Qualititive Comparative Analysis

MEBVybrané metody výzkumu mezinárodních vztahů
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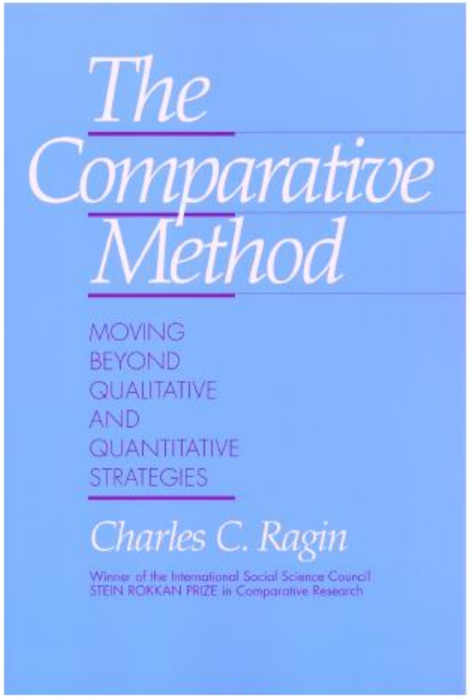
Outline

- Introduction
- Types of QCA
- Rationale for applying
- Set theory: basic logic
- Set Relations and Causal Complexity
- Calibration
- Truth Table

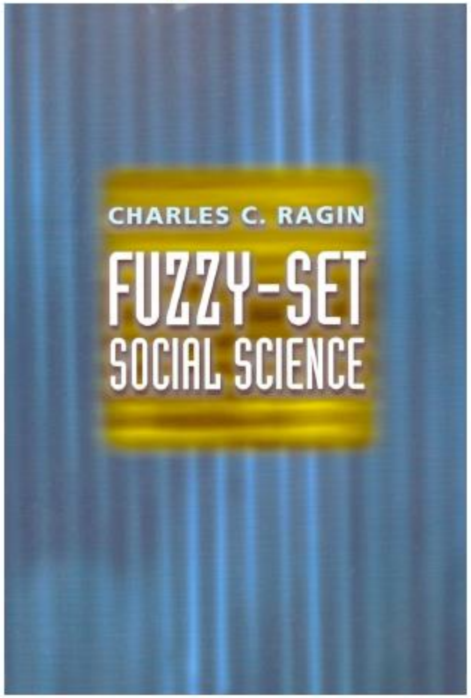
Key Books

Qualitative Comparative Analysis and Fuzzy-Sets

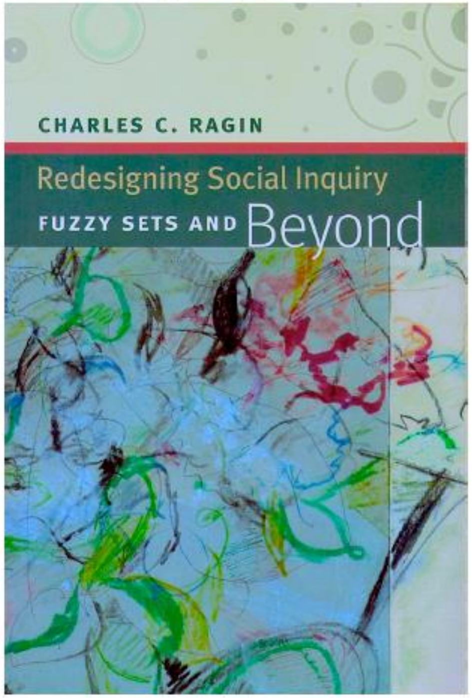
Ragin (1987)



Ragin (2000)



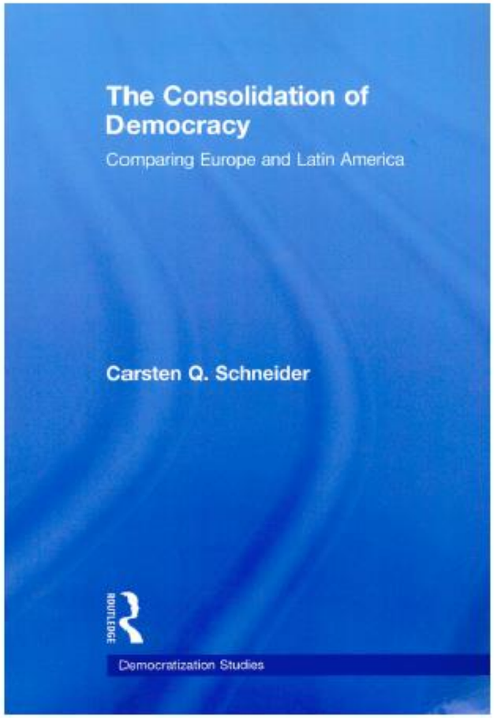
Ragin (2008)



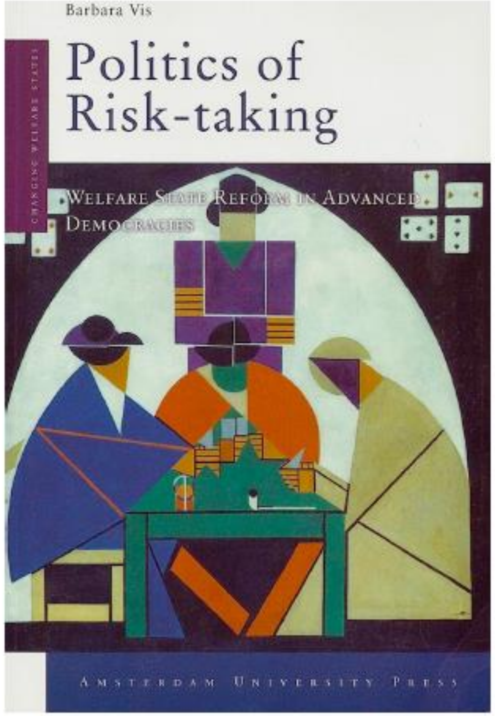
Applications of Fuzzy-Set QCA

Democratization, Welfare State, War Involvement

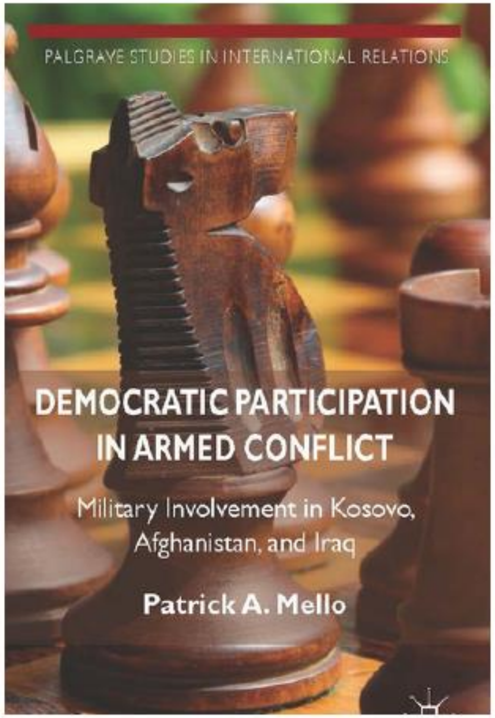
Schneider (2009)



Vis (2010)

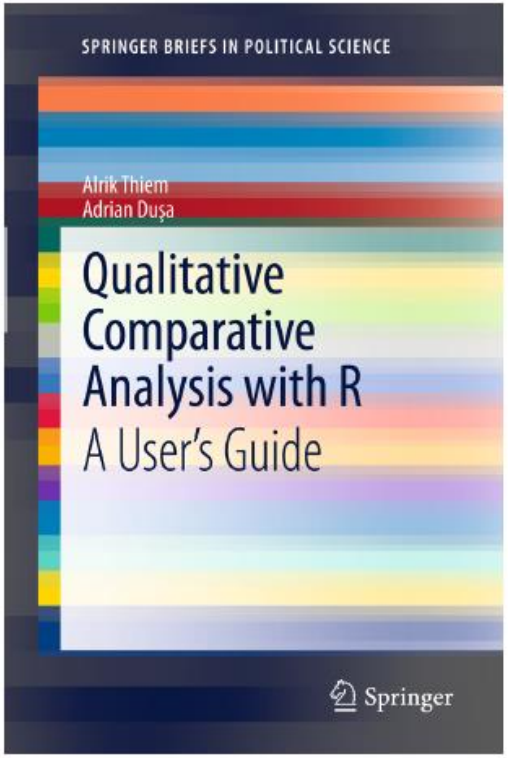


Mello (2014)

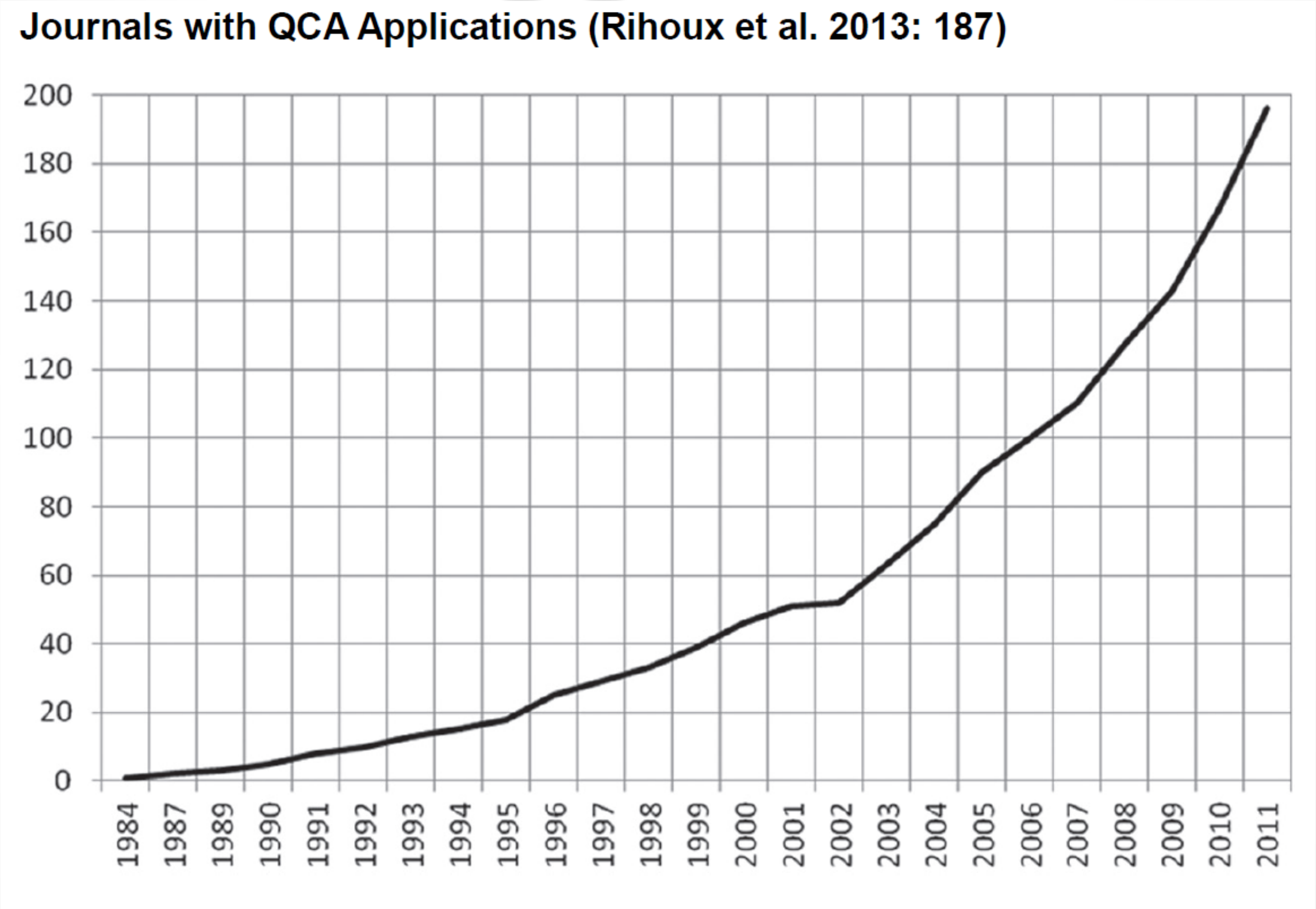


Guide to Using QCA with R

Thiem and Dușa (2013)

