Case-based methods, micro-simulation and agent-based modelling:

Bridging the divide to leverage their combined strengths

Brian Castellani, PhD.
Professor of Sociology
Durham University

We are in the middle of a several-year project to harness the respective strengths of case-based modelling (CBM), micro-simulation (MS) and agent-based modelling (ABM) for advancing social inquiry.

Despite the potential epistemological links between 'cases' and 'agents,' these three camps have yet to leverage their combined strengths.

(1) A bridge can be built, however, by drawing on Andrew Abbott's insight that 'agents are cases doing things', and

(2) David Byrne's suggestion that 'cases are complex systems with agency', and by viewing CBM, MS and ABM within the broader trend towards computational modelling of cases.

To demonstrate the utility of this bridge, we describe how CBM can utilise ABM to identify case-based trends; explore the interactions and collective behaviour of cases; and study different scenarios.

We also describe how ABM can utilise CBM to identify agent types; construct agent behaviour rules; and link these to outcomes to calibrate and validate model results.

To further demonstrate the bridge, I review

(1) A recent study we published linking CBM and ABM, based on a public health study we conducted that made initial steps in combining CBM and ABM
(2) A software package (COMPLEX-IT) we have developed that offers a new case-based microsimulation approach to modelling.

Example 1: Linking CBM and ABM

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Case-based methods and agent-based modelling: bridging the divide to leverage their combined strengths

Brian Castellani[a], Peter Barbrook-Johnson[b] and Corey Schimpf[c]

[a]Department of Sociology, Durham University, Durham, UK; [b]Centre for Research in Social Simulation, Department of Sociology, University of Surrey, Guilford, UK; [c]The Concord Consortium, Boston, MA, USA

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Example 1: Linking CBM and ABM

Why would we want to leverage CBM and ABM?

In terms of CBM researchers, they can design or use various ABMs to:
- more effectively identify case-based trends across time-space;
- explore the global dynamics and interactive behaviour of cases;
- and inspect how different scenarios might impact case-based outcomes.

In terms of ABM researchers, they can use CBM as a complexity-appropriate data framing and analysis approach to:
- more effectively identify and contextualise the complex rules governing different agents' behaviour;
- pre-identify the potential agent types and trends in a model;
- and link these types and trends to key outcomes in the model to calibrate and/or validate a model's results.

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Example 1: Linking CBM and ABM

Why would we want to leverage CBM and ABM?

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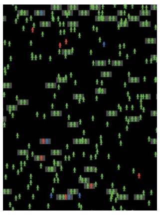
What is an ABM?

Agent-based modeling is a method of computational modeling that simulate interactions among **agents** with the purpose of viewing the effects on the system as a whole.

("Agent Based Modeling" 2013)



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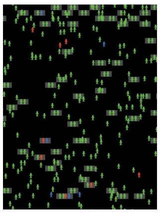
What is an ABM?

ABM vs Classical Models

Classical:'...equations expressing relationships between observable components of a system...'

ABM:'...system-level patterns emerge from...interactions.'

(Koohafkan 2013)



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So what makes up an ABM?

- Agents
- Environment
- Behaviour
- Interactions
- Time
- Scenarios

- Heterogeneity and interaction are **KEY**
  - if these are important to your question/problem – think ABM!
- ABMs include complexity of real-world in the model - interactions and feedback
  - consequence #1 of this is NO POINT PREDICTION, and only relative and broad forecasting
  - consequence #2 - Emergence – with an example...

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Emergence

- Some feature or outcome of the system, that can't be explained by simply describing the constituent parts…

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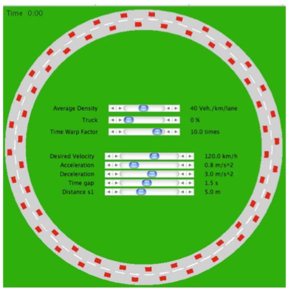
Emergence 2

- Some feature or outcome of the system, that can't be explained by simply describing the constituent parts…

www.traffic-simulation.de



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How is it done?

