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Published Version

Peer-review status of attached file:

Peer-reviewed

Citation for published item:

Cooper, B. and Glaesser, J. (2010) 'Contrasting variable-analytic and case-based approaches to the analysis of survey datasets : exploring how achievement varies by ability across configurations of social class and sex.', Methodological innovations online., 5 (1). pp. 4-23.

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METHODOLOGICAL INNOVATIONS Online

Methodological Innovations Online (2010) 5(1) 4-23

Contrasting variable-analytic and case-based approaches to the analysis of survey datasets: exploring how achievement varies by ability across configurations of social class and sex

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Abstract

The context for this paper is the ongoing debate concerning the relative merits, for the analysis of quantitative data, of, on the one hand, variable-analytic correlational methods, and, on the other, the case-based set theoretic methods developed by Charles Ragin. While correlational approaches, based in linear algebra, typically use regression to establish the net effects of several "independent" variables on an outcome, the set theoretic approach analyses, more holistically, the conjunctions of factors sufficient and/or necessary for an outcome to occur. Here, in order to bring out key differences between the approaches, we focus our attention on the basic building blocks of the two approaches: respectively, the concept of linear correlation and the concept of a sufficient and/or necessary condition. We initially use invented data (for ability, educational achievement, and social class) to simulate what is at stake in this methodological debate and we then employ data taken from the British National Child Development Study to explore the structuring of the relationship between respondents' early measured ability and later educational achievement across various configurations of parental and grandparental class origin and sex. The substantive idea informing the analysis, derived from Boudon's work, is that, for respondents from higher class origins, ability will tend to be sufficient but not necessary for later educational achievement while, for lower class respondents, ability will tend to be necessary but not sufficient. We compare correlational analyses, controlling for class and gender, with fuzzy set analyses to show that set theoretic indices can better capture these varying relationships than correlational measures. In conclusion, we briefly consider how our demonstration of some of the advantages of the set theoretic approach for modelling empirical relationships might be related to the debate concerning the relation between observed regularities and causal mechanisms.

Keywords: Correlational Analysis, Set Theoretic Analysis, Qualitative Comparative Analysis (QCA), Configurational Analysis, Necessary and Sufficient Conditions, Boolean Analysis, National Child Development Study (NCDS), Social Class, Gender, Educational Achievement.

Introduction

Much existing empirical research on social class and educational outcomes is of one of two types, comprising either large sample quantitative work employing some form of regression analysis or small to medium sample qualitative work employing some form of narrative or inductive analysis[1]. The former genre – our focus here – addresses correlations between variables and, in regression modelling, the effect of one or more variables on

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ISSN 1748-0612online
DOI: 10.4256/mio.2010.0007

some outcome. Individual cases, the carriers of the variables, usually remain in the background. It is variables that act, by having their effects on a dependent outcome variable. In the typical multivariate study, the purpose is to report the net (usually average) effect of each independent variable – i.e. its effects with other variables 'controlled' – on the chosen outcome variable. The underlying mathematics is matrix algebra and the basic tool is a symmetric measure of correlation. A typical paper will contain a table setting out a list of all the examined independent variables and, for each, a coefficient allowing its relative net importance to be assessed[2]. A typical question examined might be whether either cognitive or social variables, treated as independently contributing factors, explain more of the variance in educational achievement.

It is assumed in the default model that these 'independent' variables do indeed act independently of one another. As Ragin (2006a) argues, in this 'net effects' approach,

> … estimates of the effects of independent variables are based on the assumption that each variable, by itself, is capable of producing or influencing the level or probability of the outcome. While it is common to treat "causal" and "independent" as synonymous modifiers of the word "variable," the core meaning of "independent" is this notion of autonomous capacity. Specifically, each independent variable is assumed to be capable of influencing the level or probability of the outcome *regardless of the values or levels of other variables* (i.e., regardless of the varied contexts defined by these variables). Estimates of net effects thus assume *additivity*, that the net impact of a given independent variable on the outcome is the same across all the values of the other independent variables and their different combinations. (pp. 14-15)

Such causal homogeneity across cases is typically *assumed*. The effect of, say, measured ability on educational achievement is usually reported, net of the effects of competing variables, in terms of a single coefficient applicable to all cases in the sample or, by inference, in the population. It is usually only in particular specialist fields that the possibility of causal heterogeneity is addressed[3]. For those who regard regression models as more than description, these assumptions – actually assumptions about the causal structure of the social world – allow the prediction of an outcome for a new case from the same population to be made simply by adding the effects due to the values of various independent variables for that case.

The regression approach has received considerable critical discussion over a long period, and not only from those 'qualitative' writers who regard its being 'positivist' as an adequate reason to dismiss it. Turner (1948), long ago, raised serious worries about the assumption of 'a causally homogeneous universe' and of linearity in his discussion of statistical logic in social science. Meehl (1970) raised major problems about the conceptualisation and adequacy of 'control' variables. There is also interesting relevant discussion in Abell (1971). Lieberson (1985), in a book that deserves much greater attention, developed such critical points in a number of fruitful directions. Freedman (e.g. 1991) focused critical discussion on regression used as a causal modelling procedure. Pawson (1989) offered an incisive critique of the weaknesses of the variable analytic tradition. Abbott (2001) unpacked many of the fundamental but often unrealistic assumptions of the linear modelling approach in social science and explored some case-based alternatives. Byrne (e.g. 2002) employed complexity theory to draw attention to analytic weaknesses that flow from the central assumptions of conventional quantitative analysis.

The crucial difference between the linear algebraic approach and an alternative that drops the assumption of 'independence' is summarised by Mahoney & Goertz (2006) in their discussion of the set theoretic alternative to regression and the way in which it addresses causal complexity via the language of necessity and sufficiency. Set theoretic (Boolean) equations have a different functional form to the regression equations with which social scientists are familiar. Here is their illustrative (and deterministic[4]) example:

$$Y = (A*B*c) + (A*C*D*E)$$

In these equations the symbol * indicates Logical AND (set intersection), + indicates Logical OR (set union), upper case letters indicate the presence of factors, and lower case letters indicate their absence. In this fictional example of causal heterogeneity, the equation indicates that there are two causal paths to the outcome Y. The first, captured by the causal configuration A*B*c involves the conjoined presence in the case of features A and B, combined with the absence of C. The second, captured by A*C*D*E, requires the joint presence of A, C, D and E. Either of these causal configurations is sufficient for the outcome to occur, but neither is necessary, considered alone. The factor C behaves differently in the two configurations. The factor B in this equation is an example of what are termed INUS conditions. An INUS condition is 'an *insufficient* but *non-redundant* part of an *unnecessary* but *sufficient* condition' (Mackie, 1980, p. 62). Cartwright & Stegenga (2008) have argued, compellingly, that all *causes* are in fact INUS conditions, but that the reverse is not necessarily true.

Wanting to move away from a purely critical stance on regression modelling, Ragin (1987, 2000, 2008), in the context of political science, has developed both an account of and tools for this set theoretic analytic approach, building on the assumptions of qualitative case study but coupling these with an avowedly 'scientific' approach to social science not, in recent years at least, usually associated with that tradition. Ragin has argued that a concern with net effects has severely limited the progress of social science and has shifted his attention to complex configurational causation, to INUS conditions, to necessity and sufficiency. In his *Qualitative Comparative Analysis* (QCA), which draws on Mill's logic as developed by Mackie, combinations of the presence and/or absence of usually *non-independent* factors are seen as the necessary and/or sufficient conditions for outcomes to occur. Multiple causal paths to outcomes are seen as characterising much of the social world. Causal heterogeneity across types of cases is something to be expected, with the effects of particular causes depending on the configurations of other factors characterising the case (George & Bennett, 2005; Mahoney, 2008).

