tight coupling between them and the current social mileau should afford exploration of the Resolution Thesis. To this end, we've developed the *Reciprocal Constraints Paradigm* (henceforth *RCP*), a methodological approach for exploring the *Resolution Thesis*. The value of the *RCP* does not lie in precise formal prescriptions, but in providing a scaffold for growing our understanding of social systems, and, possibly revealing something new about the interdependencies among levels of scale.

2   The Reciprocal Constraints Paradigm

Figure 1 shows the four primary components of the *RCP*: a cognitive system with potential ties to neurophysiology, a social system, and the constraints between levels of scale. We assume that social systems and cognitive systems are derived from and exhibit an abstract set of first principles & properties, called S and C, respectively (e.g., theoretial entities, experimental paradigms, patterns in empirical data in respect to the discipines that address a particular level of scale). Defining S and C will depend on the social system or cognitive system of interest. The notion of constraint simply refers to the use of information from S & C to inform one another in a principled way. An upward-constraint refers to information from the cognitive level as informing the social level of scale; downward-constraints reverse this relation.

A primary example of entities from the cognitive level of scale are the set of allowable algorithms A such that $a \in C$. That is, A defines algorithms that are grounded in and thus recognized by work in cognitive science and psychology. Primary examples at the social level of scale are the social structures, channels of information, and dynamic aggregate signals of behavior (e.g., a distribution of degree in a social network over time) that characterize a social system, a large fraction of which are formalized using graph theory/network science. It is important to emphasize that within S are notions regarding the behavior of agents, not only social structures.

A central assumption in the *RCP* is that cognitive systems and definitions of agent behaviors in social systems are meant to represent human information-
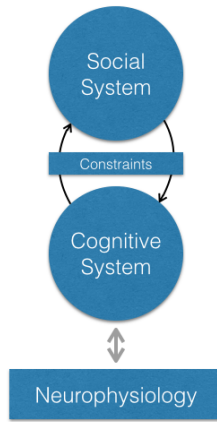
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Figure 1: The four components of the RCP are a cognitive system with potential ties to neurophysiology, a social system, and the constraints on each one from the other. In the RCP social systems and cognitive systems are assumed to be derived from and exhibit an abstract set of first principles & properties, called S and C, respectively. Also captured here is the potential for integrating neurophysiolgical considerations into the cognitive system when appropriate; these may prove as essential for some social systems (the grey two-headed arrow indicates this potential). The notion of constraint refers to the use of information from S & C to inform one another in a principled way.

processing capacities that can be described as mathematical functions[32] [4]. Thus, at the cognitive level of scale C we can define a cognitive system as $\psi_{ct} : I_{ct} \rightarrow \psi_{ct}(i)$ where I_{ct} is the set of allowable inputs and $\psi_{ct}(i)$ is the output; in S we have a corresponding agent definition as $\phi_{at} : I_{at} \rightarrow \phi_{at}(i)$ where I_{at} is the set of allowable inputs and $\phi_{at}(i)$ is the output for an agent[5].

2.1 Applying the Reciprocal Constraints Paradigm

In practice there are multiple approaches available for application of the RCP, but what unites them is the study of a human social phenomena, either defined at one level of scale or at multiple levels of scale. Naturally, the first step is to identify a social phenomena of interest, a task that is inherently tied to one's perspective. If the perspective is largely cognitive, then the focus would most likely be on understanding the psychological processes, representations, etc. in relation to social systems, but informed in some way by entities at the social level of scale S. Another perspective, at the social scale, would dictate a concern with the social structures and dynamics of the social system (multiple humans interacting) with some degree of constraint from cognitive first principles. These two perspectives are both what we call single-scale approaches to the RCP. Of course, one could take a multi-scale perspective that draws from both and likely depends on a simulation approach that captures aspects of C and S in one runnable system.

We will address the obvious issues and difficulties in applying the RCP after providing a description of some potential methods for application. The goal in this section is simply to express what it might look like to apply the RCP.

2.1.1 Single-Scale Approaches

The single-scale approach of the RCP aims to elucidate or refine a model at one level of scale by using some information from another level. The essence of this approach is captured by the following question: what are the implications of some information from another level of scale for the scale of interest.

Consider the cognitive scale. The single-scale approach amounts to mapping some properties of social systems to properties of cognitive systems for the purpose of identifying potential implications of social structure and dynamics that should be considered when evaluating a model of cognitive process or representation. For example, suppose one has in hand a theoretic model of how humans acquire attitudes from social interactions (via some learning process) that has not yet been evaluated against empirical data. From the perspective of the RCP, it would be essential to incorporate aspects of the social level of scale that have the potential to interact with aspects of the cognitive system for proper evaluation of the cognitive model of attitude acquisition. In this particular example, it seems likely that the social interactions forming the input to

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[4]This is equivalent to Marr's computational level[16].

