CASE-BASED METHODS AND AGENT-BASED MODELLING:

BRIDGING THE DIVIDE TO HARNESS THEIR RESPECTIVE STRENGTHS

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Professor of Sociology

Durham University

THANK YOU FOR THE OPPORTUNITY TO PRESENT!

I want to begin by thanking the CECAN for their support during the course of my research fellowship.

I would also like to thank my two co-authors on this project and paper, Peter Barbrook-Johnson and Corey Schimpf.

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OVERVIEW

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OVERVIEW OF ARGUMENT

- In terms of studying social complexity, two of the most dominant methodological camps are case-based methods (CBM) and agent-based modelling (ABM).

- Notwithstanding significant epistemological similarities (i.e., cases and agents are often equivalent), both camps have yet to harness the other's strengths, which has limited both approaches in terms of studying dynamics.

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- For example, CBM rarely focuses on the interactions amongst cases or their corresponding emergent behaviour; or how complex configurations might change due to different counterfactual scenarios.
- In turn, ABM has yet to use CBM to develop its agents or their rules; let alone use CBM to hypothesize how agents might interact based on different combinations of complex causal configurations.
- The purpose of my fellowship (and the papers I am writing with Pete and Corey) was to explore how the links between case-based methods and agent-based modeling could be developed. This results in two key projects:
  - Articulating the key ways in which CBM and ABM can be linked.
  - And, in turn, developing our R-Studio statistical package, COMPLEX-IT.

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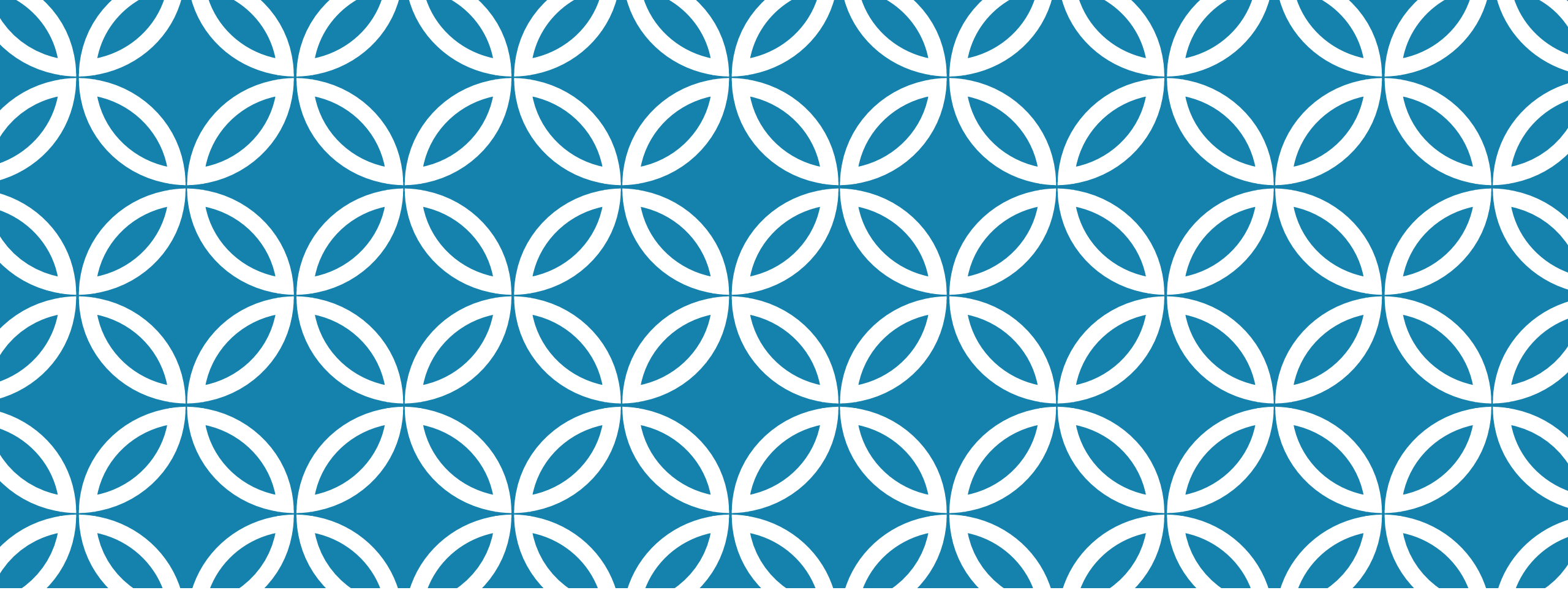

ASSERTIONS

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ASSERTION 1:

Conventional statistics are significantly limited in their capacity to study social dynamics, let alone complex global-temporal dynamics.

- Part of the problem is the static nature of these methods.
- The other is their focus on aggregates (bell shaped) distributions; rather than different and multiple trends.
- And their failure to study cases and their respective profile – which is the stuff of our globalized, digitally saturated, big data world.