In the context of education, for example, the causal role of ability might be expected to differ not only in relation to the social class and gender of an individual, but also by the type of educational regime within which the child's career is played out, and perhaps by the interaction between these. More generally, much theoretical argument in the sociology of education implicitly, and sometimes explicitly, addresses non-linearity and/or relations of necessity and sufficiency. For example:

- Boudon (1974a) accounts for the social distribution of educational achievement in terms of primary and secondary effects. The primary effects of social class create some part of the differences in measured ability/achievement early in a child's career while secondary effects, arising from the ways in which the perceived costs and benefits of subsequent educational decisions vary by class origin, lead to further class differentiation of outcomes, even amongst those with similar levels of early achievement. This account has a clear affinity with a description of the form, 'early achievement is necessary but not sufficient for later achievement'.
- Bourdieu's theory of capitals has included, at various times, the claim that educational capital has to be combined with other forms of capital to receive its full economic and social return. Here, educational capital is not sufficient for certain outcomes unless conjoined with other forms such as social capital (Bourdieu, 1974).
- Turner's (1960) classic ideal typical account of the then school systems in the USA and England implies that educational success is a function of the interaction of the stratification regime and an individual's characteristics.
- Lacey's (1970) *Hightown Grammar* included the claim that the reaction of boys to academic pressure in the grammar school was a function of their class origin / relevant family resources rather than simply linear.

- Cooper and Dunne (2000), in their sociological analysis of national testing in mathematics in England, showed how, given class differences in semantic orientation, particular forms of test item could, for children from particular class backgrounds, render mathematical knowledge necessary but not sufficient for success, while other forms could even render such knowledge unnecessary (see Cooper & Harries (2009) for further evidence).

None of these theoretical accounts of causal processes are simply linear. The ideal typical relation for linear regression has the same form as Hooke's Law describing the effect of increased force on the extension of a spring. None of these examples have an affinity with this ideal typical case of a causally homogeneous linear relation. They do seem, on the other hand, to have an affinity with the set theoretic, configurational, approach.

We have used the configurational / set theoretic approach in analysing survey data on class, education and mobility (e.g. Cooper, 2005a, 2006; Cooper & Glaesser, 2007, 2008a,b; Glaesser, 2008). In this paper, we will draw on this experience to make some general critical arguments concerning the over-reliance on correlational ways of thinking in quantitative educational research and to illustrate how the set theoretic alternative can provide a fruitful alternative approach. We have chosen to focus our discussion on one running example, the varying relationship between measured ability[5] and eventual educational achievement across types of cases.

In this paper, rather than focusing on the differences between these two approaches as they appear in the summary equations that finalise analyses of datasets, we concentrate on the properties of the basic building blocks of the two competing approaches. For most regression analyses, the basic building block is linear correlation. For the configurational approach it is the set theoretic concept of a sufficient and/or necessary condition. Our strategy will be to begin with a discussion of an artificially created sample of 194 cases for whom we have invented data on ability, later achievement and social class. The discussion of these fictional cases will allow us to bring out some clear differences between the correlational and the set theoretic approaches. First, we show that there are features of this dataset that correlational methods miss. Since these missed features – by our design – concern relations of sufficiency and necessity, we need a set theoretic approach to describe them. We therefore then interrupt our discussion to introduce the basic elements of the set theoretic approach as developed mainly by Charles Ragin. We then use this approach to make sense of the 'anomalies' that arose in our correlational analysis of the invented dataset. Having shown that the set theoretic approach can make better sense of the invented dataset than the correlational approach, we then move to present some comparable real results, drawing on some new analyses of data from the National Child Development Study (NCDS). We will make considerable use of graphical representation.

The artificial dataset: a correlational analysis

There are several reasons for including this simulation, including:

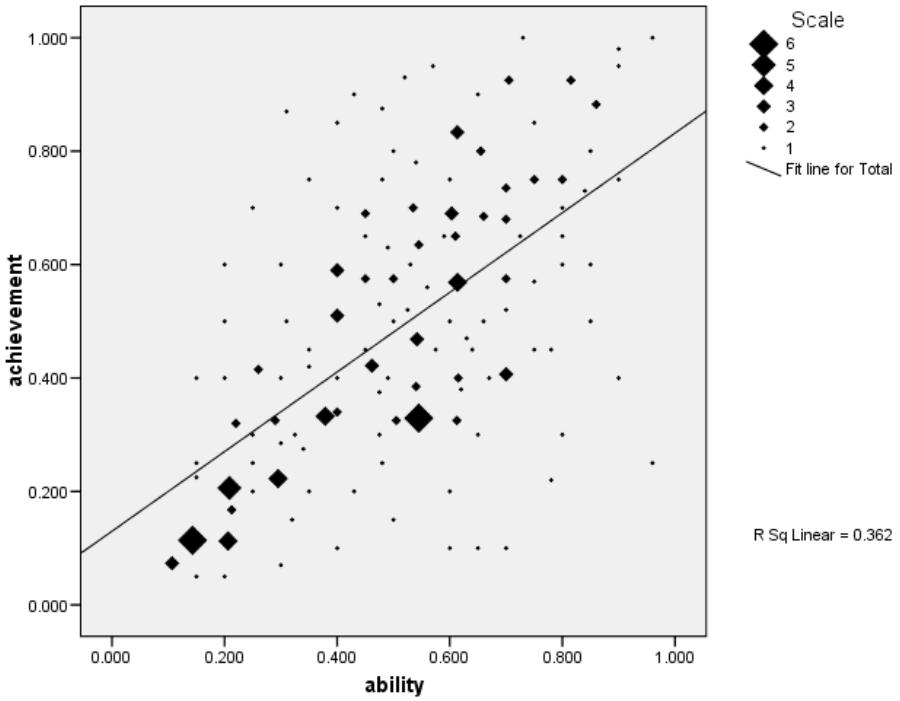
1. To discuss the causal homogeneity assumption and illustrate the ways in which it can mislead.
2. To remind us that correlations can be improved by modelling causal heterogeneity[6], i.e. by taking account of types of cases.
3. To remind us that correlations of the same size can arise from different forms of relationship.
4. To indicate that these different forms of relationship sometimes can be described better and/or more readily in terms of set theoretic models than linear algebraic models.

The invented dataset for our discussion comprises 194 cases, organised into three types of case, differentiated by a respondent's belonging to one of three social classes of origin. The two other variables are each

respondent's (early) ability and (later) achievement. These two variables have been scaled 0-1 to facilitate our subsequent comparison with a set theoretic analysis of these invented data. In constructing the dataset, we have chosen values for ability and achievement for each case, taking social class into account, in order that our analysis of the dataset will be able to demonstrate an important point. This is simply that conventional correlational analyses of data may not bring out the existence of important relations of sufficiency and/or necessity in a dataset. That the relations between the variables in our invented dataset are not only pedagogically useful but also happen to have some similarity with empirical relations in the social world will become clear later in the paper, when we turn to analyse data from the NCDS.

The discussion of the invented dataset will be organised around simple scatterplots of achievement by ability. Figure 1 is the basic scatterplot of achievement against ability for these cases, with the size of each rhombus indicating the number of cases at any point. A linear regression line has been fitted.

Figure 1: achievement by ability (invented data for 194 cases)



Many elementary textbooks would describe this, by inspection, we think, as a moderate to strong relationship with possible outliers. The correlation between achievement and ability, with all cases taken together, is 0.60, with unadjusted variance explained therefore of 0.36[7].