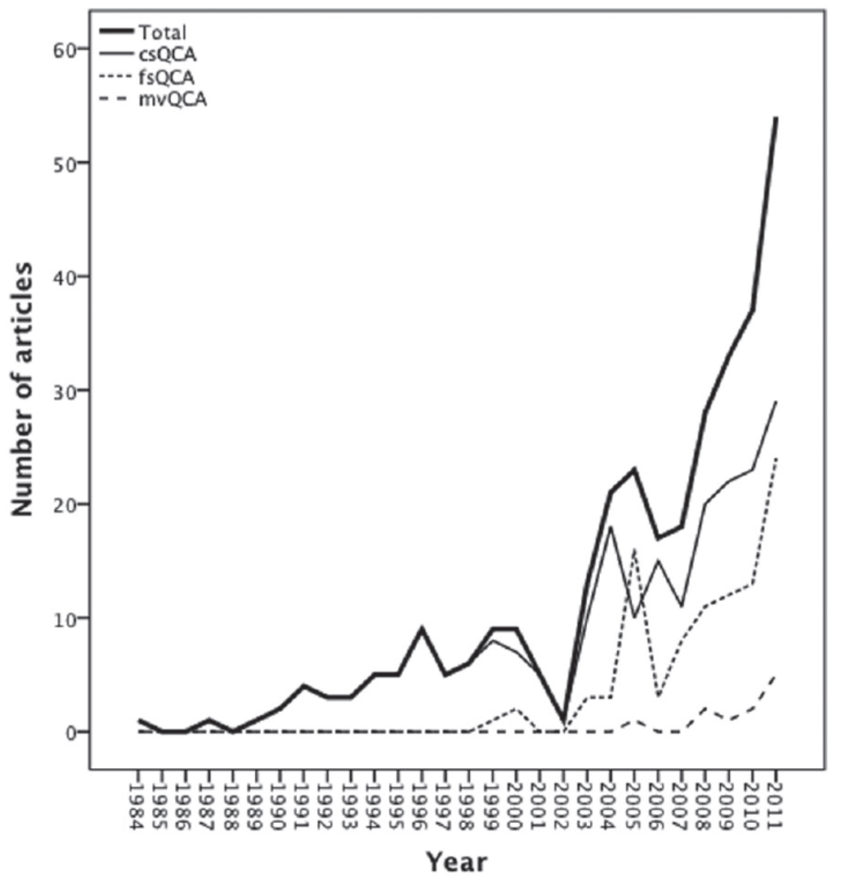


QCA Applications I



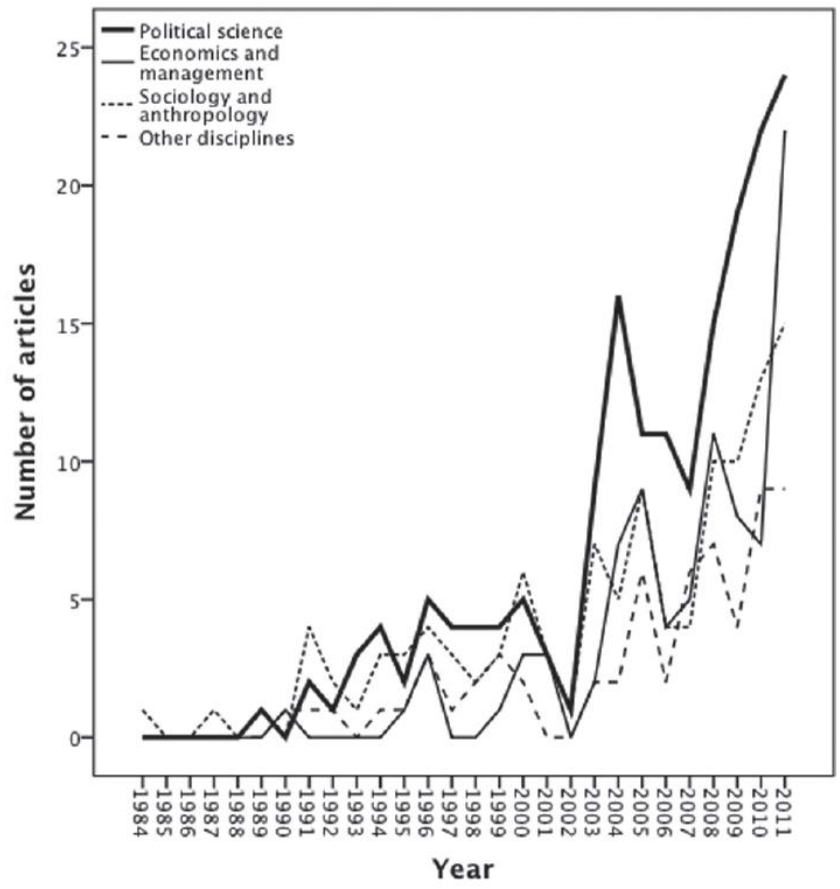
QCA Applications II

Publication by QCA Variant (Rihoux et al. 2013: 176)

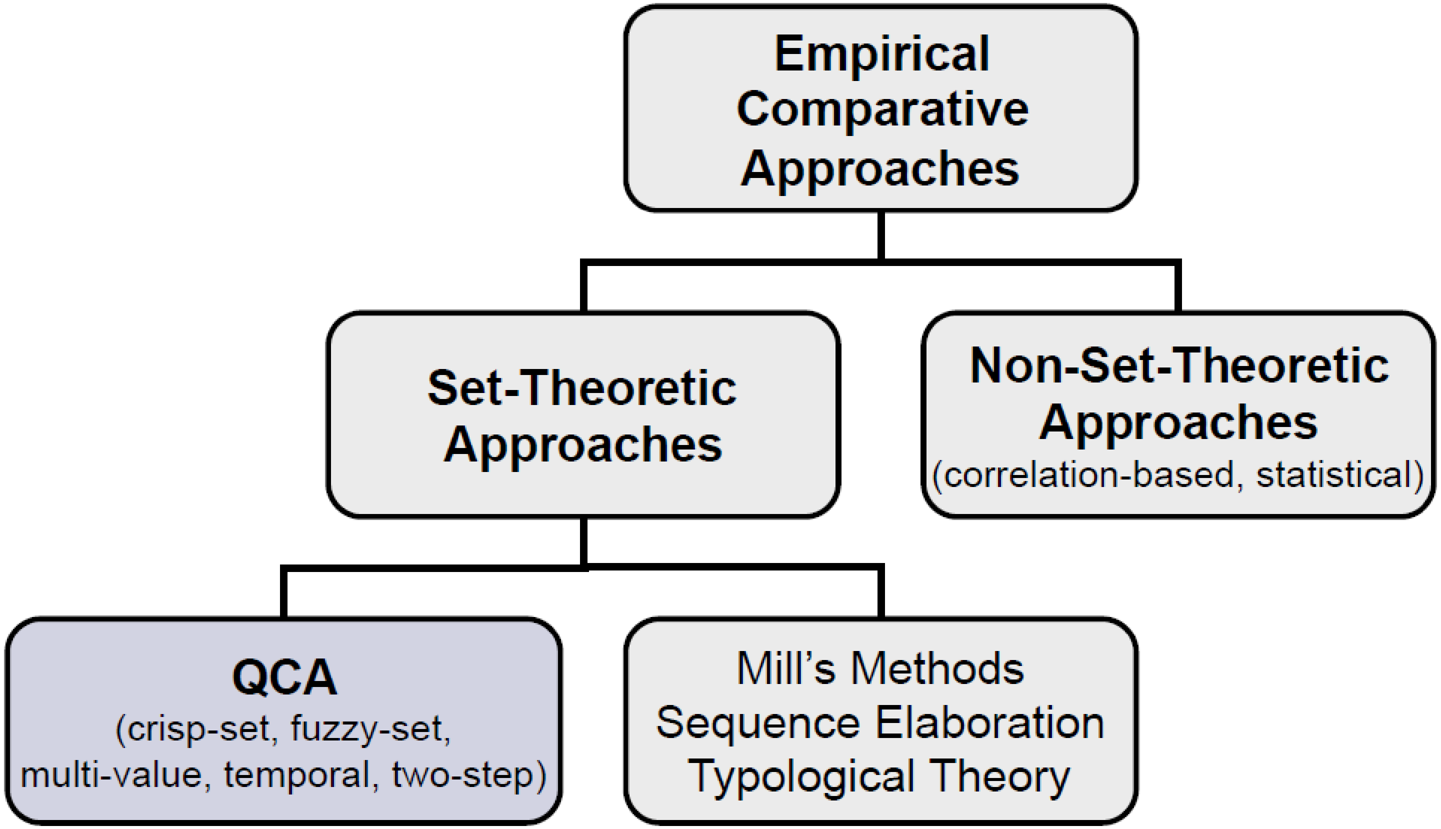


QCA Applications III

Publication by Discipline (Rihoux et al. 2013: 177)



Empirical Comparative Approaches in the Social Sciences



Types of QCA I

Crisp-Set, Fuzzy-Set, and Multi-Value Variants

Crisp-Set QCA	Fuzzy-Set QCA	Multi-Value QCA
▪ Conventional 'dichotomous' sets ▪ Values of 1 and 0	▪ Crisp and fuzzy sets ▪ Differentiated values between 1 and 0	▪ Categorical and ordinal variables ▪ Outcome has to be a crisp set
▪ Binary concepts Examples: "married" "female" "veto power"	▪ Fuzzy concepts Examples: "rich countries" "tall men" "consolidated democracies"	▪ Multinomial concepts Examples: "continent" "employment status" "UN membership"