- Write code / build model…
- From scratch – in general purpose language – Python / C++
- In specifically designed programming environment
  - Many available
  - NetLogo very well used / good support
- NetLogo – free!
  - easy to learn code (!!!) / primitives / syntax
  - create agents and environment – 'SETUP'
  - give them behaviours – 'GO'
  - record outputs
  - behaviorSpace – experiment with model

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Why and when to use ABM?

- If we are interested in modelling interactions and feedback between actors, and actors and their environment;
- If we believe heterogeneity of actors is important in the social system;
- If we are interested in the spatial dynamics of a system;
- If we believe path dependence (i.e., past decisions or states affect future decisions or states) may be an important element in the social system;
- If we believe actors in the system have behaviours that change,or adapt over time; or
- If we want to use an intuitive and flexible modelling approach for participatory modelling.
- When nature of the system and your questions make it '**appropriate**' – not always the case!

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Quick summary

- We know what an ABM is now!
- ABMs useful when we have:
  - heterogeneity
  - Interaction
  - And we want:
    - understanding
    - forecasts / prediction?
- We have a sense of how they are built
- 2 examples
  - One theoretical – but clear policy extensions
  - 1 policy example

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Quick summary

- We use models to…
  - **understand** how something works
  - **explain** patterns we have seen
  - **predict** a system's response to some change
  - Bring together **stakeholders** / share knowledge
- Models are a purposeful representation/simplification of some real system…
- So…**what to include** in the model?
  - purpose – i.e., use – is vital in this decision
- Example
  - "please model the housing market" – not that helpful
  - "please use a model to understand how price heterogeneity might emerge in the housing market" – more useful
  - "please develop a model that I can use to understand how policy X and Y might reduce excessive price heterogeneity in the housing market" – more useful
- If something is irrelevant for answering a question – i.e. to the purpose/use of the model – **chuck it out**!!

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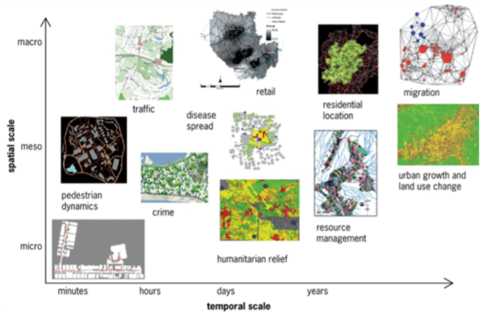
Models of all sorts of topics



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Case-based methods

Presently, case-based methods constitute a compendium of techniques.

- Examples include single-case probabilities, cluster analysis, case-based reasoning, ethnographies, legal case studies, MDSO/MSDO (most different cases, similar outcome/most similar cases, different outcome) and historical case studies (Byrne & Ragin, 2009).
- Despite such differences, the goal of these methods is roughly the same: to study a case or set of cases ideographically – that is, to gain a more holistic understanding of a specific topic of concern (Ragin & Rihoux, 2009).
- The simplest example is the case study, which is an in-depth investigation of a single case. Most approaches, however, engage in some form of case-oriented comparative or case-comparative analyses – the most popular of which is Ragin's qualitative comparative analysis (QCA) (Ragin, 2014).

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Case-based complexity

- Regardless of the method used, **case-based complexity** is anchored in four core epistemological arguments that deeply resonate with the majority of computational methods used today, as well as most users in the applied and public sectors.
- First, the case and its trajectory across time/space are the focus of study, not the individual variables or attributes of which it is comprised.
- Second, cases and their trajectories are treated as composites (profiles), comprised of an interdependent, interconnected sets of variables, factors or attributes.
- Third, the relationships and social interactions amongst cases are also important, as are the hierarchical social contexts/systems in which these relationships take place.
- And, finally, cases and their relationships and trajectories are the methodological equivalent of complex systems – that is, they are emergent, self-organizing, nonlinear, dynamic, network-like, etc – and therefore should be studied as such.