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ASSERTION 2:

- The methods of computational modeling and complex system offer useful solutions to these problems.
- Albeit only if one approaches them critically, as not all methods are equally useful for modeling and data mining social complexity -- which is one of the major points of Byrne and Callaghan 2013.
- The two of interest to us here are
  - case-based methods (CBM)
  - agent-based modeling (ABM)

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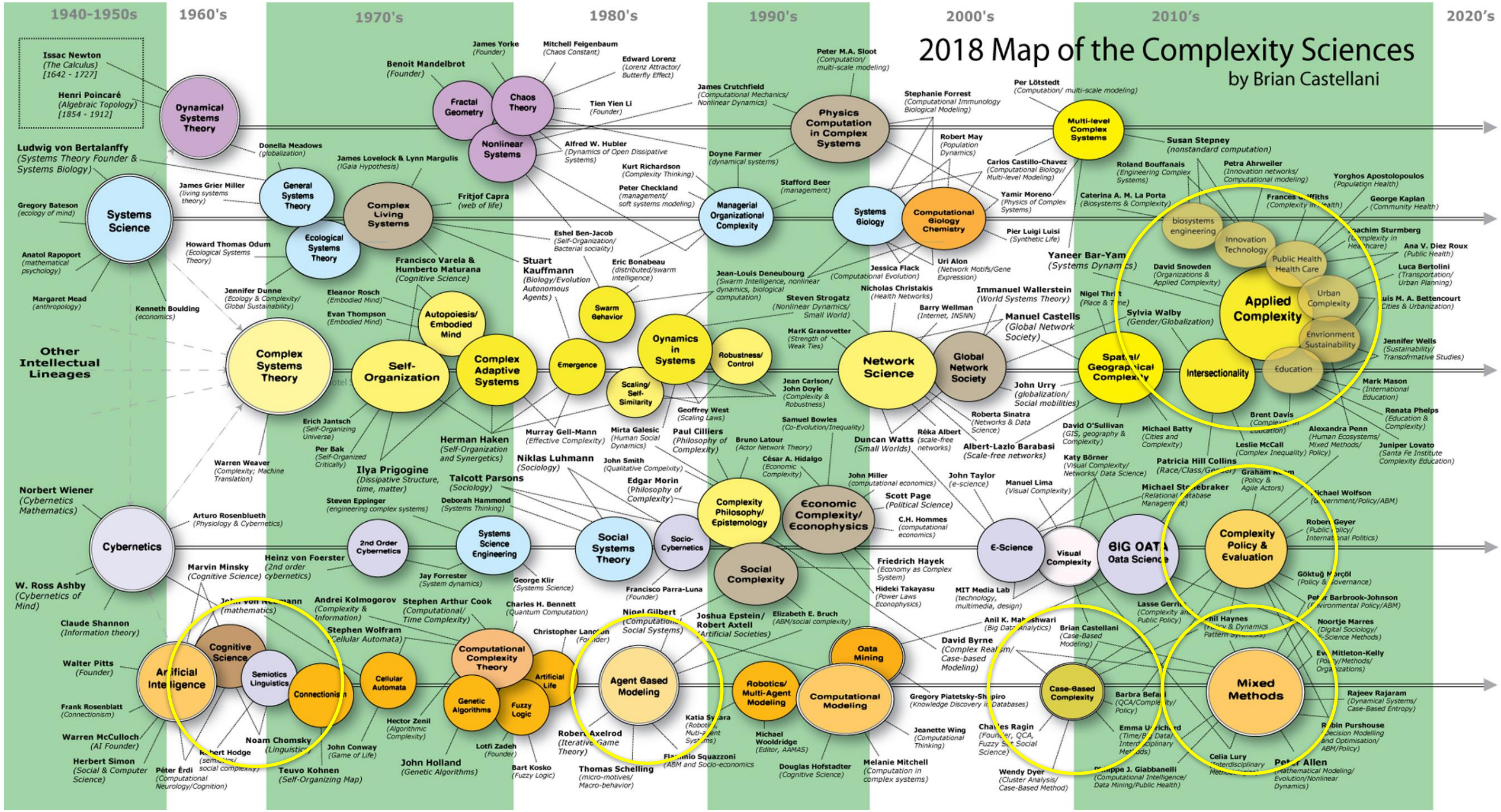
1940-1950s
1960's
1970's
1980's
1990's
2000's
2010's
2020's
2018 Map of the Complexity Sciences
by Brian Castellani
Issac Newton (The Calculus) [1642 - 1727]
Henri Poincaré (Algebraic Topology) [1854 - 1912]
Dynamical Systems Theory
Ludwig von Bertalanffy (Systems Theory Founder & Systems Biology)
Systems Science
Gregory Bateson (ecology of mind)
Anatol Rapoport (mathematical psychology)
Margaret Mead (anthropology)
Kenneth Boulding (economics)
Donella Meadows (globalization)
James Grier Miller (living systems theory)
General Systems Theory
Ecological Systems Theory
Howard Thomas Odum (Ecological Systems Theory)
Jennifer Dunne (Ecology & Complexity/ Global Sustainability)
James Lovelock & Lynn Margulis (IGaia Hypothesis)
Complex Living Systems
Fritjof Capra (web of life)
Benoit Mandelbrot (Founder)
James Yorke (Founder)
Fractal Geometry
Chaos Theory
Nonlinear Systems
Mitchell Feigenbaum (Chaos Constant)
Edward Lorenz (Lorenz Attractor/ Butterfly Effect)
Tien Yien Li (Founder)
Alfred W. Hubler (Dynamics of Open Dissipative Systems)
Kurt Richardson (Complexity Thinking)
Peter Checkland (management/ soft systems modeling)
Eshel Ben-Jacob (Self-Organization/ Bacterial sociality)
Stuart Kauffmann (Biology/Evolution Autonomous Agents)
Eric Bonabeau (distributed/swarm intelligence)
Francisco Varela & Humberto Maturana (Cognitive Science)
Eleanor Rosch (Embodied Mind)
Evan Thompson (Embodied Mind)
Autopoiesis/ Embodied Mind
Swarm Behavior
Other Intellectual Lineages
Complex Systems Theory
Self-Organization
Complex Adaptive Systems
Emergence
Dynamics in Systems
Robustness/ Control
Scaling/ Self-Similarity
Erich Jantsch (Self-Organizing Universe)
Per Bak (Self-Organized Criticality)
Warren Weaver (Complexity; Machine Translation)
Ilya Prigogine (Dissipative Structure, time, matter)
Herman Haken (Self-Organization and Synergetics)
Murray Gell-Mann (Effective Complexity)
Niklas Luhmann (Sociology)
Mirta Galesic (Human Social Dynamics)
John Smith (Qualitative Compelxity)
Paul Cilliers (Philosophy of Complexity)
Geoffrey West (Scaling Laws)
Jean Carlson/ John Doyle (Complexity & Robustness)
Samuel Bowles (Co-Evolution/Inequality)
Bruno Latour (Actor Network Theory)
César A. Hidalgo (Economic Complexity)
Edgar Morin (Philosophy of Complexity)
Talcott Parsons (Sociology)
Deborah Hammond (Systems Thinking)
Steven Eppinger (engineering complex systems)
Norbert Wiener (Cybernetics Mathematics)
Cybernetics
Arturo Rosenblueth (Physiology & Cybernetics)
W. Ross Ashby (Cybernetics of Mind)
Claude Shannon (Information theory)
2nd Order Cybernetics
Heinz von Foerster (2nd order cybernetics)
Marvin Minsky (Cognitive Science)
Jay Forrester (System dynamics)
Systems Science Engineering
Social Systems Theory
Socio-Cybernetics
Francisco Parra-Luna (Founder)
George Klir (Systems Science)
Complexity Philosophy/ Epistemology
Social Complexity
Economic Complexity/ Econophysics
Scott Page (Political Science)
C.H. Hommes (computational economics)
John Miller (computational economics)
Friedrich Hayek (Economy as Complex System)
Hideki Takayasu (Power Laws Econophysics)
Joshua Epstein/ Robert Axtell (Artificial Societies)
Elizabeth E. Bruch (ABM/social complexity)
Physics Computation in Complex Systems
Peter M.A. Sloot (Computation/ multi-scale modeling)
James Crutchfield (Computational Mechanics/ Nonlinear Dynamics)
Doyne Farmer (dynamical systems)
Stafford Beer (management)
Managerial Organizational Complexity
Jean-Louis Deneubourg (Swarm Intelligence, nonlinear dynamics, biological computation)
Steven Strogatz (Nonlinear Dynamics/ Small World)
MarK Granovetter (Strength of Weak Ties)
Nicholas Christakis (Health Networks)
Barry Wellman (Internet, INSNN)
Network Science
Global Network Society
Immanuel Wallerstein (World Systems Theory)
Manuel Castells (Global Network Society)
John Urry (globalization/ Social mobilities)
Roberta Sinatra (Networks & Data Science)