[5]Social and cognitive systems may define parameters regarding variability among a set of agents; this is not reflected here.

acquiring attitudes are dependent upon some properties of S if S contains graph G where $V(G)$ and $E(G)$ are the agents and information channels, respectively. Assuming this is true for a moment, we would need to consider if this social structure might interact with known properties of cognitive systems (C). It turns out that it is likely–a central finding in cognitive science and psychology, is that the products of learning mechanisms are sensitive to the order in which information is presented to the system (e.g., a human's generation of a mental representation of a set of stimuli depends on the order of exposure to the stimuli[6]). This is one example of trying to understand the implications of social properties on cognitive systems; what this means precisely would depend on the social phenomena of interest (e.g., early language development may depend on a different $G \in S$ compared to racial stereotypes or large-scale population biases in attitudes).

At the social level of scale there is a similar approach–mapping the properties of cognitive systems to social systems to reveal potential implications from the former to the latter. An obvious approach is an analysis of the degree to which ϕ_{at} compares to any $\psi_{ct} \in C$ for the purpose of clarifying to what degree a social agent seems to be aligned with cognitive first principles–i.e., what are the implications of cognition for the social system. For the case in which ϕ_{at} and ψ_{ct} are formally well defined, this might be relatively straightforward[7], but this is in no way guaranteed. There will certainly be cases for which ψ_{ct} is not formally defined[8].

A likely scenario is that the closest ψ_{ct} is only defined in terms of an experimental paradigm, ill-defined (non-formal) theoretical definitions and the interpretation of data resulting from application of the experimental paradigm. So, how does one go about making the comparison when the nature of the two are vastly different? One approach for comparison for this kind of case would be to explore the behavior of ϕ_{at} by simulating an experimental paradigm that is isomorphic to that used to define ψ_{ct} (assuming ϕ_{at} is defined algorithmically). In essence, this is like running an psychological experiment on artificial agents, an approach that is akin to simulation in the psychological sciences. The output of these experiments could be compared to the patterning and dynamics of human performance in C. This is one suggestion of many potentials, but we hope it illustrates well the potential difficulties.

In summary, although the single-scale approach does not represent the full-blown resolution thesis, it might afford better resolution of a target level of scale by considering some of the implications of other levels of scale. The specific phenomena of interest will drive the precise approaches used.

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[6]We see this phenomena broadly, for example, in attitude formation[5], categorization[11], and text comprehension [17]

[7]Potential methods for such a comparison would, ideally, focus not only comparison of input/output functions but also the nature of the runnable algorithm

[8]Many theoretical entities in psychology are not formalized in precise mathematical or computational terms but in terms of experimental methods and the relative interpretation of results using statistical methods and logical reasoning

2.1.2 Multi-Scale Approaches

The multi-scale approach is simple in principle: build a simulation platform that simultaneosly captures essential aspects of both S and C (e.g., an agent-based model of cognitive agents). The upward-constraints would mean a type of substitution of ψ_{ct} for ϕ_{at} (substitution might be one approach; for others this might be more akin to a focus or commitment to ψ_{ct}). The downward-constraints, generated by some measure of how well the simulated social system matches S as defined by the phenomena of interest, would serve as a signal that would suggest modifications to S, C or both. If this scheme seems simplistic, the details of application are not.

The initial issue is, naturally, to decide where to begin? Does one start with S and import aspects of C or the reverse? One might also consider starting from scratch and bringing together properties from S and C in a new way. Let's explore these options via a concrete example which will, we hope, surface some of the key difficulties.

Imagine we're interested in the patterning of obesity by race/ethnicity, a phenomena of interest with key social and policy aspects (e.g., cultural attractors, social and shared-enviromental influence, spatial patterning co-occuring with racial segregation and residential mobility) and, in fact, a pre-existing set of social simulations from which to draw (see [19]). Assume we adopt one of the existing simulation approaches, none of which incorporate much in C. Given this case, one approach would be to substitute ψ_{ct} for ϕ_{at} while keeping the other aspects identical to the original simulation. In other words, we would be infusing cognition into the agents, so to speak.

To do this, however, because both ψ_{ct} for ϕ_{at} are input-output functions, there is a minimum requirement to find a reasonable substitution such that both I_{ct} and $\psi_{ct}(i)$ are equivalent to both I_{at} and $\phi_{at}(i)$; otherwise, the simulation will not run. This is non-trivial in the sense that there is a limited but variable set of candidate ψ_{ct} to consider, some or none of which might closely resemble ϕ_{at}. The field of obesity in the health behavior tradition has several candidates, each reasonably considered as different (e.g., $\{\psi_{ct_i}, \psi_{ct_j}, \psi_{ct_k}, ...\}$). This analysis may be difficult or may limit the degree to which aspects of ϕ_{at} can be captured by substitution.