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QCA Background

QCA's home base is *comparative sociology/comparative politics*, where there is a strong tradition of case-oriented work alongside an extensive and growing body of quantitative cross-national research.

The case-oriented tradition is much older and is populated largely by *area and country experts*. In contrast to the situation of qualitative researchers in most social scientific subdisciplines, these case oriented researchers have *high status,* primarily because their case knowledge is useful to the state (e.g., in its effort to maintain or enhance national security) and other corporate actors.

Case-oriented researchers are often critical of quantitative cross-national researchers for ignoring the gap between the results of quantitative research and what is known about specific cases. They also have little interest in the abstract, high-level concepts that often characterize this type of research and the wide analytic gulf separating these concepts from case-level events and processes.

QCA, plain and simple, attempts to bridge these two worlds. This attempt has spawned methodological tools which are useful to social scientists in general.

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Four (relatively abstract) answers to the question, "What is QCA?"

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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3. QCA is ideal for small-to-intermediate-N research designs:

QCA can be usefully applied to research designs involving small and intermediate-size *N*s (e.g., 5-50). In this range, there are often **too many cases** for researchers to keep all the case knowledge "in their heads," but **too few cases** for most conventional statistical techniques.

4. QCA brings set-theoretic methods to social inquiry:

QCA is grounded in the analysis of set relations, not correlations. Because **social theory is largely verbal** and verbal formulations are largely set theoretic in nature, QCA provides a closer link to theory than is possible using conventional quantitative methods. (Most conventional quantitative methods simply parse matrices of bivariate correlations.) Note also that important causal relations, **necessity and sufficiency**, are indicated when certain set relations exist: With necessity, the outcome is a subset of the causal condition; with sufficiency, the causal condition is a subset of the outcome. With INUS conditions, cases with a specific combination of causal conditions form a subset of the cases with the outcome. Only set theoretical methods are well suited for the analysis of causal complexity.

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Qualitative Comparative Analysis

QCA engages with complex causality by treating cases as whole configurations of attributes

I.e. It considers all relevant aspects of a case at once, e.g.

- Scored highly
- Regular attendance
- No regular reading
- Did not do formative
- Started early

- Did not scored highly
- Regular attendance
- No regular reading
- Did formative
- Started late

The bare-bones basics of crisp-set QCA

Phase 1: Identify relevant cases and causal conditions

1-1. Identify the **outcome** that you are interested in and the cases that exemplify this outcome. Learn as much as you can about these "**positive**" cases.

1-2. Based on #1, identify **negative** cases—those that might seem to be candidates for the outcome but nevertheless failed to display it ("negative" cases). Together #1 and #2 constitute the **set of cases relevant to the analysis**.

1-3. Again based on #1, and relevant theoretical and substantive knowledge, identify the major **causal conditions** relevant to the outcome. Often, it is useful to think in terms of different causal "recipes"—the various combinations of conditions that might generate the outcome.

1-4. Try to **streamline** the causal conditions as much as possible. For example, combine two conditions into one when they seem "substitutable."

Qualitative Comparative Analysis

Crisp-Set QCA operationalises attributes as dichotomous categories

For example, explaining student attainment:
- **Scored highly,** i.e. summative score of **70 or higher**
- **Regular attendance**, i.e. went to **7+** lectures
- **Regular reading**, i.e. did reading for **7+** lectures **during term**
- **Formative work**, i.e. **submitted** the formative assignment
- **Early start**, i.e. started summative **3+ weeks** before deadline

Avoid arbitrary categorisation:
- Divisions should be justifiable on **theoretical**, **substantive** or **technical** grounds

Qualitative Comparative Analysis

Reading is a sufficient factor by itself and so explains some of the successful outcomes…