Our next step is to introduce the data on class origin for these cases, i.e. to explore whether there might be causal heterogeneity across our three types here. First, though, in Table 1 are the means and variances for ability and achievement by class, with class 1 having the highest mean scores for both ability and achievement. (The greater variance for ability than for achievement in classes 1 and 3 might, for someone reflecting carefully on these parameters, indicate something important.)

Table 2 provides the correlations of achievement and ability by class, with the fact that they've risen over the overall correlation (from 0.601 to 0.739) suggesting that there is some sort of causal heterogeneity across classes here. A regression of achievement on ability for each class taken separately would give us, for each, an unadjusted variance explained of 0.739 squared, i.e. 0.546, against the figure for the dataset taken as a whole

of 0.361. Something clearly was lost when the cases were considered together. Recognising causal heterogeneity here – i.e. the existence of three types of cases – improves the predictive power of the regression models considerably.

Table 1: Ability and achievement: means and variances by class (for the invented data)

social class of origin		N	Minimum	Maximum	Mean	Variance
Class 1	Ability	43	.150	.960	.53581	.043
	Achievement	43	.350	1.000	.75140	.031
Class 2	Ability	78	.150	.870	.49679	.033
	Achievement	78	.200	.890	.49724	.032
Class 3	Ability	73	.100	.960	.48056	.058
	Achievement	73	.050	.800	.30278	.035
All cases together	Ability	194	.100	.960	.49934	.045
	Achievement	194	.050	1.000	.48040	.061

Table 2: Correlations between achievement and ability by class (for the invented data)

	Pearson Correlation	n
Class 1	0.739	43
Class 2	0.739	78
Class 3	0.739	73

The three coefficients are, by design of our dataset, identical. The question remains, though, what their being identical does or doesn't signify. Though many introductory textbooks forget to remind their readers of the fact, Pearson's correlation coefficient is designed for linear relationships. Since many relationships are not linear, we cannot assume that our identical coefficients indicate that the functional form of the relationship between ability and achievement is of the same nature within each of our three classes.

In this case, does linear correlational modelling capture the functional form of the achievement/ability relationship equally well in the three class contexts? With this question in mind, in Figures 2-4 we show the scattergrams for the relation we're focussing on broken down by class (with y=x lines added to facilitate our later discussion of an alternative set theoretic analysis). Figure 5, the scattergram for all cases, is reproduced here to facilitate visual comparison with these graphs. Those readers familiar with regression modelling – assuming they belong to the subset of such readers who pay attention to the finer points of their models – will have observed that the three scatterplots in Figures 2-4 are not of the same type. Indeed, of the three plots of residuals by predicted achievement (not shown here) only that for class 2 shows no problems with the linear regression model. Each of the other two – for classes 1 and 3 – show a pattern[8] '*indicative of "abnormalities" that require corrective attention*', to quote a classic SPSS manual (Nie et al., 1975, p. 342, our emphasis).

Now, an 'abnormality' is only such within some set of modelling assumptions. Rather than address these 'abnormalities' within a regression framework, we are now going to turn to an alternative framework – the set theoretic approach – which has an intrinsic affinity with the relationships between achievement and ability in classes 1 and 3. In doing so, we will, by shifting our underlying mathematical approach from the linear algebraic to the set theoretic, effectively transform these 'abnormalities' to 'normalities'.

Figure 2: Class 1 (invented data, n=43)

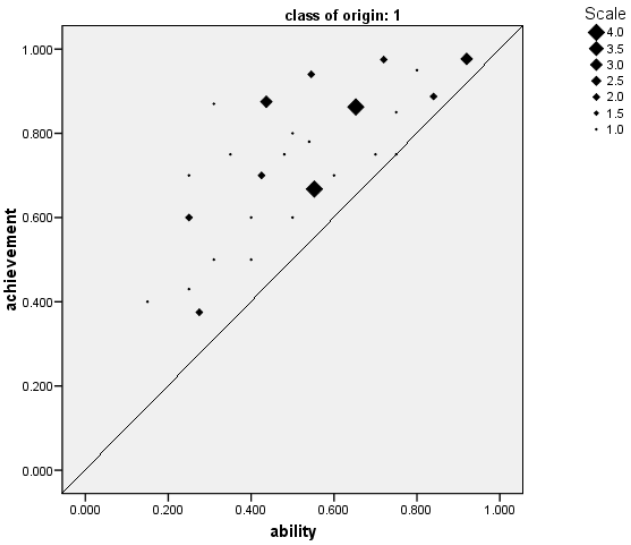


Figure 3: Class 2 (invented data, n=78)

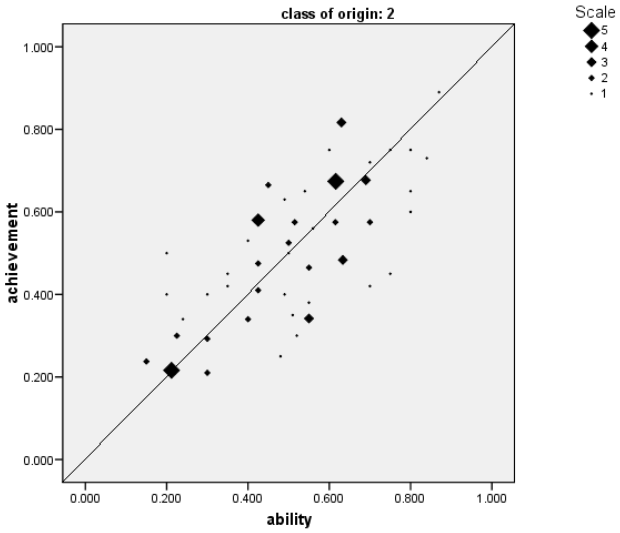


Figure 4: Class 3 (invented data, n=73)

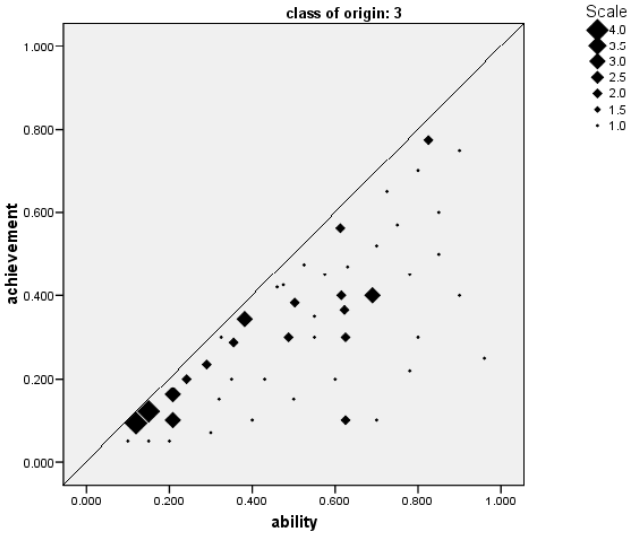
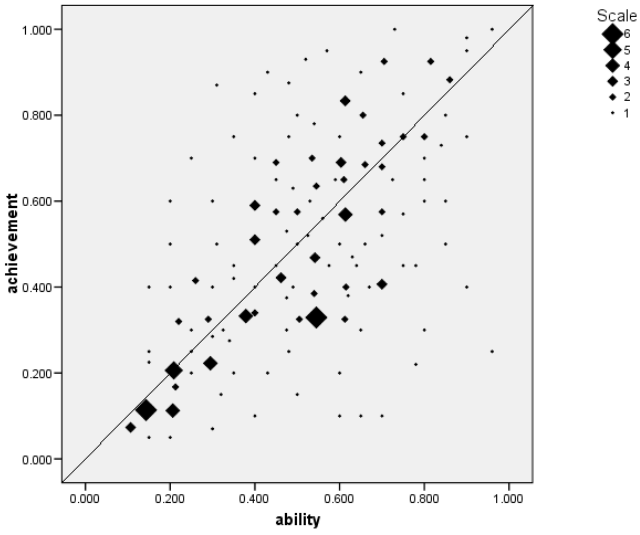


Figure 5: All cases (invented data, n=194)



Because we are working with scaled, i.e. non-dichotomous, data, we will need to employ a fuzzy set theoretic approach. Given the unfamiliarity of this approach we will now interrupt our discussion of these 194 cases in order to introduce the basic features of the set theoretic approach. Having done that, we will return to these three relationships between achievement and ability by class, treating them in terms of fuzzy sets, and reinterpreting them in the set theoretic language of necessary and/or sufficient conditions.