Réka Albert (scale-free networks)
Albert-Lazlo Barabasi (Scale-free networks)
Duncan Watts (Small Worlds)
John Taylor (e-science)
Manuel Lima (Visual Complexity)
Stephanie Forrest (Computational Immunology Biological Modeling)
Robert May (Population Dynamics)
Carlos Castillo-Chavez (Computational Biology/ Multi-level Modeling)
Yamir Moreno (Physics of Complex Systems)
Systems Biology
Computational Biology Chemistry
Jessica Flack (Computational Evolution)
Uri Alon (Network Motifs/Gene Expression)
Pier Luigi Luisi (Synthetic Life)
Per Lötstedt (Computation/ multi-scale modeling)
Multi-level Complex Systems
Yaneer Bar-Yam (Systems Dynamics)
Nigel Thrift (Place & Time)
Sylvia Walby (Gender/Globalization)
Spatial/ Geographical Complexity
Intersectionality
Susan Stepney (nonstandard computation)
Roland Bouffanais (Engineering Complex Systems)
Petra Ahrweiler (Innovation networks/ Computational modeling)
Caterina A. M. La Porta (Biosystems & Complexity)
Yorghos Apostolopoulos (Population Health)
Frances Griffiths (Complexity in Health)
George Kaplan (Community Health)
David Snowden (Organizations & Applied Complexity)
biosystems engineering
Innovation Technology
Public Health Health Care
Urban Complexity
Envrionment Sustainability
Education
Applied Complexity
Joachim Sturmberg (Complexity in Healthcare)
Ana V. Diez Roux (Public Health)
Luca Bertolini (Transportation/ Urban Planning)
Luís M. A. Bettencourt (Cities & Urbanization)
Jennifer Wells (Sustainability/ Transofrmative Studies)
Mark Mason (International Education)
Renata Phelps (Education & Complexity)
Juniper Lovato (Santa Fe Institute Complexity Education)
Brent Davis (Complexity & Education)
Alexandra Penn (Human Ecosystems/ Mixed Methods/ Policy)
Leslie McCall (Complex Inequality)
David O'Sullivan (GIS, geography & Complexity)
Michael Batty (Cities and Complexity)
Katy Börner (Visual Complexity/ Networks/ Data Science)
Patricia Hill Collins (Race/Class/Gender)
Graham Room (Policy & Agile Actors)
Michael Strathebraker (Relational Database Management)
Michael Wolfson (Government/Policy/ABM)
Robert Geyer (Public Policy/ International Politics)
E-Science
Visual Complexity
BIG DATA Data Science
Complexity Policy & Evaluation
Göktuğ Morçöl (Policy & Governance)
Peter Barbrook-Johnson (Environmental Policy/ABM)
Lasse Gerrits (Complexity and Public Policy)
Noortje Marres (Digital Sociology/ E-Science Methods)
Eve Mitleton-Kelly (Policy/Methods/ Organizations)
Mixed Methods
Rajeev Rajaram (Dynamical Systems/ Case-Based Entropy)
Robin Purshouse (Decision Modelling and Optimisation/ ABM/Policy)
Peter Allen (Mathematical Modeling/ Evolution/Nonlinear Dynamics)
Celia Lury (Interdisciplinary Methods)
Anil K. Maheshwari (Big Data Analytics)
Brian Castellani (Case-Based Modeling)
David Byrne (Complex Realism/ Case-based Modeling)
Case-Based Complexity
Barbra Befani (QCA/Complexity/ Policy)
Emma Uprichard (Time/Big Data/ Interdisciplinary Methods)
Philippe J. Giabbanelli (Computational Intelligence/ Data Mining/Public Health)
Wendy Dyer (Cluster Analysis/ Case-Based Method)
Charles Ragin (Founder, QCA, Fuzzy Set Social Science)
Gregory Piatetsky-Shapiro (Knowledge Discovery in Databases)
Jeanette Wing (Computational Thinking)
Michael Wooldridge (Editor, AAMAS)
Douglas Hofstadter (Cognitive Science)
Melanie Mitchell (Computation in complex systems)
Data Mining
Computational Modeling
Robotics/ Multi-Agent Modeling
Agent Based Modeling
Artificial Life
Fuzzy Logic
Genetic Algorithms
Computational Complexity Theory
Cellular Automata
Connectionism
Semiotics Linguistics
Cognitive Science
Artificial Intelligence
Walter Pitts (Founder)
Frank Rosenblatt (Connectionism)
Warren McCulloch (AI Founder)
Herbert Simon (Social & Computer Science)
Péter Érdi (Computational Neurology/Cognition)
Noam Chomsky (Linguistics)
John Conway (Game of Life)
Teuvo Kohnen (Self-Organizing Map)
Hector Zenil (Algorithmic Complexity)
John Holland (Genetic Algorithms)
Lotfi Zadeh (Founder)
Bart Kosko (Fuzzy Logic)
Robert Axelrod (Iterative Game Theory)
Thomas Schelling (micro-motives/ Macro-behavior)
Katia Sycara (Robotic Multi-Agent Systems)
Flaminio Squazzoni (ABM and Socio-economics
Andrei Kolmogorov (Complexity & Information)
Stephen Arthur Cook (Computational/ Time Complexity)
Stephen Wolfram (Cellular Automata)
Charles H. Bennett (Quantum Computation)
Christopher Langton (Founder)
Nigel Gilbert (Computational Social Systems)
Robert May (Mathematics)
Alfred Hodge (semiotics/ social complexity)