Scored Highly	Attendance	Reading	Formative	Started Early	Num. Cases
Yes	Regular	Regular	Yes	Yes	2
Yes	Regular	Regular	Yes	No	3
Yes	Regular	Irregular	Yes	Yes	6
Yes	Regular	Irregular	No	Yes	2
No	Regular	Irregular	Yes	No	11
No	Regular	Irregular	No	No	10
No	Irregular	Irregular	Yes	No	4
No	Irregular	Irregular	No	Yes	2

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Integrating CBMs and ABMs

Link 1: agents are cases doing things

The first link between ABM and CBM is based on recognising the extent to which the agents in an ABM can be defined as cases doing things. This link comes from Abbott's chapter *What do cases do?* in Ragin and Becker's *What is a case?* (1992). Abbott's argument is rather straightforward. He begins by defining what, for him, constitutes a case – and it is this definition that we follow throughout our study. A case is either an instance of a conceptual class or larger population (1992, p. 53). Conceptual classes are social categories or typologies such as those used in intersectionality theory (e.g. economic status, age, nationality, ethnicity, gender, educational level, etc). In such instances, a *case* is a *type*, such as an affluent, younger, professor as compared to a poor, older, lorry driver.

Advantages of link

Abbott's link between cases and agents – which has been at the empirical heart of QCA for the past 25 years (Ragin, 2014) – is useful for our epistemological bridge because it demonstrates the two ways that the agents in an ABM are cases. First, in terms of an ABM's conceptual classes, its catalogue of agent types is the same as a list of case types (e.g. for NetLogo users the 'breeds' in a model). And, in terms of an ABM's population, its subgroups (as in the case of geospatial location) are the same as a list of case subsets. The advantage of recognising these similarities is that it allows ABM researchers to make more systematic use of the CBM concept of cases to frame model development, analysis and the presentation of results.

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Integrating CBMs and ABMs

Link 2: cases are complex evolving systems

The second link between ABM and CBM, which extends Abbott's insight, can be built by recognising the extent to which most cases are complex systems and, therefore, in varying degrees agent-based. This link comes from Byrne and Ragin's *The Sage handbook of case-based methods* (2009), wherein Byrne (Chapter 5) empirically demonstrates that cases are often best modelled as complex evolving systems, given that they are: (1) comprised of a complex causal configuration of variables; (2) grounded in a wider context; (3) dependent, in part, on their initial conditions; (4) path dependent; and (5) irreducible to their constituent set-theoretical formations and therefore emergent. They are also, variously, (6) agent-based, given that few social scientific phenomena, particularly social complexity, are static or without agency.

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Integrating CBMs and ABMs

For Byrne, by saying cases are agent-based he means that cases are best understood and modelled as self-organizing, emergent, dynamic, nonlinear, and (ultimately) interactive (Byrne & Callaghan 2013). More specifically, he means that cases are often, as in an ABM, decision-making or behaviour-doing actors – which are often also in interaction with one another. Household migration patterns, as we will see in our case study, are a good example. In other instances, however, cases are better modelled as comprised of multiple forms of agency or, alternatively, sets of agents. A good example, which we will also see in our case study, is a community. Before we proceed, however, it needs to be stated up front that, despite Byrne's empirical insight, cases do not always have to be modelled as complex or agent-based, as the aims of a study might differ. Nonetheless, subsequent research by Haynes (2017) and others has strongly supported Byrne's complex systems view of cases (Castellani et al., 2015a, 2015b; Williams & Dyer, 2017).

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Integrating CBMs and ABMs

Advantages of link

In terms of CBM, Byrne's complex systems view is useful because it challenges researchers to give more attention to the various ways that their study and its composite variables are agent-based; that is, how cases engage in some form of social action or behaviour – which few QCA studies, for example, explore. In turn, it also challenges CBM researchers to think about how cases interact, how these interactions impact their respective trajectories, and what are the emergent macroscopic consequences of these various interactions, or more generally, collective behaviour. Again, these are forms of analysis that very few QCA studies do. As such, as Haynes has pointed out (2017), thinking about case-based dynamics is a major advance on CBM and, more specifically, QCA method.