Types of QCA II

The Two-Step Approach (Schneider/Wagemann 2006)

Two-Step Approach
▪ Differentiates between 'remote' and 'proximate' conditions (in terms of space, time, and causal effects) ▪ First step starts analysis of remote conditions as 'outcome-enabling conditions' (2006: 761) ▪ Second step combines proximate conditions with each outcome-enabling context (separate analyses)
▪ Number of logical remainders is substantially reduced (by dividing the conditions into separate groups) ▪ Can be used with all QCA variants
▪ Plausibility of separating remote and proximate conditions needs to be justified theoretically

Types of QCA III

Temporal QCA (Caren/Panofsky 2005, Ragin/Strand 2008)

Temporal QCA (tQCA)
▪ Seeks to introduce notions of time to QCA ▪ Introduces additional Logical operator: "/" (A/B, as in "A then B") ▪ Drastically increases the number of logically possible combinations (2→8; 3→48; 4→384) A/B, A/~B, ~A/~B, ~A/B, B/A, B/~A, ~B/~A, ~B/A ▪ Strategies to reduce these numbers have been devised (introducing limiting assumptions)
▪ Assumptions of tQCA reduce its applicability and utility for some research projects ▪ Only sequences of two conditions can be analyzed ▪ Only a subset of conditions is allowed to be part of a temporal sequence

Rational for Applying QCA I

Set Relations and Causal Complexity

Plausible suspicion that the phenomenon under study is best understood in terms of set relations and causal complexity

- Necessity
- Sufficiency
- Equifinality
- Multifinality
- Conjunctural causation
- Asymmetric causation
- INUS and SUIN conditions

Rationale for Applying QCA II

Number of Cases

Mid-Sized N (10-50 cases)

- Typical N in macro-comparative research
  - EU, OECD, US states, German *Länder*, etc.
- Too small for meaningful statistical tests
- Too large for classical comparative case studies

However:

- QCA can *also* be applied to large N
- Do *not* use QCA if you are not interested in set relations (even when having a mid-sized N)!

Set Theory: Basics

(Schneider & Wagemann 2012: Chapter 1;
see references for additional sources)

What Are Set-Theoretic Methods?

Three Shared Characteristics:

1) **Data consists of set-membership scores**

Example: Czech Republic is a European country

2) Relations between social phenomena are modeled in terms of set relations

Example: All NATO member states are democracies

-- set of democracies is a super-set of the set of NATO members

3**) Set relation are interpreted in terms of necessary and sufficient conditions**

Example: Being democratic is necessary for being a NATO member.

-- Non-democracy is sufficient for NATO non-membership

-- This entails a focus on causal complexity: equifinality, conjunctional causation, asymmetry, INUS and SUIN conditions.

What are Sets?

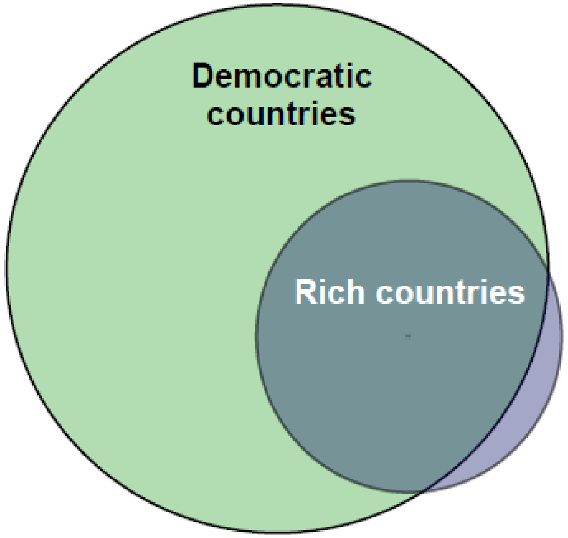
Natural and Social Kinds of Sets

	Natural kinds	Social kinds
Examples	Magnetic field, electric charge, wavelength	Democracy, security, social status
Source of constitution	Ontologically prior to human experience, essential properties	Human mind, no essential properties
Spatiotemporal stability	High stability, e.g.: H_20 has a boiling point of 100°C, earth's magnetic field (but: geomagnetic reversal)	Low stability, e.g.: social status varies across cultures, democracy looked different a hundred years ago

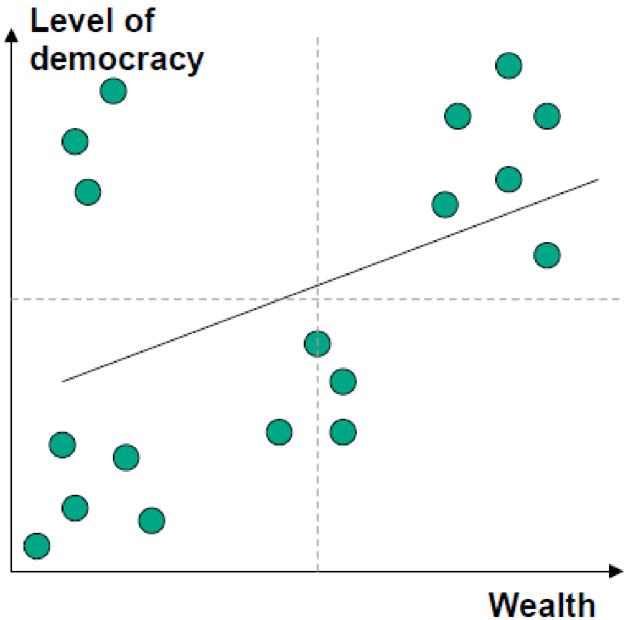
Set Theory vs. Probabalistic Theory

Example: Relationship between Wealth and Democracy

Being wealthy is (almost) sufficient for being democratic



Wealth correlates with the level of democracy



Types of Sets I

Crisp Sets

- Binary distinction: membership (1) vs. non-membership (0)
- Emphasizes *qualitative* differences between cases

Examples:

Set of “large countries”:

Russia	→ Yes	→ 1
Canada	→ Yes	→ 1
Slovenia	→ No	→ 0
Austria	→ No	→ 0

Set of “conservative parties”:

Republicans (US)	→ Yes	→ 1
Partido Popular (ES)	→ Yes	→ 1
Labour (UK)	→ No	→ 0
Greens (DE)	→ No	→ 0

Criticism

- Loss of empirical information due to dichotomization
- Dividing line between members and non-members of a set is overstated at times

Dilemma of Crisps Sets

Sorites Paradox

A heap of sand

- Remove a grain of sand from the heap and it remains a heap of sand
- Remove another grain and it still remains a heap of sand, and so forth
- Until a single grain of sand is left

Is that still a heap?
When did the heap turn into a *non*-heap?

Types of Sets II

Fuzzy Sets

- Originated in 1965 by Lofti Zadeh (Berkeley)
  - Applied in computer science, philosophy, mathematics, linguistics, and many other areas (cf. McNeill/Freiberger 1993)
- Fuzzy sets allow for partial membership in sets
  - Any value between 0 and 1 can be assigned
  - Three qualitative anchors
    - Full membership in a given set (1)
    - Point of maximum ambiguity (0.5)
    - Full non-membership in a given set (0)
  - Qualitative *and* quantitative differences can be accounted for
  - Semantic basis allows for linguistic qualifiers
- Fuzzy sets do <u>NOT</u> reflect probabilities!

Crisp and Fuzzy Sets (Ragin 2008: 31)

Crisp set	Three-value fuzzy set	Four-value fuzzy set	Six-value fuzzy set	"Continuous" fuzzy set
1 = fully in	1 = fully in	1 = fully in	1 = fully in	1 = fully in
			0.8 = mostly but not fully in	
		0.67 = more in than out	0.6 = more or less in	Degree of membership is more "in" than "out": $0.5 < X_i < 1$
	0.5 = neither fully in nor fully out			0.5 = cross-over: neither in nor out (maximum ambiguity)
		0.33 = more out than in	0.4 = more or less out	Degree of membership is more "out" than "in": $0 < X_i < 0.5$
			0.2 = mostly but not fully out	
0 = fully out	0 = fully out	0 = fully out	0 = fully out	0 = fully out

Fuzzy Sets

Advantages and Challenges

Advantages

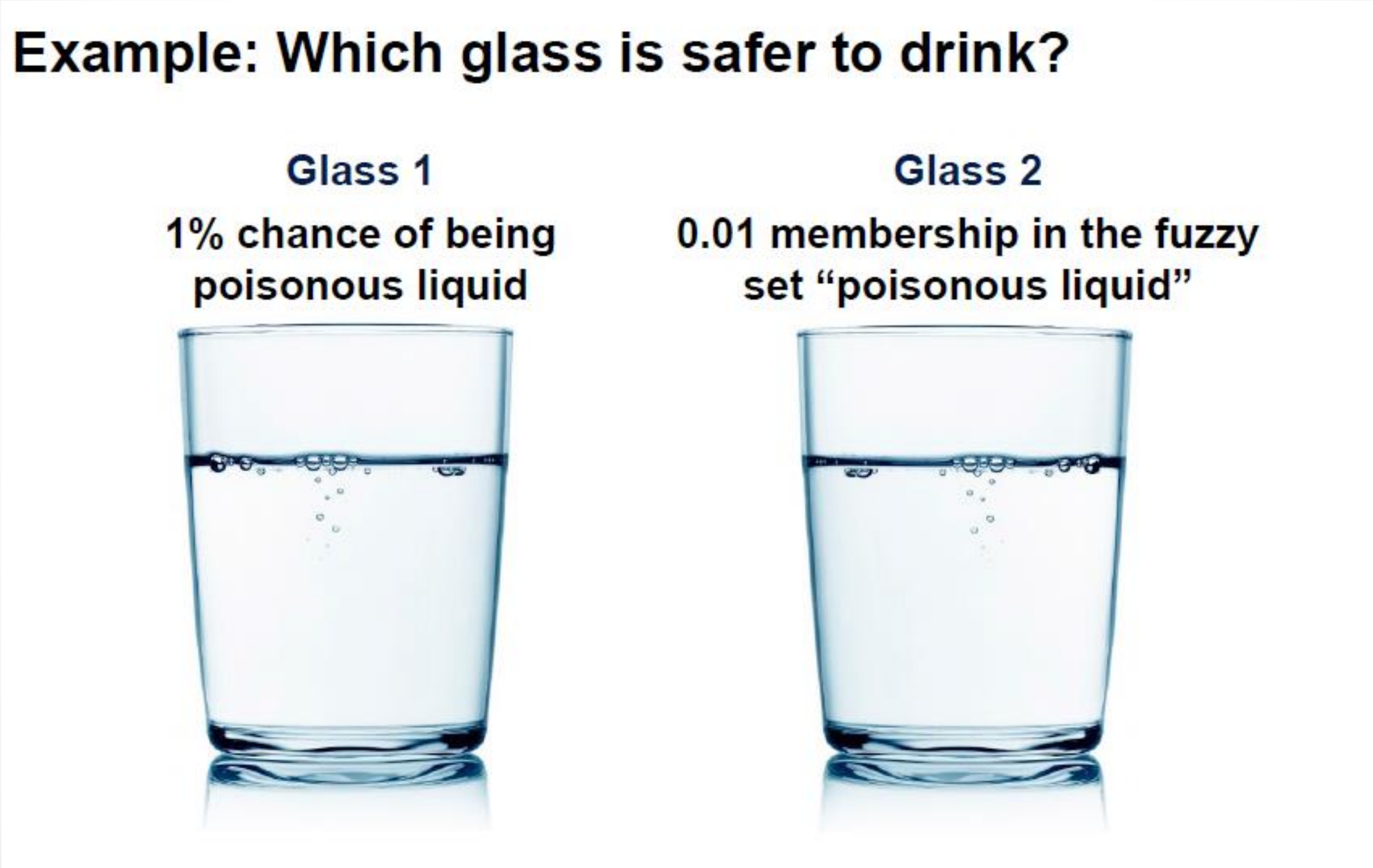
- More information than crisp sets
- Differences in kind *and* differences in degree
- Closer correspondence to theoretical concepts
- Meaningful variation can be specified