- An **agent-based model** (**ABM**) is a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole.
- It combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming. Monte Carlo methods are used to introduce randomness.
- Agent-based modeling is related to, but distinct from, the concept of **multi-agent systems** or **multi-agent simulation** in that the goal of ABM is to search for explanatory insight into the collective behavior of agents obeying simple rules, typically in natural systems, rather than in designing agents or solving specific practical or engineering problems.
- Agent-based models are a kind of microscale model that simulate the simultaneous operations and interactions of multiple agents in an attempt to re-create and predict the appearance of complex phenomena.

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1. QCA is a method that bridges qualitative and quantitative analysis:

Most aspects of QCA require **familiarity with cases**, which in turn demands in-depth knowledge. At the same time, QCA is capable of pinpointing decisive cross-case patterns, the usual domain of quantitative analysis. QCA's examination of cross-case patterns respects the **diversity** of cases and their **heterogeneity** with regard to their different causally relevant conditions and contexts by comparing cases as configurations.

2. QCA provides powerful tools for the analysis of causal complexity:

With QCA, it is possible to study "**INUS**" conditions—causal conditions that are insufficient but necessary parts of causal recipes which are themselves unnecessary but sufficient. In other words, using QCA it is possible to assess causation that is very complex, involving **different combinations of causal conditions** capable of generating the same outcome. This emphasis contrasts strongly with the "net effects" thinking that dominates conventional quantitative social science. QCA also facilitates a form of counterfactual analysis that is grounded in case-oriented research practices.

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ASSERTION 3:

- *However, as with all methods, there are several limitations to ABM and CBM.*
- *Also, while both methods were designed to better model complex causality; and while the concepts of cases and agents are often epistemologically and methodologically equivalent; these two methods have yet to be harnessed by either camp for their respective strengths.*
- *The time is ripe for exploring these links as mixed-methods computational modeling and complexity methods have become widely popular.*

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ASSERTION 4:

- Cases and agents are equivalent in three important ways:
  - First, they are similar in that they are based on a profile of key factors;
  - Second, they are based on the concept of differences, which link to important and different outcomes;
  - Third, they are linked in time/space to each other through the concept of *agency*:
  - Andrew Abbott:

> By asking what cases do, I am assuming that the case is an agent. This idea is somewhat foreign to some sociological traditions. We don't generally think of the cases in the General Social Survey as agents with intentions and histories. But it is precisely my intent to begin with the question of what such cases "do" in the Weberian (etc.) sense of social action. What kinds of activities do they undertake? What do they try to accomplish? What kinds of agents are they?

  - This is not to say that they are always equivalent.

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ASSERTION 5: HOW CBM HELPS ABM

- Narratives and Stories about cases and social life
- Bridges the qualitative-quantitative divide
- Case-Based Holism
- Focused on cases, which can be used to identify agents and their corresponding different complex configurations (profiles of factors). In other words, the focus is on cases, not variables, and therefore keeps ABM oriented toward its overall goal (how variables go together) from the beginning, rather than having to stitch things together later!
- Provide complex causality better than conventional statistics
- Focuses on the link between cases and outcomes!
- Allows for easier rule extraction

Also, one can go from ABM to CBM, using the latter to empirically validate a model.