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Integrating CBMs and ABMs

Link 3: ABM and CBM as computational modelling

The third link between ABM and CBM can be built by recognising how both methods are part of the larger *case-based modelling trend* in computational methods. Before we proceed, however, a caveat is necessary. Unlike the previous two links, the third is not specific to QCA. Instead, it focuses on connecting ABM and CBM to recent advances in computational modelling, which are variously case-based. From this perspective, a typical row vector c_i in a computational model, mathematically speaking, is comparable to a QCA or ABM case and its profile. In turn, a database D consisting of row vectors $c_i = (x_{i1}, x_{i2} \ldots, x_{ik})$ – even if calibrated using Boolean algebra – is roughly similar to a QCA *truth table* or, alternatively, an ABM set of agents.

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Integrating CBMs and ABMs

- Following Witten, Frank, Hall, and Pal (2016), examples of the latest trends in computational modelling include data mining (e.g. Bayesian statistics, cluster analysis), social network analysis (agent-network theory, complex networks), data visualisation (e.g. computer graphics, visual complexity), machine intelligence (e.g. genetic algorithms, artificial neural nets), dynamical systems theory (e.g. continuous dynamical systems, synergetics), and geospatial models (e.g. gravity models, spatial analysis).
- And all of these methods (albeit to varying degrees) can be counted as an improvement on conventional statistics, mainly because they avoid variable-focused and aggregate-based one-size-fits-all solutions.
- In other words, they are better at modelling complex causality because (similar to QCA) they are case-based (Burrows & Savage 2014). For example, by focusing on MRI images (as cases), neural nets can identify tumour or disease types and their change over time; genetic algorithms, in turn, can identify reliable trends in stocks (cases) for strong investment opportunities; and, by treating storms or automobiles as cases, differential equations modelling can detect subtle changes in weather or traffic patterns (Witten et al., 2016).

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Integrating CBMs and ABMs

Advantages of link

- First, the utility of this link is that it widens the definition of case-based methods, in particular QCA, to include the techniques of computational modelling.
- Second, as others have likewise been doing (e.g. Gilbert et al., 2018; Keuschnigg et al., 2018), this connection allows us to further link ABM with the latest advances in computational modelling, particularly longitudinal methods.
    - Unlike QCA, most computational modelling methods regularly focus on how cases, in the form of trends, evolve across time/space (Han, Pei, & Kamber, 2011).
    - This improvement in modelling cases longitudinally is key, as it allows us to make an important advance on social science methods.

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Advantages for CBMs

Overall, as our case study hopefully suggests, for CBM scholars the main advantage of combining their methods with ABM is that:

- they can more effectively study the behaviours and interactions of cases;
- the impact these social inter-actions have on their respective trajectories and trends;
- and, in turn, the larger emergent macroscopic systems of which they are a part.
    - Such an advance is significant, particularly for QCA, because other than a small set of specific methods, such as dynamic pattern synthesis (Haynes, 2017) and case-based density modelling (Rajaram & Castellani, 2012), most CBMs are not designed to study multiple longitudinal trends across time, or they do not do so as effectively as ABMs.
- The other major advance that ABM provides for CBM is that, once a model has been developed, it provides the capacity to further explore counterfactuals and to inspect how different scenarios or interventions might impact case-based outcomes or drive a study in a different or more desired direction, as in the case of public policy or social services.

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Advantages for ABMs

- The main advantage CBM provides ABM is the capacity to engage in a more sophisticated preliminary investigation of the causal complexity it seeks to simulate.
- In other words, to repeat an earlier point, CBM allows ABM researchers to more explicitly and formally connect together – under a common goal of embracing rather than reducing complexity – CBMs that cluster or catalogue cases and their complex causality with their ABMs, which study the collective dynamics of these cases (as agents) in complex systems terms across time/space.
- Such an advance is significant because, beyond the collection of qualitative or historical data, current convention in ABM relies heavily on conventional variable-based statistics for use in the model-building phase, specifically the design and validation of micro-level agent rules (Yang & Gilbert, 2008).
- These traditional approaches provide analyses that contradict the complexity-based epistemology of ABM. By making use of CBM analyses in the model design phase, ABM researchers will no longer have to take part in this epistemological cognitive dissonance.