Challenges

- How to define the qualitative anchors (0.5 especially)?
- What variation is relevant and what is not?
- False impression of preciseness (direct method of calibration)

→ Fuzzy sets offer greater conceptual validity when translating concepts into sets, but they are also more demanding and open to manipulation (On "standards of good practice" see Schneider/Wagemann 2010, Mello 2013)

Fuzzy Sets vs. Probabilism



Probability

1% Chance of being poisonous liquid

On average, one glass out of 100 consists of poison.

Fuzzy Sets

0.01 Membership in the fuzzy set "poisonous liquid"

Even if you had 100 glasses of this liquid, each single glass would still hold only 0.01 membership in the fuzzy set "poisonous liquid".

Set Operations

Three Basic Operators

Logical AND (*)

- Minimum value across sets

Example: Conservative government with public support (on some policy issue), Set C "conservative government", Set P "public support", Denmark in 2001/Afghanistan (0.96,0.70): C*P = 0.70

Logical OR (+)

- Maximum value across sets

Example: Countries with parliamentary veto rights OR constitutional restrictions in security policy, Set V "veto rights", Set C "restrictions", Japan 2003/Iraq (0.60, 1.00): V+C = 1.00

Set Operations II

Three Basic Operators

Negation (~)

- Membership value in the set ‘not A’ (1-A)

Example: “Military non-participation” (~MP) in the Iraq War,
Set MP “military participation”, Norway (0.3): 1-0.3 = 0.7

Set Operations III

Basic Operators – Examples

		AND (min)	OR (max)	NOT (1-A)
A	B	A*B	A+B	~A
1	0	0	1	0
0.9	0.4	0.4	0.9	0.1
0.3	0.2	0.2	0.3	0.7
0	0.8	0	0.8	1

Set Operations IV

Summary – Basic operations and notations

Operator	Logic of propositions	Boolean algebra	Set theory
AND	Conjunction $\wedge$	Multiplication *, (·)	Intersection $\cap$
OR	Disjunction $\vee$	Addition $+$	Union $\cup$
NOT	Complement $\neg$, ~	Negation 1–D	Negative Set
Inclusion	If–then relation $\rightarrow$, $\Rightarrow$		Subset $\subset$

Source: Schneider/Wagemann 2012: 54 (Table 2.3)

Set Operations V

Basic Operators – Exercises

Fuzzy-set scores: A (0.1), B (0.7), C (0.9), D (0.3)

1. (A*B) + (C*D) =

   [(0.1)*(0.7)] + [(0.9)*(0.3)] =
   (0.1) + (0.3) = 0.3

2. (A*D) + (B*C) =

   [(0.1)*(0.3)] + [(0.7)*(0.9)] =
   (0.1) + (0.7) = 0.7

3. (A*~D) + (B*~C) =

   [(0.1)*(1 - 0.3)] + [(0.7)*(1 - 0.9)] =
   [(0.1)*(0.7)] + [(0.7)*(0.1)] =
   (0.1) + (0.1) = 0.1

Set Operations VI

Rules for Complex Sets

Commutativity

- The order in which elements are connected (through AND, OR) is irrelevant (does not hold for the complement, as 1-A ≠ A-1)

  A * B = B * A ; A + B = B + A

Associativity

- The sequence in which elements are combined is irrelevant

  (A * B) * C = A * (B * C) ; (A + B) + C = A + (B + C)

Distributivity

- When both AND and OR operators are used in the same logical expression, shared elements can be factored out

  A * B + A * C = AB + AC = A (B + C)

Set Operations VII

Universal Set and Empty Set

The Universal Set

- If the union (logical OR) of a set with its complement (negation) is created, then the "universal set" will result

  $A + \sim A = U$

The Empty Set

- If the intersection (logical AND) of a set with its complement (negation) is created, then the "empty set" will result

  $A * \sim A = \emptyset$

Set Operations VIII

De Morgan’s Law

Two Rules:

- If a statement is negated, then all *elements* that have been present become absent, and vice versa
- If a statement is negated, then all *logical operators* become inverted (AND to OR, and vice versa)

Example: ~(AB + ~CD)
= (~A + ~B) * (C + ~D)

De Morgan´s Law

(Limited) Applicability for Solution Terms

Two Rules:

- If a statement is negated, then all *elements* that have been present become absent, and vice versa
- If a statement is negated, then all *logical operators* become inverted (AND to OR, and vice versa)

Example: ~(AB + ~CD) = (~A + ~B) * (C + ~D)

Can this be applied to necessary and sufficient conditions?

Example: $A \rightarrow Y$ = $\sim A \leftarrow \sim Y$ (Is this statement true?)

De Morgan's Law can <u>only</u> be applied if

- Outcome and solution have a perfect overlap
- Truth table contains no logical contradictions

Set Operations

Operations on Complex Sets – Examples

- **Negation:** F + [G*(~H + ~I)]

  De Morgan's law: ~F*[~G + (H*I)] = ~F*~G + ~F*H*I

- **Intersection** (Logical AND): [F + G*(~H + ~I)] * (~FG + G~H)

  = (F + G~H + G~I) * (~FG + G~H)
  = F~FG + FG~H + G~H~FG + G~HG~H + G~I~FG + G~IG~H
  = ~~F~FG~~ + FG~H + G~H~FG + G~HG~~~H~~ + G~I~FG + G~IG~H
  (erase empty set and superfluous expressions)
  = FG~H + ~FG~H + G~H + ~FG~I + G~H~I
  (sorted alphabetically)
  = FG~H + ~FG~H + G~H + ~FG~I + G~H~I
  (erase superfluous subsets of G~H)
  = G~H + ~FG~I = G(~H + ~F~I)

Set Relations

(Schneider & Wagemann 2012: Chapter 3;
see references for additional sources)

Causal Complexity I

Defining Characteristics

- Equifinality
  - Different conditions, same outcome
- Conjunctural causation
  - Combination of conditions produce outcome
- Causal asymmetry
  - Presence/absence of outcome have different explanations
- Multifinality
  - Same condition, different outcomes
- Time, timing, and sequence
  - Order of events has causal implications

Causal Complexity II

Degree of Causal Complexity across Methods

Case Studies	Qualitative Comparative Analysis	Standard Regression Analysis
▪ All elements of causal complexity ▪ Limited generalizability, sometimes idosyncratic	▪ Equifinal, conjunctural, asymmetric, multifinal ▪ Enables generalization across population ▪ Only little, if any, modelling of time, timing, sequence	▪ Unifinal, additive ▪ Enables broad generalization across cases ▪ More complex relations can be modelled

Set Relations I

Necessary Condition – Definition

- Whenever we observe the outcome (Y), we also see the condition (X)

  → The condition is *necessary* for the outcome to occur

  (For cases with ~Y, we neither care nor need to know about their membership score in X, because neither cases with X nor ~X violate a statement of necessity)

- Formal:
  - Membership of cases in X ≥ membership of cases in Y
  - X is a *superset* of Y (and Y is a *subset* of X)

Set Relations II

Sufficient Condition – Definition

- Whenever we observe the condition (X), we also see the outcome (Y)

  → The condition is *sufficient* for the outcome to occur

  (For cases with ~X, we neither care nor need to know about their membership score in Y, because neither cases with Y nor ~Y violate a statement of sufficiency)

- Formal:
  - Membership of cases in Y ≥ membership of cases in X
  - Y is a *superset* of X (and X is a *subset* of Y)

Set Relations III

Necessity and Sufficiency – Notation

Necessary condition: $X \leftarrow Y$ (X is necessary for Y)

Sufficient condition: $X \rightarrow Y$ (X is sufficient for Y)

INUS condition: "an *insufficient* but *necessary* part of a condition, which is itself *unnecessary* but *sufficient* for the result" (Mackie 1965: 245)

$$A + \boxed{B}C \rightarrow Y$$

SUIN condition: "a *sufficient* but *unnecessary* part of a factor that is *insufficient* but *necessary* for an outcome" (Mahoney et al. 2009: 126)

$$A \leftarrow Y \quad ; \quad A = \boxed{B} + C$$

Set Relations IV

Necessity and Sufficiency – Presentational Forms

- Crisp sets
  - Boolean notation
  - Truth table
  - 2x2 Table
  - Venn diagram
- Fuzzy sets
  - Boolean notation
  - Truth table
  - XY plot