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ASSERTION 6:HOW ABM HELPS CBM

- The importance of counterfactuals (thinking non-observed cases)
- Interactions and inter-(re)actions
  - How cases influence one another
  - How cases respond or change in relation to one another
- The importance of time and trajectory
  - Individual case-base trajectories
  - How cases evolve across time
- Emergent behavior and global-temporal dynamics

Supports future data collection, mainly in terms of thinking about additional factors; but also in terms of potential interactions and other dynamics that have yet to be considered.

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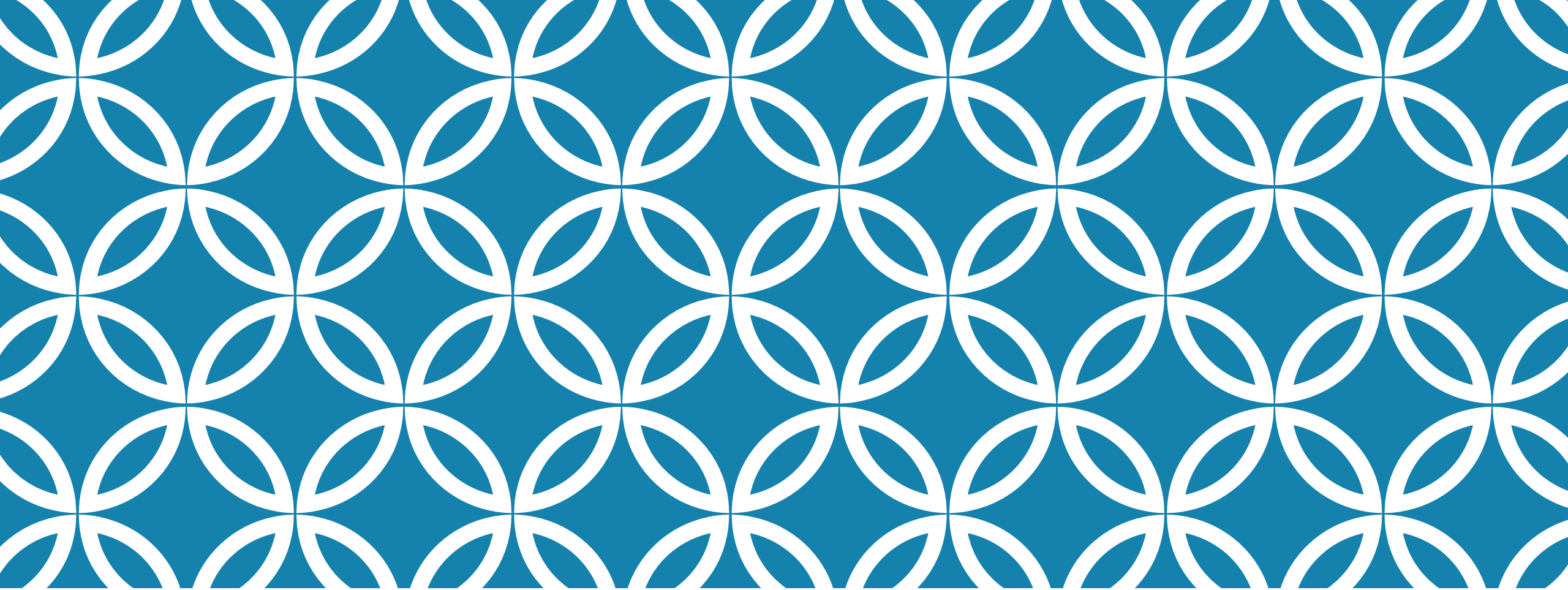

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Case-Based Modeling & The SACS Toolkit

A New Approach to Modeling Complex Social Systems

SACS

sociology and complexity science

SACS SOCIOLOGY AND COMPLEXITY SCIENCE

"According to case-based complexity, cases are complex profiles comprised of a set of inter-dependent variables, which are contextually dependent, nonlinear, dynamic, evolving, self-organizing,emergent, etc. in short, cases have the same characteristics as a complex system. Theoretically speaking, then, cases can be treated and modeled as complex system..."

SEE PAPERS BELOW

BACKGROUND: Building on the case-comparative methods of ***Charles Ragin*** and, more recently, the case-based complexity theory of ***David Byrne*** a new set of methodological techniques and arguments have emerged for the study of complex systems, called case-based complexity science and case-based modeling---for more information, click here to see Byrne and Ragin's 2009, ***Sage Handbook of Case-Based Method***.

CASE-BASED COMPLEXITY SCIENCE: Scholarly activity that seeks to actively integrate case-based methods with complexity science for the purpose of modeling complex systems as cases.

CASE-BASED ENTROPY: An effective way to define and measure the diversity of complexity ***D*** in a probability distribution is through a specific form of Shannon entropy ***H***.

1. OVERVIEWS OF COMPUTATIONAL MODELING AND THE SACS TOOLKIT

2015 Castellani, B., R. Rajaram, J. Gunn, and F. Griffiths. "**Cases, Clusters, Densities: Modeling the Nonlinear Dynamics of Complex Health Trajectories.**" Complexity, Early View

2014 Rajaram, R, and B. Castellani. "**The Utility of Non-equilibrium Statistical Mechanics, Specifically Transport Theory, for Modeling Cohort Data.**" Complexity, Early View

2009 Rajaram, R., & Najafi, M. "**Exact controllability of wave equations in Rn coupled in parallel.**" J. Math. Anal. Appl., 356,7-12

2009 Rajaram, R., & Najafi, M. "**Analytical treatment and convergence of the Adomian Decomposition Method for a system of coupled**

13(7): 1005-1018.