Basics of the set theoretic approach

Conventional sets are not, of course, fuzzy. Cases are either in or out of any set. If we were to dichotomise our two scales we could create sets of high ability and high achieving individuals. Forgetting our 194 cases for the moment, let us instead imagine some other artificial datasets for which we have this information. The Venn diagram in Figure 6 shows a case of perfect sufficiency (logical and, plausibly, causal). The condition set, that containing cases with high ability, is a subset of the outcome set, containing all cases achieving highly. It is important to note that while high ability is sufficient for high achievement here, it is not necessary. There are members of the set of high achievers who are not of high ability (the yellow subset). In this imaginary world there are other routes, or causal paths to high achievement. Of course, in the real social world there are not likely to be many relationships as simple and apparently deterministic as this. The next example addresses this.

Figure 7 is only slightly different, but the difference is a crucial one. Here, in another entirely imaginary world, a small proportion of the membership of the high ability set (shown in red) is not contained within the set of high achievers. We do not have a relationship of perfect subsethood and therefore of perfect sufficiency. We do, however, have something that approaches it. This is termed in the literature either quasi-sufficiency, near sufficiency or probabilistic sufficiency. Clearly, there can be degrees of it. The proportion of the condition set that is contained within the outcome set can be used as a simple measure of the *consistency* of the relationship with one of perfect sufficiency (Ragin, 2006b).

In one strand of the qualitative tradition of case study – one where causes are still happily discussed – and also in the literature on QCA, a likely next analytic move for Figure 7 would be to identify some other causal factor which, combined with high ability, would characterise just those cases who are within the set of high achievers (i.e. the green subset). Perhaps they are of high ability **and** not from a lower class background, for example. We would then have here a simple example of a conjunctural or configurational cause: being of high ability and not of lower class origin, conjoined, would be sufficient for the outcome.

Figure 6: Perfect sufficiency of high ability for high achievement in some imaginary world

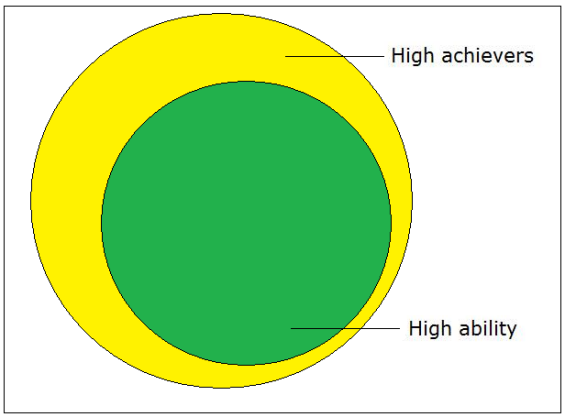
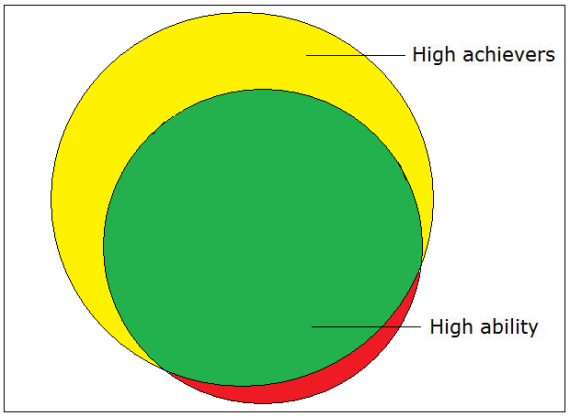


Figure 7: Quasi-sufficiency of high ability for high achievement in another imaginary world



While we are examining these diagrams we should also mention the concept of explanatory *coverage* (Ragin, 2006b). In Figure 6 the proportion of the high achievers set that is overlapped by the high ability set is clearly the proportion of those with the outcome 'explained' by their having high ability (subject to this claim making theoretical sense). Coverage in the set theoretic approach is analogous to variance explained in the regression

approach and can be partitioned similarly in more complicated set theoretic models where there are multiple causal paths to an outcome (Ragin, 2008).

We have shown that sufficiency, in the set theoretic context, is equivalent to a subset relationship. The condition set must be a subset (or near subset) of the outcome set. In the case of necessity, this is reversed, and the outcome set must be a subset of the condition set[9]. Figure 8 shows a situation in which the high achievers are a subset of those with high ability. Here, high ability is necessary (logically and, plausibly, causally) for high achievement, but it is not sufficient. Again, the analyst might want to explore factors that, combined with high ability, created combinations of conditions that were also sufficient. Being of high ability and from a high social origin might be a candidate configuration.

Figure 8: Perfect necessity of high ability for high achievement in yet another imaginary world

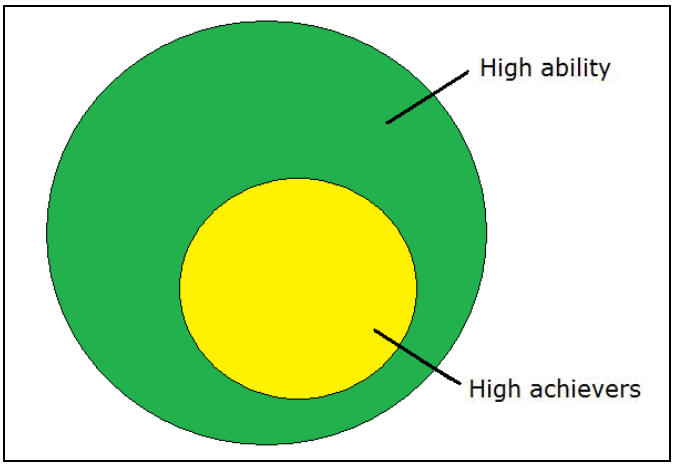


Table 3: Membership in the sets 'high achiever' and 'high ability'

	Not high achiever	High achiever
High Ability	Cell 1	Cell 2
Not high ability	Cell 3	Cell 4

These subset relationships can also be discussed in the context of crosstabulations of membership in two sets (Boudon, 1974b; Ragin, 2000). In the tradition of correlational analysis, there is a concern with symmetry. For a high correlation we would want cases mainly in both of cells 2 and 3 of Table 3[10]. However, a concern with sufficiency (or necessity) moves us away from this concern with symmetry. To test whether high ability is sufficient for high achievement, we only need to look at the first row, containing cells 1 and 2. The crucial thing is that there be no (or very few) cases in cell 1, since these contradict the claim that being of high ability is sufficient (or quasi-sufficient) for high achievement. Similarly, for necessity of high ability for high achievement, we only need to look at cells 2 and 4, and we don't want to see cases in cell 4. If we were testing for joint sufficiency and necessity of high ability for achievement, we would, of course, want to see no (or few) cases in cells 1 and 4.