Necessary Condition

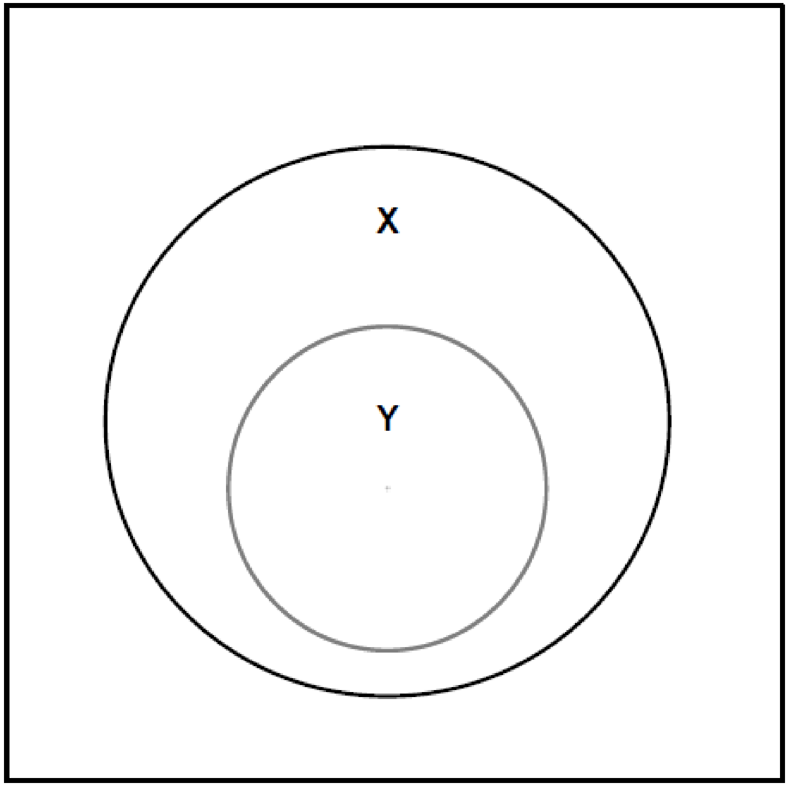
2x2 Table

Any case in this cell violates a (deterministic) statement of necessity

		Outcome 0	Outcome 1
Condition	1	Not important	Cases
	0	Not important	No cases

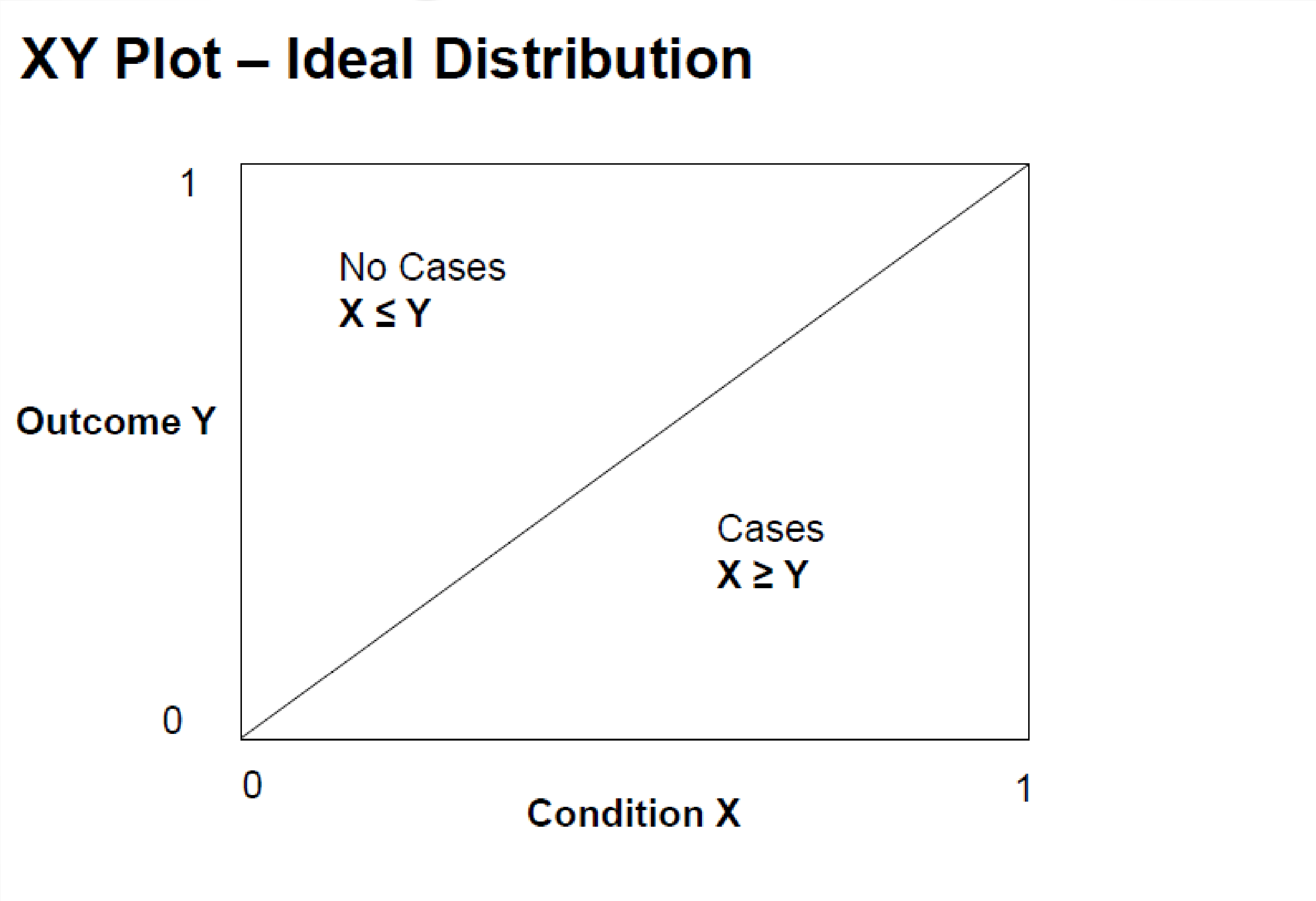
Necessary Condition

Venn Diagram



X is a *superset* of Y
(and Y is a *subset* of X)