We are now, already, at an interesting point in this hypothetical scenario because it yields potentially difficult decision points. For example, if ϕ_{at} does not match any existing ψ_{ct_i}, what is implied? Well, it depends. At first glance, it seems reasonable to assume that ϕ_{at} might be wrong in that it isn't capturing the right set of components. But, it could be equally true that the health behavior field, in respect to the processes for which the agent model was developed to study, has yet to develop interest in a match for ϕ_{at}. One could easily complicate this decision point further or add layers of complication, but we wanted to point out that it gets complicated, fast.

Let us assume that we find a suitable ψ_{ct} to substitute for ϕ_{at}. Our next task would be to consider the downward-constraints in this scenario. Imagine that along with a pre-existing social simulation from which to co-opt, come empirical

data, judged of adequate quality, that could be used to compute an objective function w.r.t. the simulations accuracy given our substitution of ψ for ϕ. This signal, then, would serve as the downward-constraint; i.e., a signal that may indicate issues with the cognitive model[9].

Let us assume that the simulation does poorly in terms of accuracy; what is to be done? One might conduct a set of Monte-Carlo simulations to measure the departure from accuracy with respect to the parameters of ψ_{ct} and consider optimizing these parameters to maximize accuracy. But, this raises a serious concern; some would rightly argue that not all parameters in ψ_{ct} should be free to vary on theoretical grounds[24]. So, there are theoretical considerations in C that are not directly represented in ψ. Another concern is that unless the properties in S captured in the simulation completely reproduce the empirical data (within a reasonable degree of tolerance), one needs to consider, given the objective function, whether to vary some components in the simulation that represent something in S instead of or in addition to features of C. In other words, in the above scenario it may not be sufficient to only focus on changing C; decisions must be made in this regard.

The above scenario is but one approach, one that is largely *fixing S and importing C*. But what if we *fix C and generate S* instead? What does this look like? We will stay with the obesity example from above, but change the scenario such that we don't know about any simulation approaches that represent mainly S. Instead, imagine that S is composed of a set of population-level empirical studies, some of which include information on social networks and the built environment, and some theoretical statements about peer-influence on social networks. Furthermore, similar to the scenario above, there is a limited set of candidate ψ_{ct} to consider ($\{\psi_{ct_i}, \psi_{ct_j}, \psi_{ct_k}, ...\}$) in the health behavior tradition and, likely, other aspects of C that may not be represented in them (e.g., categorization, learning, and attractor dynamics). Further, only one of these candidates[10], ψ_{ct_i}, is in a computational formalism; we decide that this will be our starting point. Analysis of ψ_{ct_i} reveals that it captures the learning and on-the-fly formation of attitudes towards specific health behaviors (considered a precursor to behavior); it is composed in a general manner such that it applies to virtually any health behavior, and; it is empirically grounded using traditional health behavior theory measurment techniques (in one particular behavioral domain).

These features are useful, but some key components are missing that are akin to first principles of sociological theory. In particular, ψ_{ct} is mute with respect to the generation of social structure and related dynamics (e.g., decision making for initiating/dissolving relationships; social influence mechanisms in terms of how others' behavior or attitudes can potentially serve as the input to the system). Thus, at minimum, some decision points arise in terms of how the simulation implements generation and change in network structure the mechanism of social

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[9]One might reasonable use the difference between accuracy given ψ and ϕ instead for comparison purposes

[10]There do exist a small handful of computationally implemented health behavior theories; see [20] for a review

influence.

To this end, one could start by implementing a static network topology that captures regularities found in empirical studies of human social networks and disallow change in the network ties as the simulation progresses. In terms of social influence, we might assume that what is spreading are attitudes and that exposure to others' attitudes can serve as input to an agent and, further there is a knowable stochastic function between attitude and behaviors relating to obesity, e.g., energy balance behaviors relating to caloric intake and use)[11] At this point, we could build out further the social structure and dynamics in relation to the problem of interest using both theoretic and empirical components from S, e.g. racial/ethnic distributions in obesity.

Notice, that what is going on here is a process of building from a cognitive kernel and adding layers of assumptions from S where S includes different kinds of information/footnoteThis is very similar to standard practice in social simulation that uses agent-based approaches except that the kernel starts from first principles of computational social psychology. At some point, we need to run the simulation and determine how to apply the downward-constraint. We explore this next.