So far, we have discussed crisp sets – those where a case simply is either in or out of a set, i.e. whose set membership is numerically given as either one or zero. Those familiar with the history of mathematics will not be surprised to learn that mathematicians have developed an account of sets, usually termed fuzzy sets, where membership is allowed to vary between these limits of zero and full membership. An example often used to illustrate partial membership is that of adulthood (Kosko, 1994). While most judges would agree that an age of ten would rule out adulthood (giving a membership score of zero) and one of 30 would rule it in (giving a membership score of one), there would be much more discussion about the age range 15 to 21, characterised by ambiguity. Here it would seem inappropriate to allocate a score of either zero or one – the only possibilities available in the crisp set context. In fuzzy set based descriptions of cases a score of 0.9 might be used for the 20 year-old to indicate almost full, but not quite full, membership of the set of 'adults'. A nineteen year-old might be allocated a score of 0.8[11].

The operations of conventional set theory (intersection, union, negation, subsethood, etc.) all have equivalents in fuzzy set theory (Goertz, 2006; Ragin, 2000; Smithson & Verkuilen, 2006). There is considerable ongoing debate within mathematics about the best way to define some of these operators in the fuzzy set context. We will use some commonly agreed and fairly intuitive versions. For example, the simplest way of assessing fuzzy subsethood uses an arithmetic approach. If the membership of a case in set A is less than or equal to its membership in set B, then this case passes the test for fuzzy subsethood (also called fuzzy inclusion). The proportion of cases *with non-zero membership* in the condition set A passing such a test can be used as a simple test of consistency with a relationship of sufficiency for some outcome set B (for a fuller account of the development of more complex measures of consistency with sufficiency and necessity in Ragin's work, see Cooper, 2005b). We will introduce other definitions as and when required.

We will now return to our 194 invented cases. From this point we will assume that our 0-1 scales for ability and achievement have arisen from a fuzzy calibration of these two factors, i.e. they are measures of partial membership in two fuzzy sets.

The artificial dataset: a (fuzzy) set theoretic analysis

First, we need to look again at the scatterplots (Figures 2-4). Simple inspection shows that the three graphs by class have different forms. Figure 2, for class 1, has all cases above or on the y=x line and is usually called an upper triangular plot (Ragin, 2000). Figure 4, for class 3, has all cases below or on the y=x line and is usually called a lower triangular plot. Figure 3, for class 2, is, more or less, characterised by reflective symmetry around the y=x line.

What, within a set theoretic approach, do these features indicate? We have already explained the simple arithmetic test for fuzzy subsethood. If we take Figure 2 for class 1, we can see that, for each case, the membership in ability is less than or equal to its membership in achievement. In fuzzy set terms, the ability set is a subset of the achievement set. Ability is sufficient for achievement. More intuitively, across the whole range of ability, a case's partial membership in the ability set is an effective floor below which its membership in the achievement set doesn't fall. Ability is not however necessary for achievement. This must be so, within the rules of fuzzy set theory, since the relevant test cannot be passed (for necessity, y scores must be lower to or equal to x scores). More intuitively, this can be seen by noting that high membership scores in achievement can be gained – in this imaginary world – with fairly low membership scores in ability. The upper triangular plot represents, then, a sufficient but not necessary relationship. In this imaginary world, there must be other causal paths to high achievement than simply ability alone (involving, one might speculate, such enabling conjoined factors as private tuition, private schooling, support from highly educated parents, etc.).

Similar reasoning shows that Figure 4, for class 3, represents a necessary but not sufficient relationship. Here membership in ability sets a ceiling for achievement, but there are cases where achievement does not seem to reflect ability as strongly as in others. Here, we can speculate, there must be other conjoined constraining factors that explain these cases' positions away from the diagonal (perhaps such conjoined constraining factors as poverty, etc.).

Clearly, we invented our 194 cases so that these two graphs would show perfect triangular plots. The simple arithmetic index of consistency with sufficiency (the proportion of cases with ability less than or equal to achievement) has its maximum value of 1 for class 1, and the analogous measure of necessity here is near zero. The pattern is reversed for class 3. What about class 2 (Figure 3)? This looks more like a textbook scatterplot, of course. The simple measure of sufficiency is 0.59 and of necessity is 0.54[12]. Even allowing quasi-sufficiency, we would not want to argue that, for class 2, ability is either sufficient or necessary for achievement. It might be, of course, when conjoined with some additional factors, but we have not designed our dataset set to explore such complexities. We can, however, note that the relation for class 2 is more-or-less symmetric. These results, together with those for the 194 cases taken as one group, are set out in Table 4[13].

Table 4: Set theoretic testing of the ability => achievement relationship (n=194, invented data)

Simple inclusion algorithm	Sufficiency	Necessity	Result: Ability is …
All classes together	0.459	0.598	Neither sufficient nor necessary
Class 1	1.000	0.023	Sufficient but not necessary
Class 2	0.590	0.539	Neither sufficient nor necessary
Class 3	0.000	1.000	Necessary but not sufficient

By presenting the analysis separately by class – in order to bring out the phenomenon of causal heterogeneity – we have moved the configurational nature of this analysis temporarily offstage. However, an examination of Table 4 allows us to write this simple example of a configurational set theoretic equation concerning sufficiency:

CLASS_1*ABILITY => ACHIEVEMENT

where capital letters indicate membership in the sets and the asterisk indicates set intersection. Ability, then, is sufficient for achievement – in this imaginary world – when it is conjoined with membership in class 1.

We created this example to illustrate an important point. A correlational approach, because it assumes linearity as a default, is not well-suited to address causality understood in terms of necessity and sufficiency. Indeed, we have shown how three identical correlation coefficients can be associated with three different forms of set theoretic relationship. What about real social data? How might we apply these ideas and techniques to bring out any complex asymmetric causality that characterises the social world? In the next section we will provide an illustration, drawing on the NCDS.

Social class and educational achievement in the NCDS: an illustration of the set theoretic analytic approach

Our purpose here is illustrative. We compare the merits of set theoretic and correlational descriptions of the ability/achievement relationship across types of conjuncturally defined cases. The relationship between these variables seems likely, given the claims of such sociologists as Boudon and Bourdieu, to vary, non-linearly, across types of classed and gendered cases. As we have shown above, a set theoretic approach should be an appropriate and fruitful way to elucidate any such causal complexity[14]. Specifically, we assess the set theoretic quasi-sufficiency of ability for achievement over types of cases defined by configurations of the conditions father's class, grandfathers' class and sex. We demonstrate that causal heterogeneity characterises the ability/achievement relationship, and that it has the same form as that described for our invented dataset.