Necessary Condition



Succificient Condition

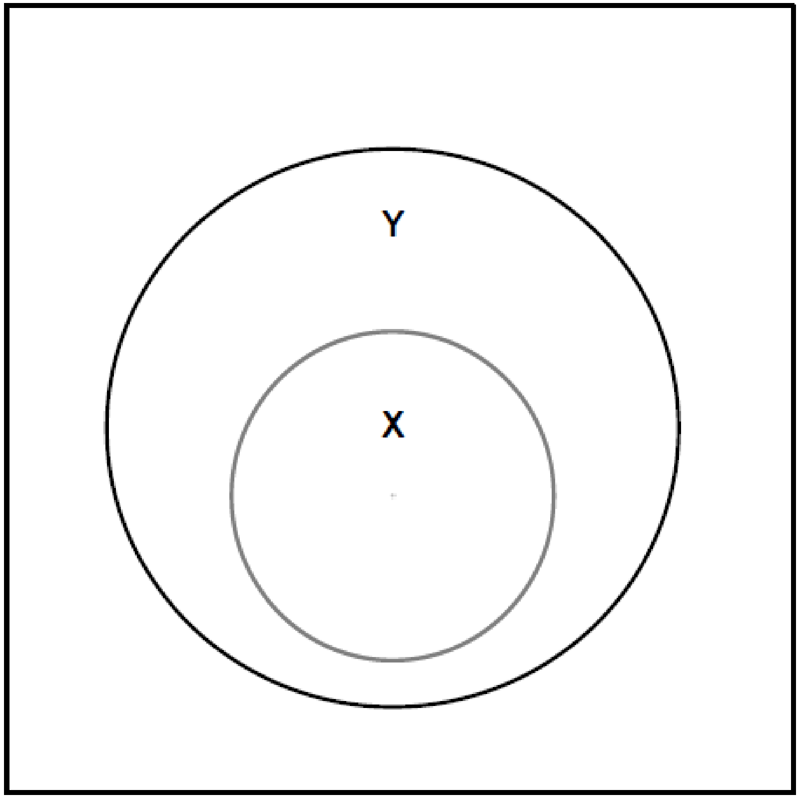
2x2 Table

Any case in this cell violates a (deterministic) statement of sufficiency

		Outcome	
		0	1
Condition	1	No cases	Cases
	0	Not important	Not important

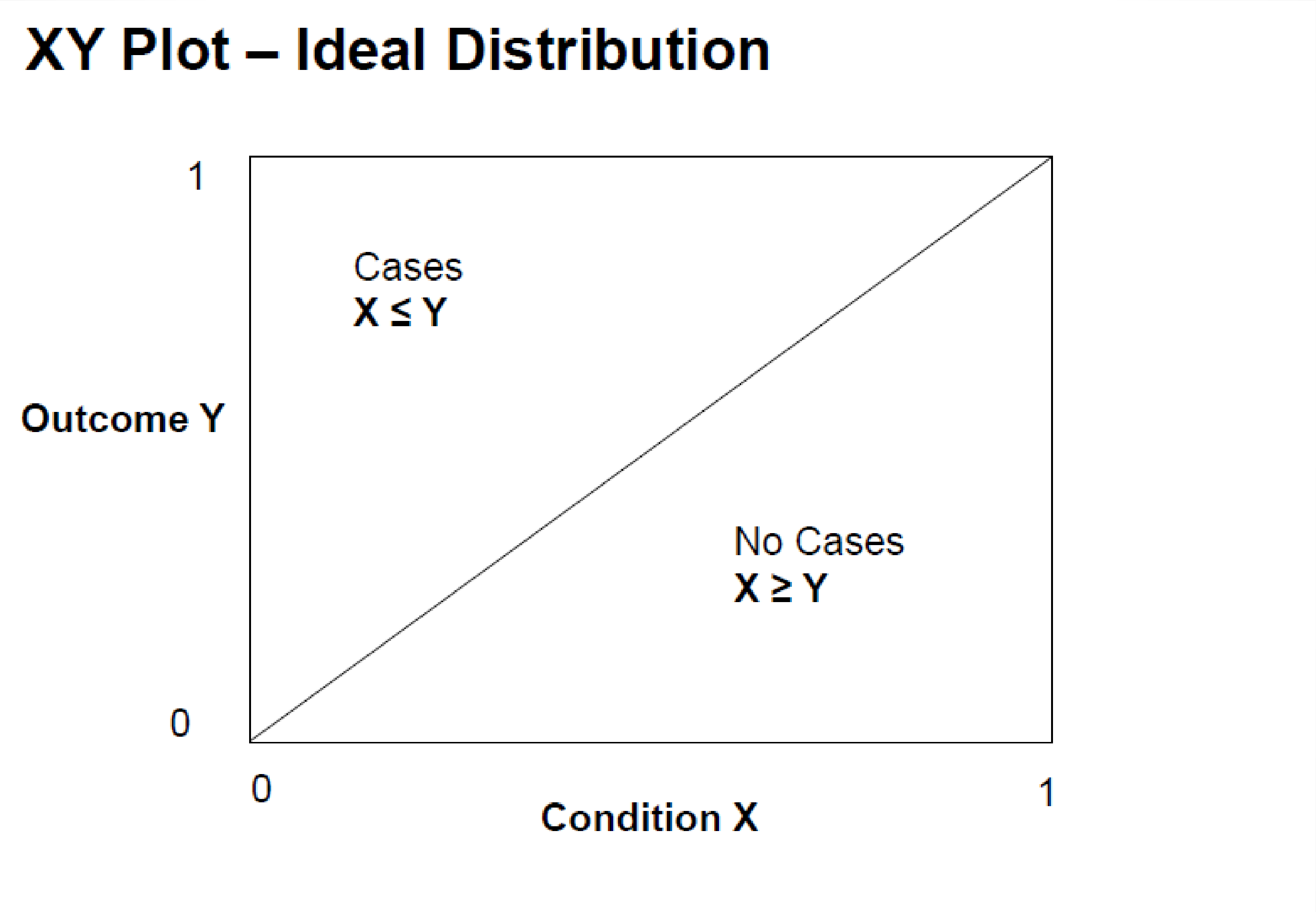
Sufficient Condition

Venn Diagram



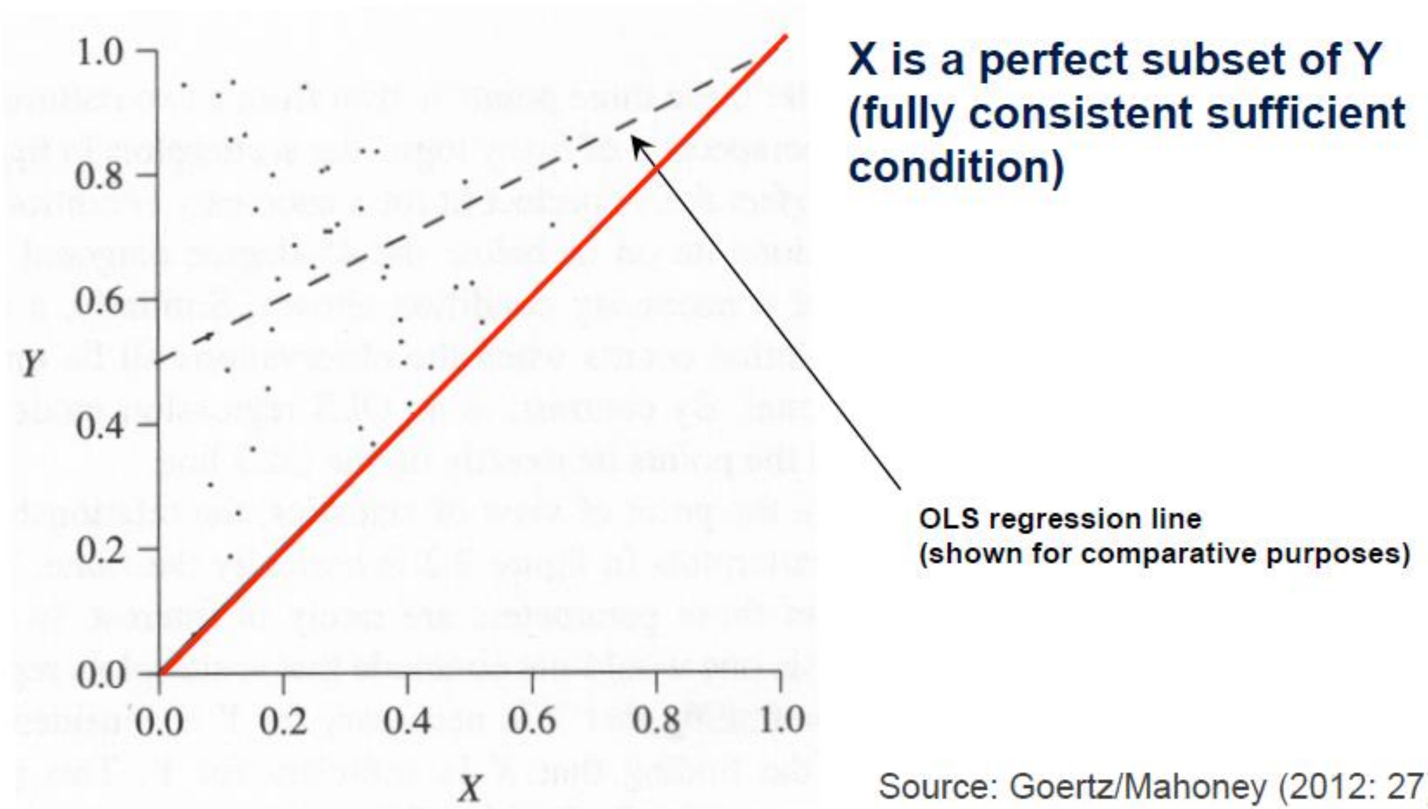
X is a *subset* of Y
(and Y is a *superset* of X)

Sufficient Condition



Sufficiemt Condition

XY Plot – Example



Source: Goertz/Mahoney (2012: 27)

Set Relations

Necessity and Sufficiency – Summary

Necessity

$X \leftarrow Y$

$X_i \geq Y_i$

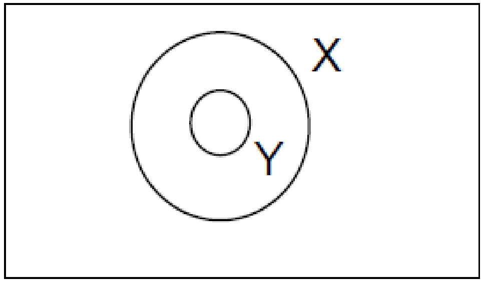
X superset of Y

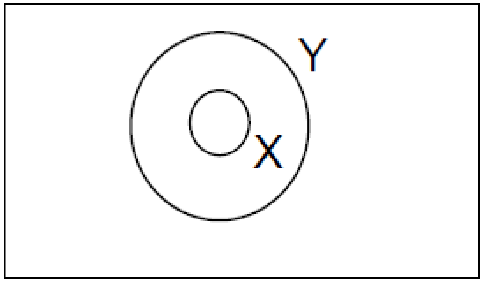
Sufficiency

$X \rightarrow Y$

$X_i \leq Y_i$

X subset of Y

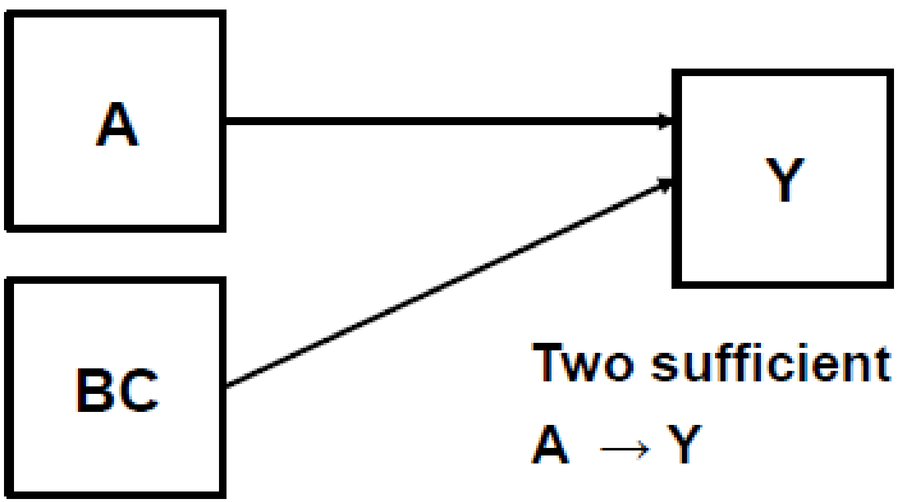




Causal Complexity

Equifinality and Conjunctural Causation

- Different factors, same outcome (*equifinality*)
- Combinations of conditions can lead toward an outcome, whereas their constituents might not lead to the outcome by themselves (*conjunctural causation*)



Two sufficient pathways to Y:

A $\rightarrow$ Y

BC $\rightarrow$ Y

Causal Complexity

INUS and SUIN Conditions

INUS condition: "an *insufficient* but *necessary* part of a condition, which is itself *unnecessary* but *sufficient* for the result" (Mackie 1965: 245)

$$A + BC \longrightarrow Y$$

SUIN condition: "a *sufficient* but *unnecessary* part of a factor that is *insufficient* but *necessary* for an outcome" (Mahoney et al. 2009: 126)

$$A \longleftarrow Y \quad ; \quad A = B + C$$

Causal Complexity III

Causal Asymmetry

- Presence and absence of outcome have different explanations
  - Economic growth → Democratization
  - Clientelism → Non-democratization
- Presence and absence of condition produce different outcomes
  - Wealth → Democracy
  - Non-wealth → BOTH presence and absence of democracy
- Antonym: Symmetric causation
  - An increase or decrease in the independent variable(s) leads to increase or decrease in the dependent variable

Causal Complexity IV

Multifinality

- Same factor, different outcomes
  - “Arab Spring” protests → Regime change (Tunesia, Egypt)
  - “Arab Spring” protests → No regime change (Syria, Morocco)
- Antonym: Unit (causal) homogeneity
  - Independent variable has the same effect on the dependent variable across all cases