Brian Castellani

Rajeev Rajaram

We found that skewed-right complex systems obey the law of restricted diversity; that is, when plotted for a variety of natural and human-made systems, as the diversity of complexity —> ∞ (primarily in terms of the number of types; but also, seco
a limiting law of restricted dive
cases to simpler types. Even m
scale-free 60/40 rule: when m
the cases in these systems resi
lower bound of equiprobable d
and whether or not the distrib
extension of the Pareto Princip
small percentage of the total diversity; that is, while the top 20 percent of cases constitute a sizable percentage of the total diversity in a system, the bottom 60 percent are highly constrained.

VISIT: http://www.personal.kent.edu/~bcastel3/

Figure 2: Self-Organizing Topographical Map of Eleven Major and Minor Trends

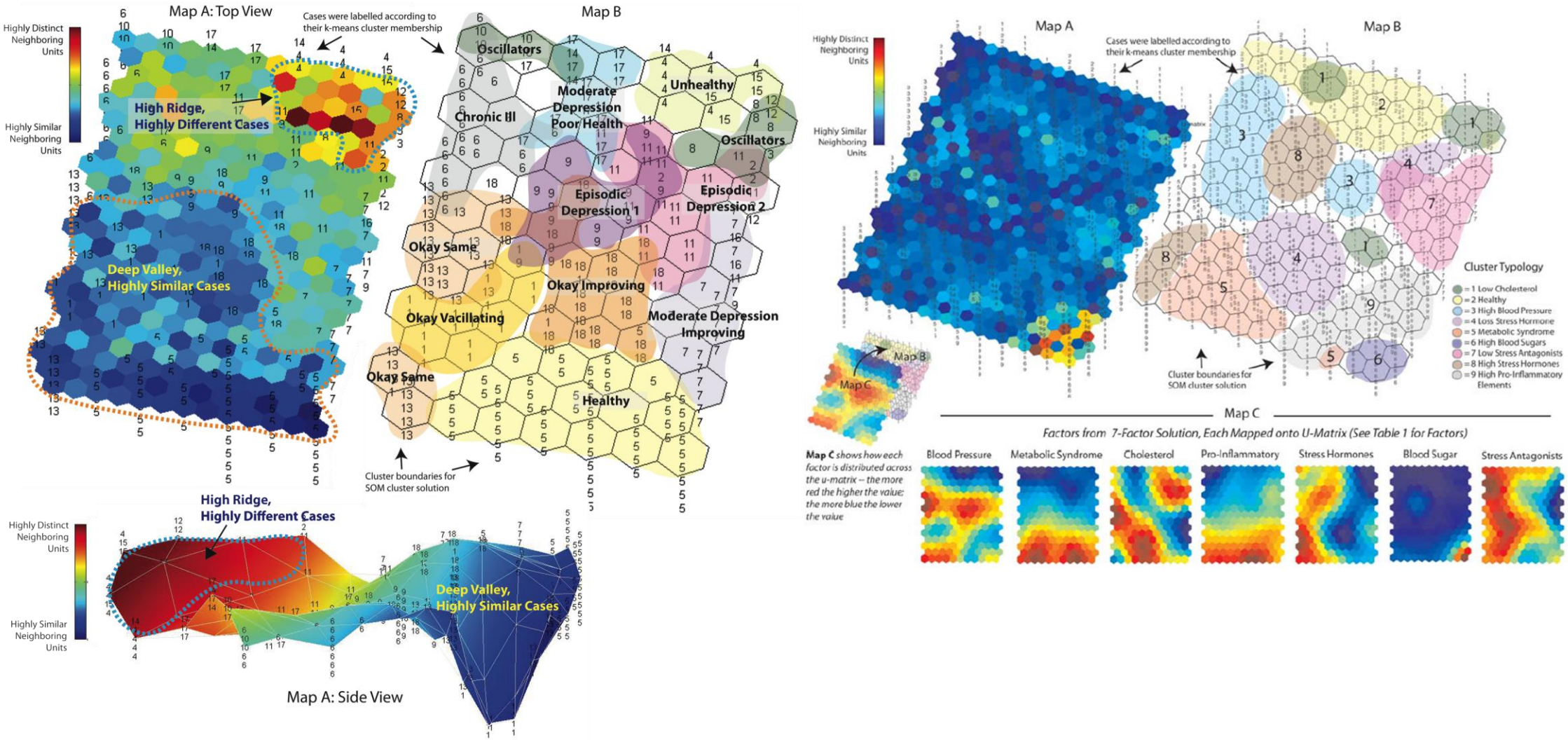


Figure 1: Eleven Major and Minor Comorbid Depression/Physical Wellbeing Trends

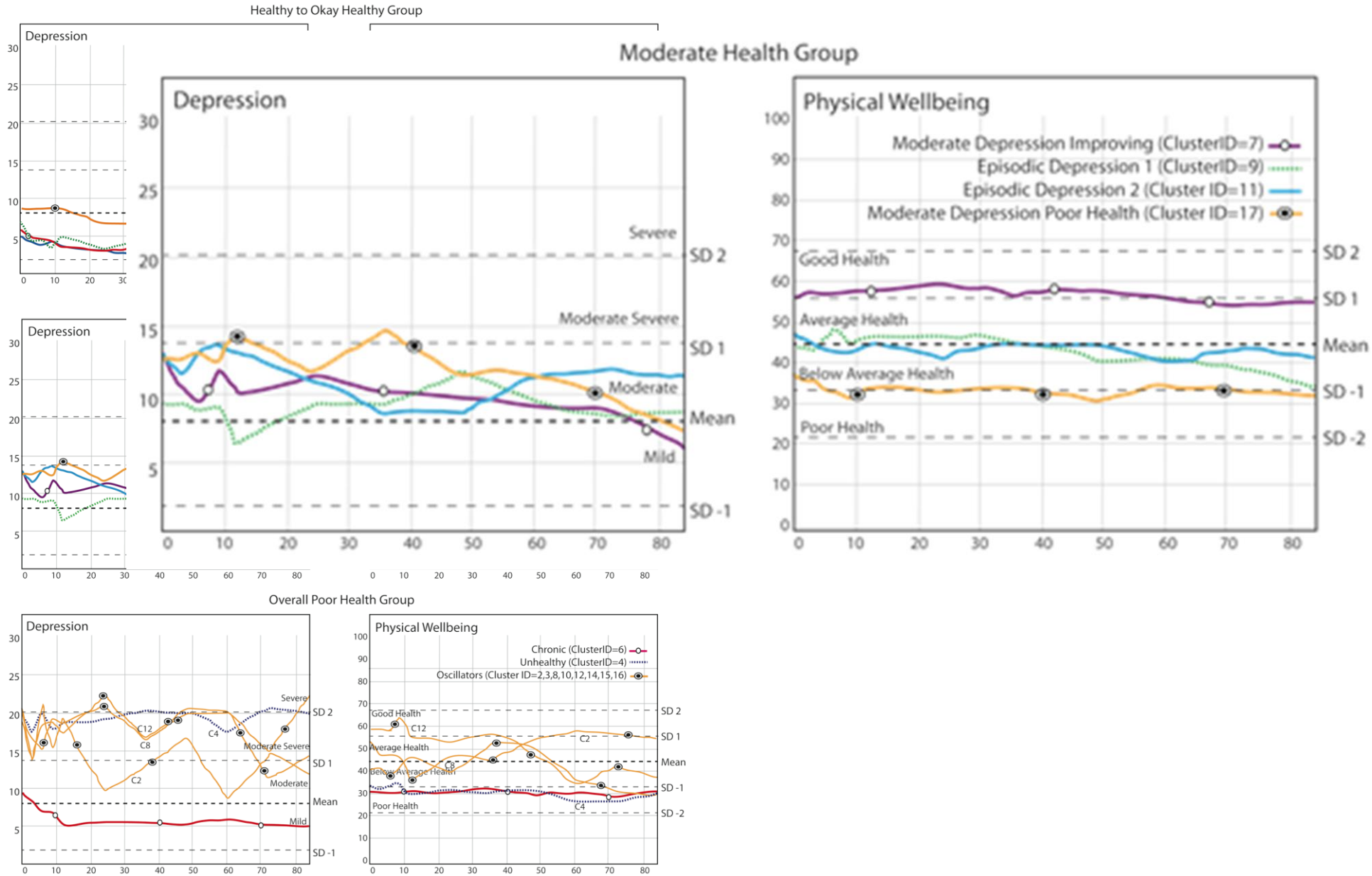
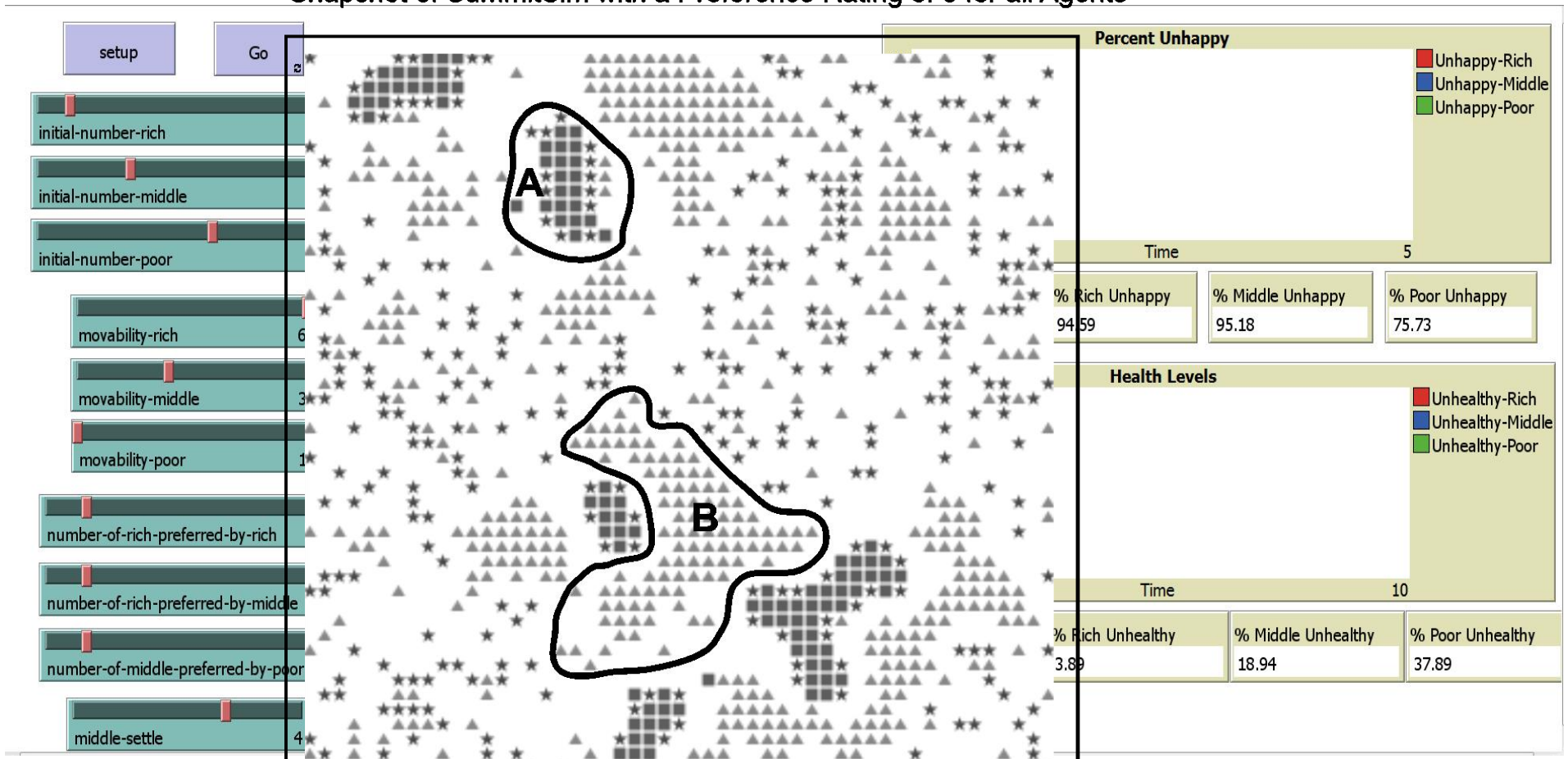