Advantages for ABMs

In terms of the specifics of model design, using or conducting a CBM analysis has the following advantages. First, it would provide ABM researchers further information from which to identify the different agent types for their model. In the case of Castellani et al. (2015b), for example, the results of their CBM inquiry allowed them to identify and validate the use of three key agent types: rich, middle and poor households.

Second, it would allow ABM researchers to more effectively calibrate their models (e.g. choose the best micro-level agent or model designs and parameter values that make the model produce plausible results) and create the rules and conditions that govern the behaviour of different agents. For example, in the case of Castellani et al. (2015b), they were able to realise that the key rules revolved around rich agents trying to escape into suburban neighbourhoods of privilege and position, while chased closely behind by middle agents, who were being pursued by the poor but upwardly mobile households. They were also able to write these rules as a continuum from very aggressive outmigration to restricted outmigration, which allowed them to test varying levels of segregation.

Advantages for ABMs

More abstractly, the outputs of CBM analysis – in which casual complexity is described more fully for a particular setting – provide modellers a richer picture of the factors (i.e. different configurations of factors associated with an outcome) that are important to model or include in their micro-level agent rules. In the case of Castellani et al. (2015b), for example, this picture included larger deindustrialisation trends in the Midwest and the turn by the middle and professional classes to a life in the suburbs.

Finally, using CBM allows ABMs to link their different agent types and their corresponding trends to key outcomes to empirically validate the complex emergent results of an ABM – which are often difficult to narrate and interpret, or are compared uncritically to traditionally aggregated data (i.e. using averages). For example, Castellani et al. (2015b) were able to take the results of their suburban sprawl model and compare its results with actual geospatial data of out-migration trends (broken down in the same way as their case groups) in the county they studied, which they found did reasonably support the community-level insights of their model. However, given the limitations and lack of available data, they were not able to empirically validate the model's insight that a more restricted approach to suburban sprawl would dissolve the community-level health poverty traps they found in their data.

Advantages for ABMs

More abstractly, there are two key ways CBM analysis could be used to aid in model validation. First, micro-level outcomes could be validated using the findings of CBM analysis; that is, patterns that are observed in real data using CBM could be looked for in model behaviour. Second, real-world data used in model development and validation could be aggregated or re-framed in case-based forms, or indeed data could be collected in case-based forms, to allow the model to validate against more appropriate benchmarks (i.e. rather than against population averages which do not capture non-normal distributions).

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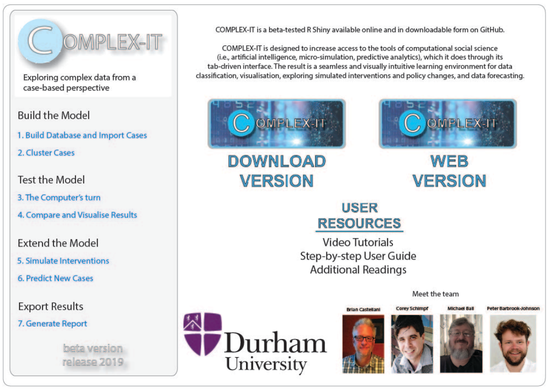
What is COMPLEX-IT?



Case-based scenario simulation

Integrating microsimulation and case-based methods

Third, it offers the ability to analyze how different clusters or the entire complex system of study might react to various possible scenario changes or interventions in order to help users plan for the multiple contingencies and paths the cluster/trends and system face.

Fourth, unlike agent-based modeling, CBSS always empirically dependent and driven, starting with the user's data (Castellani, Barbrook-Johnson & Schimpf 2019). In other words, one has to use data to employ the CBMM approach.