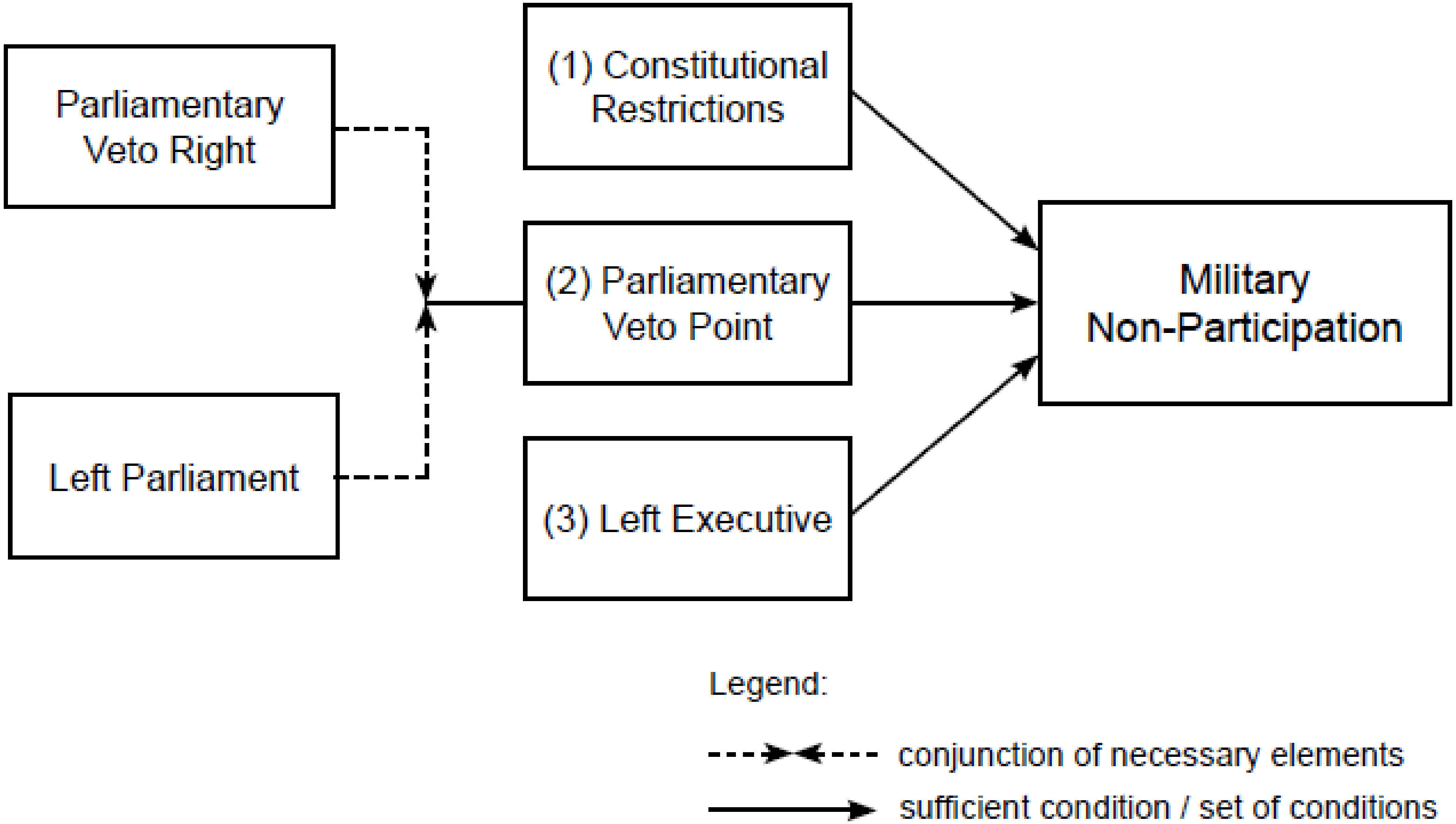
Causal Complexity V

Time, Timing, and Sequence

- Order of events has causal implications
  - First property rights, then economic liberalization
    - Functioning Market Economy (DV)
  - First economic liberalization, then property rights
    - Non-Functioning Market Economy (DV)
- Antonym: Static analysis
  - Sequence of independent variables is causally irrelevant
  - A + B = B + A,   A * B = B * A
- tQCA can be performed with the QCA package for R
- Notions of timing and sequence can also be included in the research design (calibration of conditions, indicators)

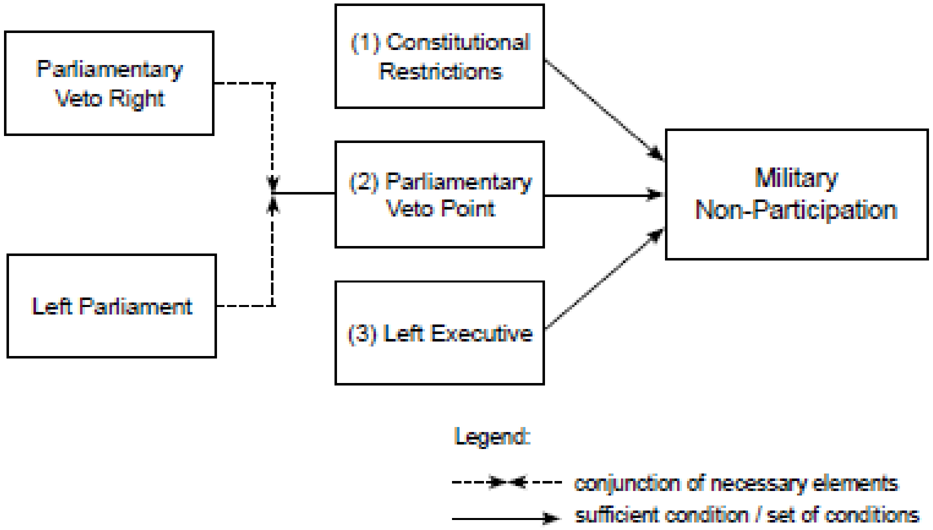
Causal Complexity – Example 1

Military (Non-)Participation in Iraq (Mello 2012)



Causal Complexity – Example 1

Military (Non-)Participation in Iraq (Mello 2012)



Theory:

C + (V * ~P) + ~E → ~MP

[C] Constitutional Restrictions
[V] Parliamentary Veto Rights
[P] Right Parliament
[E] Right Executive
[V*~P] Parliamentary Veto Point

[MP] Military Participation

Measurement and Calibration

Measurement and Calibration

What is needed for calibration?

- Assigning set-membership values requires:
  - Plausible and consistent rules for assigning values
  - Close correspondence with the concept of interest (content validity)
- "Substantive knowledge provides the external criteria that make it possible to calibrate measures" (Ragin 2008: 82)

Three Approaches to Calibration

Qualitative Calibration	Direct Method of Calibration	Indirect Method of Calibration
▪ Crisp and fuzzy sets	▪ Fuzzy sets only	▪ Fuzzy sets only
▪ Values are directly assigned by the researcher	▪ Qualitative break-points are determined by the researcher	▪ Initial, preliminary assignment of values by the researcher
▪ Theory-guided, qualitative calibration process that draws on external criteria	▪ Interval-scale variables are trans-formed into fuzzy-set values using log odds (software-based: fsQCA, R, Stata)	▪ Values are then regressed onto the raw data (interval-scale variable), (software-based: R, Stata)
▪ Widely used	▪ Widely used	▪ Less often used

Example 1: Direct Method
(Ragin 2008: 89)

Target fuzzy set:
"developed countries"

Country	National income (US$)
Switzerland	40,110
United States	34,400
Netherlands	25,200
Finland	24,920
Australia	20,060
Israel	17,090
Spain	15,320
New Zealand	13,680
Cyprus	11,720
Greece	11,290
Portugal	10,940
Korea, Rep.	9,800
Argentina	7,470
Hungary	4,670
Venezuela	4,100
Estonia	4,070
Panama	3,740
Mauritius	3,690
Brazil	3,590
Turkey	2,980
Bolivia	1,000
Cote d'Ivoire	650
Senegal	450
Burundi	110

Raw data

Qualitative anchors

20,000

5,000

2,500

Example 1: Direct Method (Ragin 2008: 89)

Country	National income (US$)	Deviations from crossover
Switzerland	40,110	35,110.00
United States	34,400	29,400.00
Netherlands	25,200	20,200.00
Finland	24,920	19,920.00
Australia	20,060	15,060.00
Israel	17,090	12,090.00
Spain	15,320	10,320.00
New Zealand	13,680	8,680.00
Cyprus	11,720	6,720.00
Greece	11,290	6,290.00
Portugal	10,940	5,940.00
Korea, Rep.	9,800	4,800.00
Argentina	7,470	2,470.00
Hungary	4,670	−330.00
Venezuela	4,100	−900.00
Estonia	4,070	−930.00
Panama	3,740	−1,260.00
Mauritius	3,690	−1,310.00
Brazil	3,590	−1,410.00
Turkey	2,980	−2,020.00
Bolivia	1,000	−4,000.00
Cote d'Ivoire	650	−4,350.00
Senegal	450	−4,550.00
Burundi	110	−4,890.00

Calculate raw data deviation from the crossover point

20,000

5,000

2,500

Example 1: Direct Method (Ragin 2008: 89)

Country	National income (US$)	Deviations from crossover	Scalars	Product	Degree of membership	
Switzerland	40,110	35,110.00	.0002	7.02	1.00	
United States	34,400	29,400.00	.0002	5.88	1.00	
Netherlands	25,200	20,200.00	.0002	4.04	0.98	
Finland	24,920	19,920.00	.0002	3.98	0.98	
Australia	20,060	15,060.00	.0002	3.01	0.95	20,000
Israel						
Spain						
New Zealand						
Cyprus						
Greece						
Portugal						
Korea, Rep.						
Argentina						5,000
Hungary						
Venezuela						
Estonia						
Panama						
Mauritius						
Brazil						
Turkey						2,500
Bolivia						
Cote d’Ivoire						
Senegal						
Burundi						

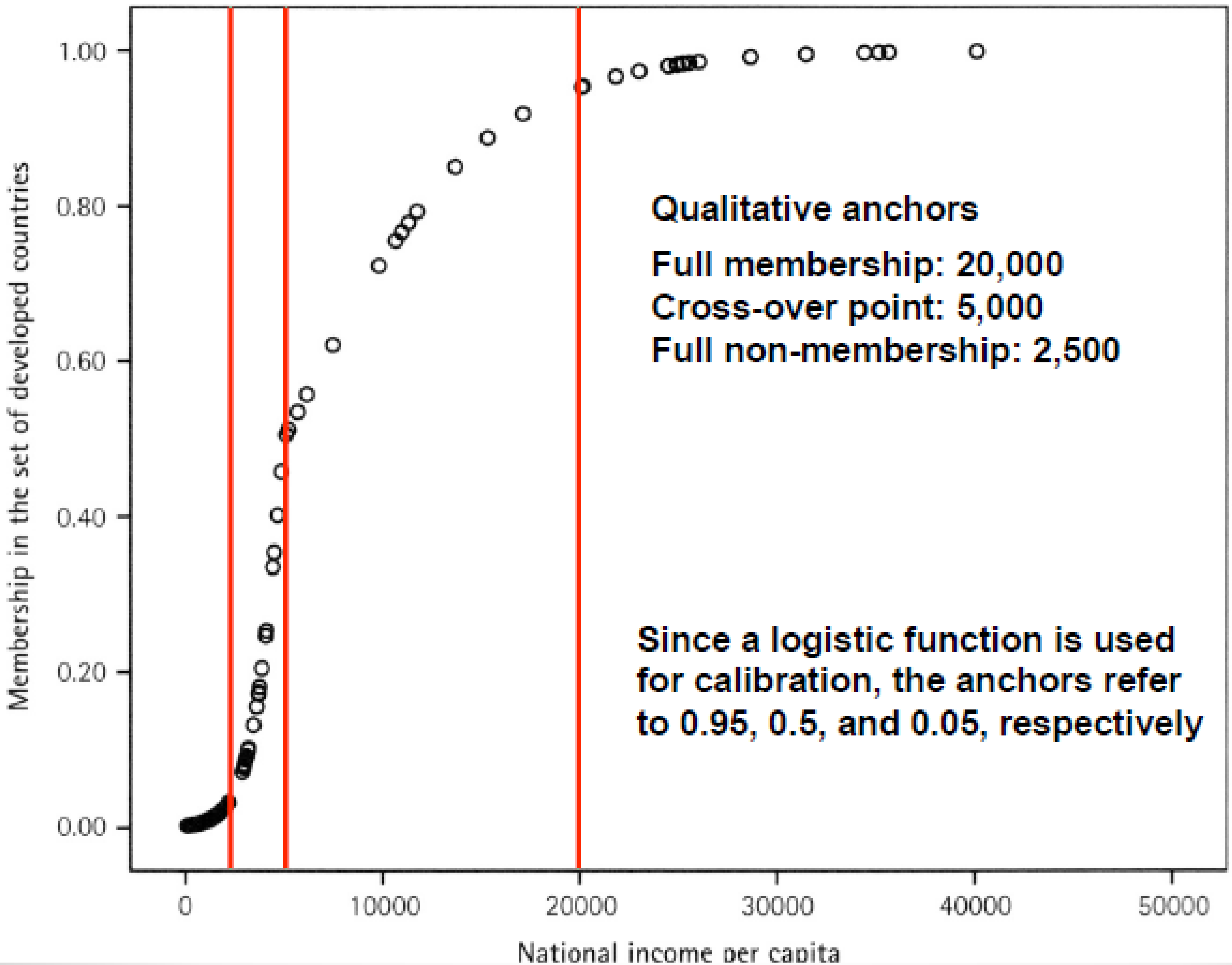
$3 / (20{,}000 - 5{,}000) = 0.0002$

Calculate scalars for deviation scores *above* and *below* the crossover

- log odds for the threshold for full (non-)membership (3.0 and -3.0)
- Divided by deviation from crossover