Once the simulation is runnable, the downward-constraint could operate, as describe above, by computing an objective function w.r.t. the accuracy of the simulation compared to extant empirical data. Here, the issues are mainly the same as in the *fixing S and importing C case described above* with an important, subtle difference. In this case, although, depending on the provenance of the data sources (to mean, roughly, which level of scale do they originate from), there will be decision points in terms of whether to modify C or S, the focus should, at least initially, be on C. In the limiting case, imagine that the only data we have is from C, e.g., some behavioral studies that reveal something about the learning and formation of attitudes about obesity related behaviors and the relation between attitudes and the behaviors. All of these studies, further, were conducted at the individual-level and reveal little about social structure and dynamics. In this case, the objective function would be computed with respect to how well ψ_{ct_i} captures the variation in these data alone. In this case, it is possible that aspect of both C and S could be modified in the simulation to optimize the objective function. What is interesting about this limiting case is that C may still depend on S. Getting the S right would be essential in a real-world empirical causal sense.

These two examples are largely hypothetical versions of the multi-scale approach to the RCP. The value, we hope, is to provide some sketches of what it might look like in practice. Clearly, there are many issues that are raised, even by these sketches, let alone by the general notion of the RCP and the *Resolution Thesis*. We address some of the obvious of these issues next.

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[11]We've implemented prototypes of this sort[21]

3 Discussion

Thus far, we have presented the *Resolution Thesis*, its motivation, an approach for acting on its premises and some examples of what application of the *RCP* might look like. The latter was, largely, an exercise in emphasis–application of the *RCP* is fraught with difficulties on several dimensions, e.g.: theories about the individual-level behavior may have little overlap with theories developed in a sociological or demographic context; compute resources may outstrip what is available when integrating cognitive modeling with social modeling; adjudicating over many free parameters across levels of scale given one error signal will not be clear-cut; defining and developing algorithms of behavior from largely ill-defined, non-formal descriptions of individual-level behavior may require conducting clever human subjects experiments; there may be issues with the quality and sparsity of data w.r.t. both observations and theoretical entities. In short, the emphasis was really on the difficulty of application of the *RCP*. This is not just building fancier high-fidelity agent-based models, but on building a novel multi-scale scientific approach that can be leveraged for a broad range of applications. Our goal was to motivate the development, in the future, of such an approach.

At this point, we do not want to labor over these specific issues mapped onto a specific set of cases or the potential solutions to some of these issues that are currently under consideration[22]. Instead, we want to provide our vision of the next generation *RCP*.

3.1 Moving Forward

One way to understand the *RCP* is as a repair for a series of historical accidents–the ones that generated strong divisions between disciplines at or close to the scale of the individual, e.g., neuroscience, psychology, psychiatry and cognitive science on one hand and disciplines at larger scales, e.g, sociology, demography, communications, and economics on the other. Within these disciplines, there are camps, so to speak, that are equally far from each other as are some of these disciplines (e.g., agent-based approaches in economics compared to neoclassical economics; or, cognitive science and social psychology). The issue, for our thesis and the *RCP*, is we see these divisions reflected in the various approaches for simulation of human behavior. The repair, so to speak, is designed to increase the degree of confidence we have in developing an understanding of social systems from a truly multi-scale perspective This understanding, we surmise, will afford more accurate simulations of social systems and, maybe, increase the capacity for policy to affect positive social change through the use of such simulations.

Public health may prove illustrative. The 2000s saw a burst of activity centered around using a complex systems approach to population health[12](REF 2006 AJPH, the 2007 Michigan Conf; the ISSH attempts). (See [?, ?, ?] for

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[12]Also called "Systems Science" approaches in public health.

summaries of this approach over the past decade.) The principal approaches pushed in this era were social network analysis, agent-based modeling, and system dynamics with game theoretic and micro-simulation approaches having a smaller but noticeable presence. Cognition and high-fidelity cognitive modeling approaches were not incorporated into these efforts, not even as ways to consider systems of individuals, until very recently (see ORR Book Chapter), although a nascent set of efforts were put forth to capture individual level behavior without direct implementation into social system [**?**] using computational and mathematical modeling approaches over the past decade.

From this ferment, the application of the *RCP* there is little option than to be somewhat piecemeal in nature. It is as if one is forced to coble together a shoe from parts of a car, not impossible, but potentially more work than may be justified by the ends. This is not only an issue in public heaath, but in economics, defense concerns, intelligence concerns, energy, and other large-scale population concerns that incorporate human socio-technical systems. In short, no disciplinary structure has put serious effort into systematically building up a multi-scale approach to social modeling.

In closing, we would like to suggest the following idea for moving forward. The next generation application of the *RCP* that we envision is something more modular and iterative, an approach that begins to build social structure from first principles of lower levels of scale to higher levels of scale. By example,

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