FIGURE 7:
Snapshot of SummitSim with a Preference Rating of 3 for all Agents



NOTE: Rich Agents = Squares; Middle Class Agents = Stars; and Poor Agents = Triangles. **Cluster A** identifies one of the dense clusters of rich agents. **Cluster B** identifies one of the dense clusters of poor agents; which complexity scientists would call a poverty trap.

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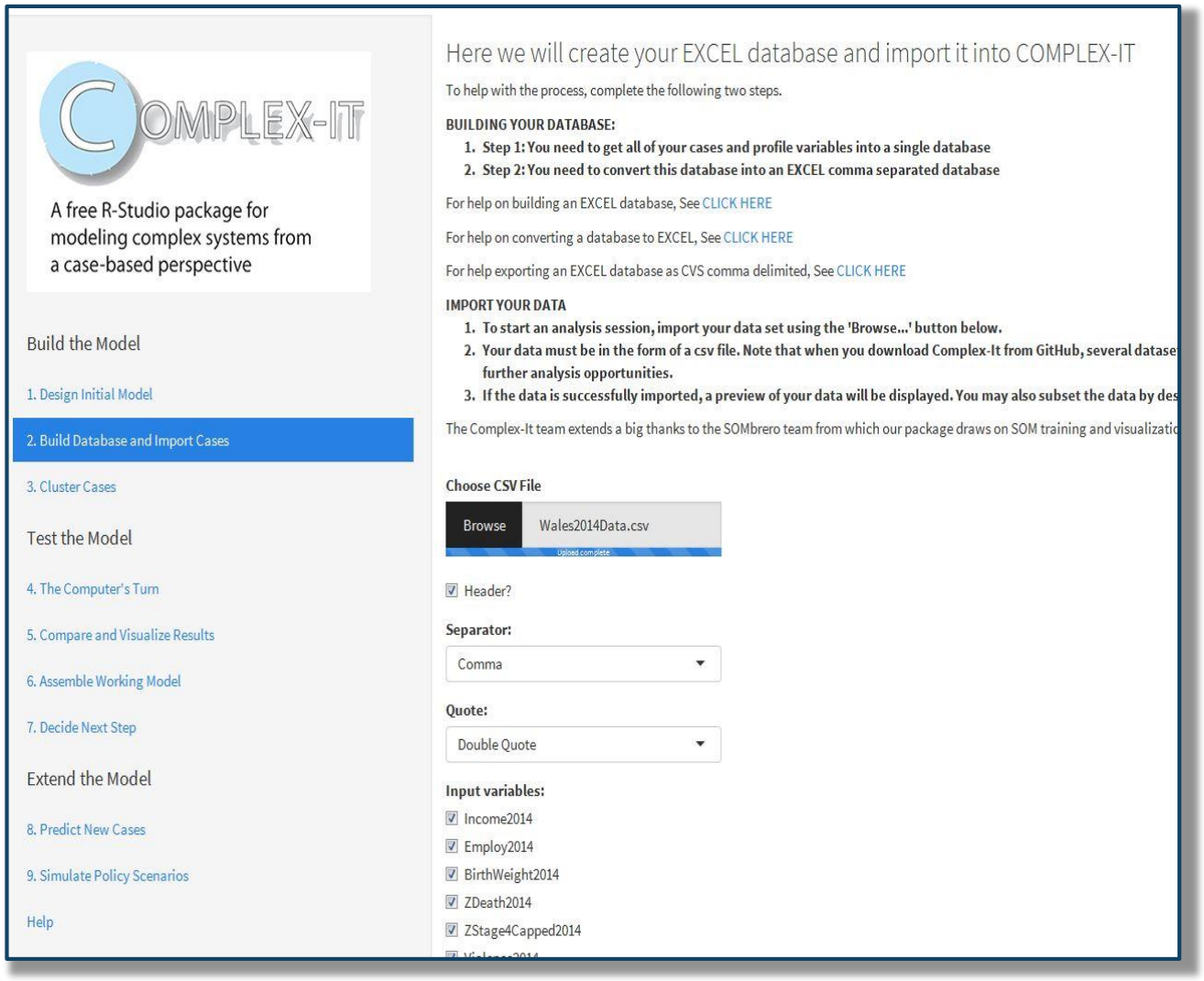
COMPLEX-IT

Designed to make the otherwise highly complex tools and techniques of data mining accessible to a wider and less technical audience.

Currently, COMPLEX-IT's suite includes:

- k-means cluster analysis
- the Kohonen topographical neural net
- a series of data visualization techniques
- case prediction
- a tab for simulating policy scenarios
- a tab for designing an agent-based model

COMPLEX-IT also includes a step-by-step series of questions that, concurrent with the actual process of data analysis, take the user through the model design process – all of which ends with a generated report on the results of one's study.



VISIT: http://www.personal.kent.edu/~bcastel3/complexit.html