Data and variables

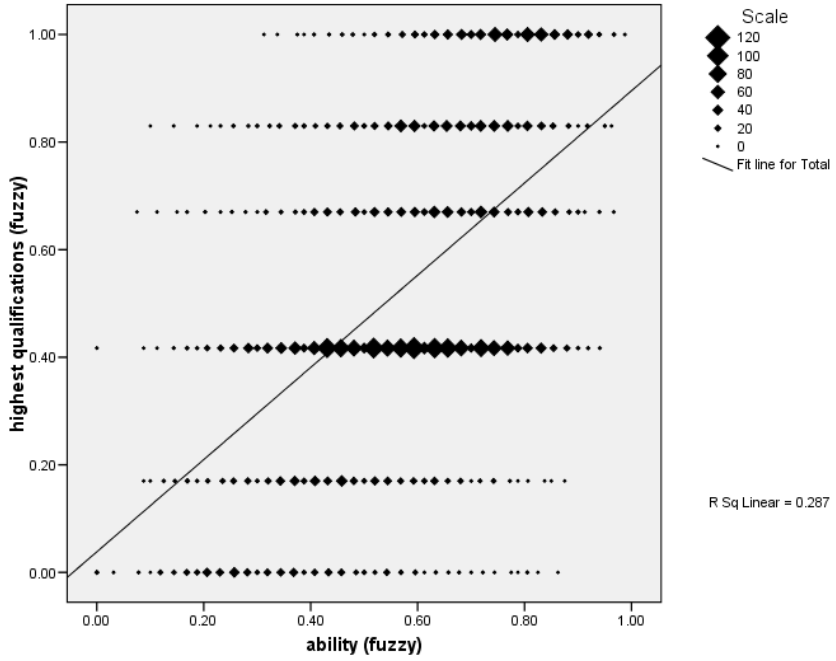
The NCDS is an ongoing longitudinal study of individuals born in one week in March 1958. We use a sample of 5117 cases from the NCDS with no missing values on the variables we employ here (and also class at birth, which we are using in some extended analyses not reported here)[15]. Measured ability (n920) is taken at age 11. The measure of achievement, highest qualifications obtained, is taken at age 33 and includes both academic and vocational qualifications (HQUAL). Because of the ways each grandfather's class was recorded we will be using the categories of the Registrar General's scheme for these, but we will be using an approximation to Goldthorpe's class scheme for the respondent's father's[16] class (at the respondent's age of 11). Given the illustrative nature of the analysis here, this mixing of categories, though undesirable, is of no consequence, we believe, for our arguments. We have, of course, to calibrate, as fuzzy sets, the original distribution of scores for the measures of highest qualification and ability. For highest qualifications we have used the calibration employed for another purpose in Cooper (2005a) which ranges from a membership of 0 for no qualification to 1 for a degree or better[17]. For measured ability, we have employed a very simple calibration (a linear transformation) which just rescales the original scores (0-80) to 0-1[18].

Causal heterogeneity: how does the ability/achievement relation vary by class background?

Before presenting evidence of causal heterogeneity in these data, we should provide the summary picture for all of the cases taken together. Figure 9 shows the distribution of achievement by ability for the 5117 cases, with the size of each rhombus indicating the number of cases at any point. A linear regression line has been fitted. The correlation coefficient is 0.535, with variance explained of 0.286. The scatterplot looks, at this global level, like a textbook example of a linear relation with a moderate correlation coefficient.

We can begin our exploration of heterogeneity with a hypothetical argument about likely relations. If we consider two contrasting sets of cases (i.e. configurations of factors), males with a class of origin towards the top of the social class distribution who also had grandfathers towards the top of this distribution, and then, by contrast, females who had fathers and grandfathers towards the bottom of the distribution, we can hypothesise, from the literature on class, gender and schooling in the relevant period, that ability might have tended towards being a sufficient condition for achievement for the former group (but perhaps not a necessary one) and towards being a necessary condition for the latter group (but perhaps not a sufficient one). As explained earlier, if this is so, we should expect an upper triangular plot of achievement against ability in the first case and a lower triangular plot in the second.

Figure 9: Achievement by ability with regression line (n=5117, from NCDS)



Taking these two subsets identified for our initial exploration, the two contrasting graphs in Figures 10 and 11 show the relevant scatterplots. In Figure 10 the cases are 60 males whose father was in Goldthorpe's class 1 (the upper service class) and whose grandfathers were both in either Registrar General's social class I or II. In Figure 11 the cases are the 94 females whose own father was in Goldthorpe's class 7 (the semi and unskilled manual working class) and whose grandfathers were both in RG class IV or V. The correlation between achievement and ability for the 60 males with the configuration capturing higher social origins here is 0.505 and for the 94 females with lower origins it is 0.472. These linear measures of the relationship suggest no important difference. However, an inspection of the scatterplots suggests that there is an important difference and that it is as predicted, with tendencies to triangular plots being clear to see.

Figure 10: 60 males from high class origins

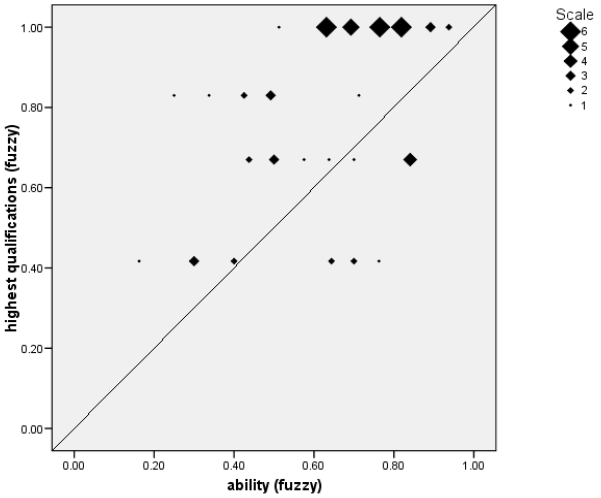
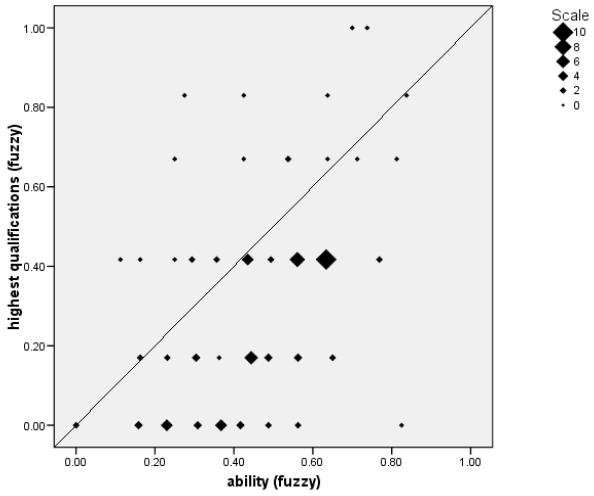


Figure 11: 94 females from low class origins



We cannot, of course, expect perfect triangular plots to turn up in an exploration of relations in the social world. Why not? The adequacy of the fuzzy set calibrations will be a contributory factor, as well as measurement error, plus the fact that this is a very simple model omitting many factors, and also the role of 'chance', however understood. Nevertheless, Figure 10 tends to the form of an upper triangular plot (sufficient, but not necessary) and Figure 11 to the form of a lower triangular plot (necessary, but not sufficient). If we calculate the simple fuzzy inclusion indices[19] of consistency with sufficiency and necessity we obtain, for Figure 10, values of 0.833 and 0.167 respectively. For Figure 11, the pattern is reversed, and we obtain 0.207 and 0.721. These values (on a 0-1 scale, recall) bear out the results of the visual inspection. Summarising, the clear tendencies are that:

- For the configuration
  HIGH_GRANDFATHERS'_CLASS*HIGH_FATHER'S_CLASS*MALE,
  ABILITY is sufficient, but not necessary, for later ACHIEVEMENT.
- For the configuration LOW_GRANDFATHERS'_CLASS*LOW_FATHER'S_CLASS*male,
  ABILITY is necessary, but not sufficient, for later ACHIEVEMENT.