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What is COMPLEX-IT?

- COMPLEX-IT is a web-based software tool that can be accessed through the web or downloaded and run locally and which is designed to increase the access of policy evaluators to the tools of computational social science (i.e., artificial intelligence, micro-simulation, predictive analytics).
- It does this through an intuitive interface, with quick access to introductions on concepts and methods, and directions to richer detail and information for those who want it.

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What is COMPLEX-IT?

- The result is a seamless and visually intuitive learning environment for exploring your complex data; from data classification, to visualisation, exploring simulated interventions and policy changes, and finally, data forecasting.
- You don't need any technical expertise to start using COMPLEX-IT, all that is required is a data set you want to explore, and a curious mind!

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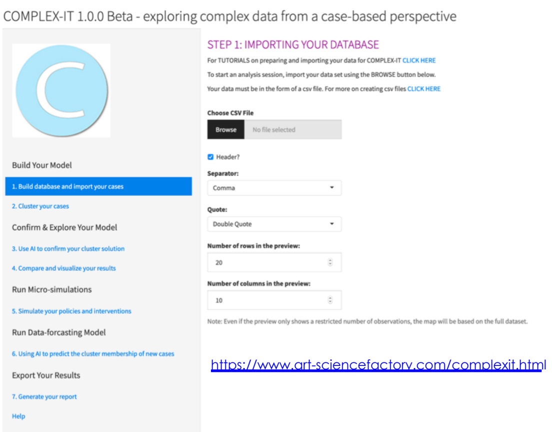
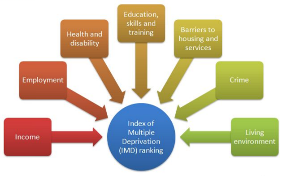


https://www.art-sciencefactory.com/complexit.html

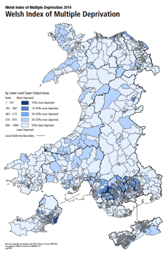
WELSH DEPRIVATION INDEX

What is Multiple Deprivation?

The Index of Multiple Deprivation is the government's geographical measure of multiple deprivation, produced every three years. It takes into account seven types of deprivation and combines them into one index where 1 is the most deprived and 32,482 is the least deprived in England and Wales.



garrysimmons.org.uk



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Case-based scenario simulation

Integrating microsimulation and case-based methods

The purpose of CBSS is to create a simulated environment for users to visually and statistically explore different possible scenarios and outcomes for the clusters of cases identified earlier in the data analysis process.

To do so, CBSS follows case-based modeling in leveraging k-means cluster analysis as a user-driven way to identify major and minor clusters/trends among a set of cases.

The case cluster/trends identified by k-means are then corroborated and extended through the self-organizing map (SOM), an artificial neural network technique that preserves the topography of analyzed data and which is commonly used in conjunction with k-means.

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Case-based scenario simulation

Integrating microsimulation and case-based methods

The scenario simulation component of CBSS enables targeted exploration of how case trends respond to various plausible scenarios they may encounter, ranging from strategic interventions in the systems of study to external events affecting it.

CBSS draws inspiration and builds upon two methodological traditions.

- First, it is informed by microsimulation and agent-based modeling, which model differentiated units at approximately the same level of abstraction (usually the microscopic level), such as a set of famers in a rural community. CBSS similarly emulates differentiated units, however, its focus is mesoscopic in the form of case-based clusters and trends.
- Second, CBSS draws on the tradition of scenario analysis or scenario planning, a broad collection of techniques for developing multiple scenarios an entity might experience. These scenarios are then evaluated in terms of their impact on the entity in order to learn about possibilities scenarios might engender and inform decisions about the entity under uncertain circumstances. This mode of scenario exploration is central to scenario simulation presented here.

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THANK YOU
QUESTIONS

brian.c.castellani@durham.ac.uk
TWITTER: @complexcase