Before moving on, we can note that a possibly fruitful next stage here would be to zoom in on the cases in order to explore what it is about those in Figure 10, for example, that puts some on one side of the sufficiency line and some on the necessity side. To some extent very individual factors will be involved (e.g. a bout of bad health, parental disputes, etc.) but there are also likely to be factors that split these 60 cases into meaningful subtypes (secondary school type and/or social composition of school attended, etc.). We are currently exploring some of these. An issue that arises very quickly – and one that tends to be glossed over in regression studies – is that of limited diversity (Ragin, 2006a). Even with large samples, a study employing more than a handful of factors soon encounters cells with few or even zero cases.

Any such zooming-in, we should note, does not take the form of seeking to control for other independent variables in the way the 'net effects' / 'average effects' regression approach does. It rather further specifies the nature of a type of case by expanding the configurational description or specification of its type. Here, the factors in the configuration are – subject to theoretical meaningfulness – seen as operating conjuncturally rather than additively to produce their effects. For example, a well-off grandfather may have helped with the fees necessary to put a son of moderate measured ability who had failed to win a selective grammar school place through a private school. Here, the grandfather's decision may have acted as an (enabling) switch, moving the child from a non-selective secondary modern school future where academic examinations may not have been available to one where they were, and hence *allowing* ability to produce its (perhaps moderate) effects.

We have obviously, for illustrative purposes, chosen two clearly contrasting examples. We can note, in passing, that from the point of view of theory development and testing, this is often an appropriate strategy (Seawright & Gerring, 2008). These two graphs would count against any simple theory that claimed that ability operated causally in the same manner across contexts of social class. The idea of an 'average effect' of ability on achievement (though it can be calculated) is not apparently a very useful one here. Having noted this, we can, without producing endless graphs, use the simple indices of consistency with sufficiency and necessity to explore the achievement/ability relation over various types of cases, setting them alongside standard Pearson correlation coefficients. We will do this in a way that illustrates the zooming-in idea, focussing, given space constraints, on just the sufficiency relationship.

Table 5 focuses initially on a fairly crude typology – just considering cases by paternal class of origin. We can see that the correlations vary little by class but that the simple fuzzy inclusion measure of consistency with sufficiency varies a lot. While, at this degree of resolution, none of the consistency measures is close to the 1.0 that would indicate perfect sufficiency, there is a clear pattern, with class 1 being nearest to this upper limit and class 7 furthest away. On the assumption that there is still likely to be considerable causal heterogeneity within each of these seven categories, we next aim to reduce this further by adding additional factors to the one (father's class) that gives us our types in this table. Theoretically meaningful candidates include sex and grandfathers' class. Let us start by adding sex to give types characterised by father's class and sex (Table 6). Once again the variability in the correlation measures is small, especially in comparison with the measures of consistency with sufficiency. More importantly, having increased the degree of resolution of our analysis, we now see both increases and decreases beyond the upper and lower limits we found when just class was conjoined with ability. For males from class 1 families, the index of consistency with sufficiency is 0.691; for females from class 7 it is 0.258.

Table 5: The ability -> achievement relation within types defined by paternal class origin

Goldthorpe Class	Correlations	N	Consistency: a measure of the degree to which ability is sufficient for achievement
1	0.455	585	0.643
2	0.494	876	0.545
3	0.457	498	0.464
4	0.544	313	0.373
5	0.502	322	0.391
6	0.486	1612	0.403
7	0.496	911	0.320

Table 6: The ability -> achievement relation within types defined jointly by paternal class origin and sex

Sex	Goldthorpe Class	Correlations	N	Consistency: a measure of the degree to which ability is sufficient for achievement
Male	1	0.468	288	0.691
Male	2	0.486	418	0.610
Male	3	0.444	246	0.569
Male	4	0.516	166	0.463
Male	5	0.581	172	0.453
Male	6	0.518	775	0.488
Male	7	0.503	439	0.386
Female	1	0.453	297	0.596
Female	2	0.520	458	0.485
Female	3	0.490	252	0.361
Female	4	0.616	147	0.272
Female	5	0.438	150	0.320
Female	6	0.478	837	0.325
Female	7	0.510	472	0.258

Table 7: The ability -> achievement relation within types defined jointly by paternal class origin, grandfathers' class and sex

Sex	Grandfathers both in class RG I or II	Goldthorpe Class	Correlations	N	Consistency: a measure of the degree to which ability is sufficient for achievement
Male	Yes	1	0.505	60	0.833
Male	Yes	2	0.539	40	0.700
Male	Yes	3	0.378	10	0.600
Male	Yes	4	0.574	39	0.605
Male	Yes	5	-0.310	7	0.571
Male	Yes	6	0.573	17	0.647
Male	Yes	7	0.556	9	0.778
Male	No	1	0.475	228	0.654
Male	No	2	0.479	378	0.601
Male	No	3	0.445	236	0.568
Male	No	4	0.501	127	0.421
Male	No	5	0.598	165	0.448
Male	No	6	0.517	758	0.485
Male	No	7	0.512	430	0.378
Female	Yes	1	0.358	59	0.661
Female	Yes	2	0.531	56	0.679
Female	Yes	3	0.604	11	0.818
Female	Yes	4	0.429	37	0.324
Female	Yes	5	0.822	3	0.667
Female	Yes	6	0.367	17	0.588
Female	Yes	7	0.733	9	0.333
Female	No	1	0.452	238	0.580
Female	No	2	0.507	402	0.458
Female	No	3	0.472	241	0.340
Female	No	4	0.649	110	0.255
Female	No	5	0.446	147	0.313
Female	No	6	0.483	820	0.319
Female	No	7	0.503	463	0.257

The final step we will take here is to add grandfathers' class to our typology. Let us assume that having both grandfathers in RG classes I or II is likely to have provided various cultural and financial resources to the respondent, some directly, some via his or her parents. Service class fathers, for example, will differ in important ways as a function of their own class origin. We now have cases defined in terms of the factors father's class, sex and whether grandfathers were in RG class I or II. Even with the grandparental generation treated dichotomously, this step generates a table with 28 rows[20] (Table 7). The problem of limited diversity is immediately apparent in Table 7. We would not want to draw strong conclusions from rows with very small numbers (though an in-depth examination of these unusual cases might, if possible errors of measurement or data entry could be ruled out, generate interesting insights). We now have, at this level of resolution, a row (in

yellow) representing the 60 cases discussed earlier (see Figure 10) with a consistency with sufficiency of 0.833. For these cases – defined by class over two generations and gender – measured ability is close to being sufficient for later achievement. This particular sufficiency relation could be written, in set theoretic notation, to indicate that, for the configuration FATHER'S_CLASS_1 * GRANDFATHERS'_CLASS_RGI_OR_RGII * MALE, ABILITY is quasi-sufficient for ACHIEVEMENT.

Inspection of the table shows other interesting relationships. In particular, several other sets of cases, of both sexes, have fairly high indices of consistency with sufficiency. It is also possible to see configurations of class and gender where ability is far from being sufficient for achievement (even though our splitting of grandfathers towards the top end of the social structure will tend to dilute such relationships). For example, for females from paternal social class 7, not having both grandfathers in RG class I or II, the index of consistency is just 0.257. For these cases, ability was clearly not sufficient for later achievement. We could present a similar tabular analysis for other levels and categories of the social class factors, and for necessity in addition to sufficiency, but won't, for reasons of space. The crucial point to note is that the correlation coefficients in Table 7 do not provide the insights provided by the set theoretic index of sufficiency.

We should add that, in the same way as a regression equation can be written to summarise the overall patterns of relationship between a dependent variable and some 'independent' variables in a dataset, a set theoretic equation can also be written to summarise those configurations of conditions that are sufficient for some outcome (with a form similar to the example we used earlier from Mahoney and Goertz's paper; see Ragin, 2000). We have no space to explain and illustrate this here (for a worked example for the dataset analysed here, see Cooper & Glaesser, 2009).

Conclusion

The debate that arose concerning Bhaskar's (1975, 1979) realist accounts of both natural and social science (e.g. Pawson, 1989; Ron, 2002) was, in part, focussed on the role regularities play in constructing causal accounts. From the perspective of early Bhaskarian realism, regularities were neither sufficient nor necessary for the establishment of knowledge concerning causal/generative mechanisms. They are not sufficient, if only because correlations are not always causal. They are not necessary, if only because complex interacting mechanisms in open systems can lead to the blocking of causal tendencies. These are sound arguments. However, it is important not to throw the baby out with the bathwater. Regularities can appear in open systems, though they may be less than perfect and may be complex in nature. They can also be made visible in closed systems, such as those artificially closed systems produced in experiments (Bhaskar, 1975; Cartwright, 1999). In the analysis of survey data, they can be expected to be more readily found when causal heterogeneity is correctly identified and taken into account, i.e. when types of cases are correctly identified, as we have shown here. By looking at relationships within the context of configurationally defined types, we have aimed to create a set of relatively closed systems in each of which the specific nature of the relationship between ability and achievement could be better discerned.

In open systems, since it is always likely that several causes will interact to produce the observed relationships in a dataset, the social scientist needs special tools to make visible the regularities associated with any particular subset of variables. The standard technique for producing/analysing the regularities arising from the action of any particular factor, net of the effects of other factors, is regression, built on the basis of correlation. Ron (2002) has argued that realists should not, contrary to the claims of some, underestimate the usefulness of this set of techniques. Nor do we, especially if what is wanted is knowledge of some average effect. On the other hand, the question must be asked, is regression-based modelling, built on the assumption of causally independent variables and linear algebraic correlation, likely to have a greater or lesser affinity with the

complex causality that characterises the social world than the set theoretic approach, built on the assumption of conjunctural causation and the concept of a sufficient and/or necessary condition? We are suggesting that, in some contexts, including that of the sociology of class and educational achievement, the answer may be that correlation-based regression models have a lesser affinity than set theoretic ones.

Pawson (2008) has recently stressed what is common to some uses of correlational methods (by 'sucessionists') and set theoretic methods (by 'configurationists') – a failure to focus on generative mechanisms in their search for the answers to 'why?' questions. He recommends a realist approach, focussing on such mechanisms, in their place. We are sympathetic to his critique. However, we would argue that, in the development and testing of theories that are themselves formulated – or can be appropriately reformulated – in the language of INUS conditions, of complex relations of sufficiency and necessity, the set theoretic approach is likely to be more useful than regression modelling for describing/testing empirical consequences, simply because the functional forms it employs have a greater affinity with the claims of such theories. Complex causality in the world requires appropriately complex models. The discussion earlier of our two examples, one invented, one real, was intended to provide some arguments and evidence for this claim.

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[1] The strengths of the qualitative tradition are its focus on meaning and interpretation, its concern to understand sequences of events and outcomes in context and its holistic treatment of individual cases. Notwithstanding the use of quantitative indicators in the not so distant past (Lacey's, Hargreaves', Ball's and others' studies of ability grouping all employed these long before 'mixed methods' became a focus of discussion), much recent case-based work in the sociology of education has eschewed numbers and formal analytic procedures.

[2] See, for example, all four papers in the October 2008 issue of *Sociology of Education*.

[3] For example, via the use of multilevel modelling in school effectiveness studies.

[4] This example assumes no empirical exceptions.

[5] Or early attainment, if some readers prefer that interpretation.

[6] This can be addressed in a regression framework too, of course, but in a correlational rather than a set theoretic manner, i.e. in a way that assumes that 'net effects' of individual variables are meaningful. See Clark et al. (2006) for an interesting relevant discussion.

[7] A visual examination of the residuals plotted against the predicted value of achievement suggests no major problems with the regression model. It is always possible, of course, to play at (descriptive) curve fitting to improve variance explained. If we do this, using SPSS, we can raise the variance explained from 0.36 by using either a power curve (to 0.44) or an S curve (to 0.46).
[8] The plots for classes 1 and 3 have a conical / funnel shape.
[9] In these simple cases, the proportional measure of the extent to which ability is necessary for achievement is equal to the explanatory coverage of ability for achievement when the sufficiency of ability for achievement is assessed.
[10] Or, alternatively, but less realistically given the example being used, in 1 and 4.
[11] A crucial difference from an interval scale measure for age should be noted. All ages over some threshold will here receive a score of one, indicating full membership of the set. From the set theoretic perspective, differences over this threshold are not relevant ones. Whether this calibration decision is actually appropriate in any particular context is a matter, of course, of the relevant kinds that exist in the social world and of their causal properties.
[12] Given some cases are on the y=x line, these don't add to one.
[13] An analysis using a more sophisticated measure of consistency (Ragin, 2008, p. 52) produces the same pattern of results, though, depending on where thresholds for quasi-sufficiency are set, can allow class 2 and the overall sample to be described as showing quasi-sufficiency and quasi-necessity.
[14] In this discussion we are, of course, using 'summarising' variables. The actual mechanisms and/or processes by which 'class' produces its causal effects are not our focus in this paper. Instead, we are attending to competing forms of description that might have greater or less affinity with the sorts of regularities, or tendencies towards them, that underlying causal mechanisms and processes produce.
[15] As is common in analyses of these data, our sample is much smaller than the original cohort, partly through attrition, partly because of missing values on these variables.
[16] There are no data on grandmothers and we use paternal class for the family to avoid the loss of many more cases that would arise were we to use a maternal measure.
[17] This is calibrated as a fuzzy set thus: No qualification: 0; CSE 2-5 / equiv NVQ1: 0.17; O Level / equiv NVQ2: 0.42; A Level / equiv NVQ3: 0.67; Higher qualification NVQ4: 0.83; Degree / higher NVQ5 , 6: 1.0 .
[18] Cooper (2005a) used a more complex calibration in line with the particular purposes of that paper. Here, our purpose is to illustrate the potential of the set theoretic approach as transparently as possible and, for this reason, we have chosen this simple approach. On the crucial importance of calibration, see Ragin (2006a, 2008).
[19] It is important to note that these are calculated only for cases with some degree of membership in the condition set (sufficiency) or in the outcome set (necessity) respectively, while the correlation coefficient is calculated for all cases.
[20] Within it, of course, we would expect the rows where GFs_I_II=1 to be more homogeneous that those where GFs_I_II=0.

Biographies

Barry Cooper is a Professor of Education in the School of Education at Durham University where he was, from 1998 to 2005, Director of Research. He was from 2004-2007 co-editor of the *British Educational Research Journal*. His interests are in the sociology of education, especially social class and educational achievement and the sociology of assessment, research methods (most recently, working with Judith Glaesser, exploring the application of fs/QCA to large datasets and the relations between fs/QCA and cluster analysis) and the evaluation of educational aid projects. His most recent book was, with Máiréad Dunne, *Assessing Children's Mathematical Knowledge: Social class, sex and problem-solving*.

Dr. Judith Glaesser is an ESRC Research Fellow in the School of Education at Durham University. Her interests include sociology of education, inequality and meritocracy in education, and research methods, particularly fs/QCA. She studied for a PhD at Konstanz University (published as *Soziale und individuelle Einflüsse auf den Erwerb von Bildungsabschlüssen).* Currently, with Barry Cooper, she is exploring the application of case-based methods to large datasets in comparing transitions in the English and German secondary school systems.