$-3 / (2{,}500 - 5{,}000) = 0.0012$

Example 1: Set "developed countries" (Ragin 2008: 92)



Example 1: Direct Method (Ragin 2008: 89)

Country	National income (US$)	Deviations from crossover	Scalars	Product	Degree of membership
Switzerland	40,110	35,110.00	.0002	7.02	1.00
United States	34,400	29,400.00	.0002	5.88	1.00
Netherlands	25,200	20,200.00	.0002	4.04	0.98
Finland	24,920	19,920.00	.0002	3.98	0.98
Australia	20,060	15,060.00	.0002	3.01	0.95
Israel					
Spain					
New Zealand					
Cyprus					
Greece					
Portugal					
Korea, Rep.					
Argentina					
Hungary					
Venezuela					
Estonia					
Panama					
Mauritius					
Brazil					
Turkey					
Bolivia					
Cote d'Ivoire					
Senegal					
Burundi					

20,000

5,000

2,500

Multiply deviation by scalar

Convert product to scores from 1 to 0

e.g., Netherlands:

20,200.00 * 0.0002 = 4.04
exp (4.04) / [1 + exp (4.04)]
56,83 / (1 + 56,83)
0.98

Example 2: Direct Method
(Ragin 2008: 100)

Target fuzzy set:
"democratic countries"

Country	Polity score
Norway	10
United States	10
France	9
Korea, Rep.	8
Colombia	7
Croatia	7
Bangladesh	6
Ecuador	6
Albania	5
Armenia	5
Nigeria	4
Malaysia	3
Cambodia	2
Tanzania	2
Zambia	1
Liberia	0
Tajikistan	−1
Jordan	−2
Algeria	−3
Rwanda	−4
Gambia	−5
Egypt	−6
Azerbaijan	−7
Bhutan	−8

Polity score 9

Polity score 2

Polity score -3

Country	Polity score	Deviations from crossover	Scalars	Product	Degree of membership
Norway	10	8.00	0.43	3.43	0.97
United States	10	8.00	0.43	3.43	0.97
France	9	7.00	0.43	3.00	0.95
Korea, Rep.	8	6.00	0.43	2.57	0.93
Colombia	7	5.00	0.43	2.14	0.89
Croatia	7	5.00	0.43	2.14	0.89
Bangladesh	6	4.00	0.43	1.71	0.85
Ecuador	6	4.00	0.43	1.71	0.85
Albania	5	3.00	0.43	1.29	0.78
Armenia	5	3.00	0.43	1.29	0.78
Nigeria	4	2.00	0.43	0.86	0.70
Malaysia	3	1.00	0.43	0.43	0.61
Cambodia	2	0.00	0.00	0.00	0.50
Tanzania	2				
Zambia	1				
Liberia	0				
Tajikistan	−1				
Jordan	−2				
Algeria	−3				
Rwanda	−4				
Gambia	−5				
Egypt	−6				
Azerbaijan	−7				
Bhutan	−8				

Polity score 9

Polity score 2

Polity score -3

e.g., Cambodia:

0.00 * 0.00 = 0.00

exp (0.00) / [1 + exp (0.00)]

1 / (1 + 1)

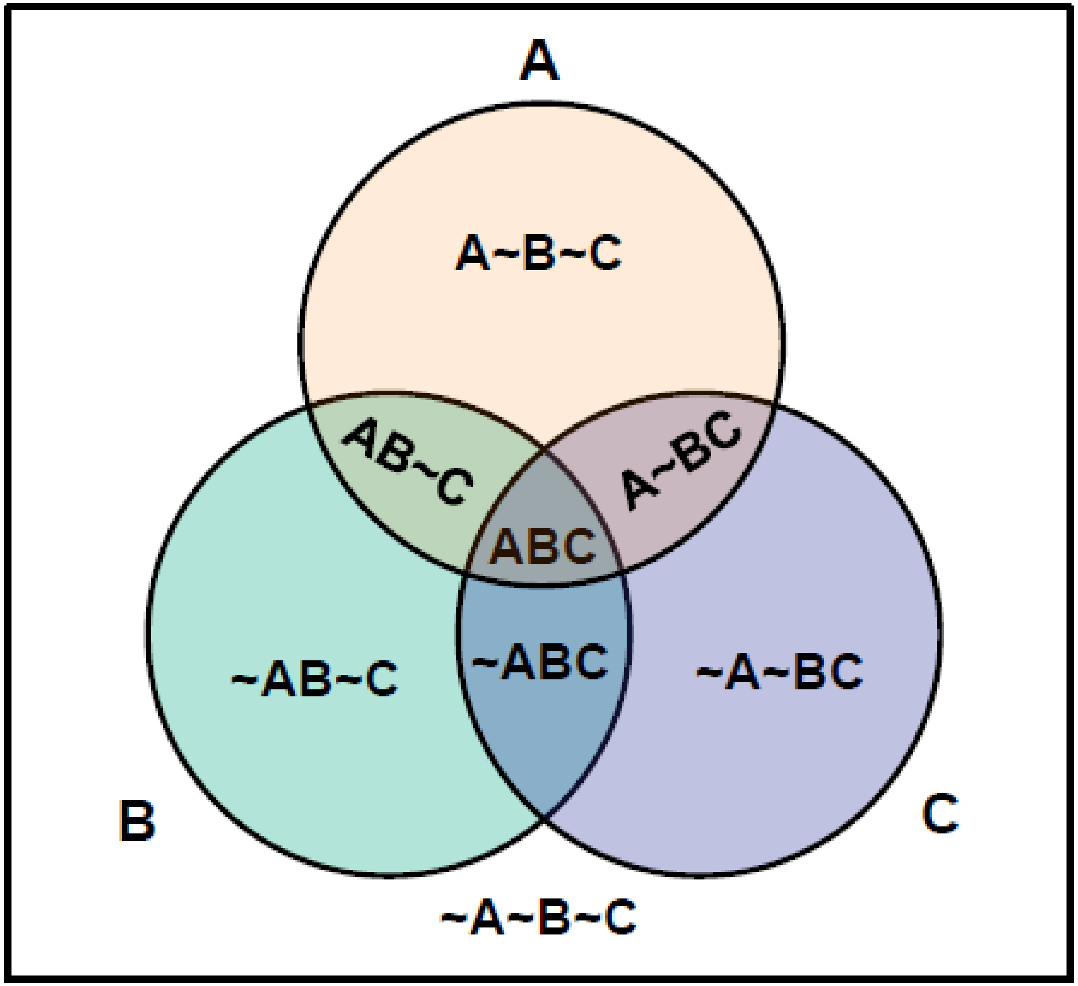
0.50

Truth Tables

(Schneider & Wagemann 2012: Chapter 4;
see references for additional sources)

Truth Tables

Logically Possible Combinations



2^3 (A, B, C)
= 2x2x2
= 8 Combinations
= 8 Rows (Truth Table)

2^4 = 16 Rows
2^5 = 32 Rows
2^6 = 64 Rows
2^7 = 128 Rows

Truth Tables

From Data Matrix to Truth Table

How to get from a data matrix to a truth table?

- Write down all 2^k combinations
- For each *case*, determine to which truth table row it belongs
- For each *row*, check if it is consistent with the statement of sufficiency by looking at each case's membership in the outcome

Truth Tables (Example with Crisp Sets)

From Data Matrix to Truth Table

	Conditions			Outcome
Cases	A	B	C	Y
ARG	1	1	1	0
PER	1	0	0	0
BOL	1	1	0	0
CHI	0	1	0	1
ECU	1	0	0	0
BRZ	0	1	1	1
URU	1	0	1	1
PAR	0	0	1	1
COL	0	0	0	1
VEN	1	1	1	0

Data Matrix

Y: Stable democracy
A: Violent breakdown
B: Ethnic homogeneity
C: Fragmented party system

Truth Tables (Example with Crisp Sets)

From Data Matrix to Truth Table

	Conditions			Outcome	
Row	A	B	C	Y	
1	0	0	0	1	COL
2	0	0	1	1	PAR
3	0	1	0	1	CHI
4	0	1	1	1	BRA
5	1	0	0	0	PER, ECU
6	1	0	1	1	URU
7	1	1	0	0	BOL
8	1	1	1	0	ARG, VEN

Truth Table

Y: Stable democracy
A: Violent breakdown
B: Ethnic homogeneity
C: Fragmented party system

Truth Tables

From Data Matrix to Truth Table

Cases	A	B	C
ARG	0.8	0.9	1
PER	0.7	0	0
BOL	0.6	1	0.1
CHI	0.3	0.9	0.2
ECU	0.9	0.1	0.3
BRZ	0.2	0.8	0.9
URU	0.9	0.2	0.8
PAR	0.2	0.3	0.7
COL	0.2	0.4	0.4
VEN	0.9	0.7	0.6

Exercise

Summarize the information gained from this table and reduce the Boolean expressions as far as possible!

Row	Conditions A	B	C	Sufficient for Y	Cases with membership ≥ 0.5 in row
1	0	0	0	1	COL (0.6)
2	0	0	1	1	PAR (0.7)
3	0	1	0	0	CHI (0.7)
4	0	1	1	0	BRZ (0.8)
5	1	0	0	0	PER (0.7), ECU (0.7)
6	1	0	1	1	URU (0.8)
7	1	1	0	0	BOL (0.6)
8	1	1	1	0	AR (0.8), VEN (0.6)

Row	Conditions A	B	C	Sufficient for Y	Cases with membership ≥ 0.5 in row
1	0	0	0	1	COL (0.6)
2	0	0	1	1	PAR (0.7)
3	0	1	0	0	CHI (0.7)
4	0	1	1	0	BRZ (0.8)
5	1	0	0	0	PER (0.7), ECU (0.7)
6	1	0	1	1	URU (0.8)
7	1	1	0	0	BOL (0.6)
8	1	1	1	0	AR (0.8), VEN (0.6)

~A~B~C + ~A~BC + A~BC → Y

~A~B + A~BC → Y

~B(~A + AC) → Y

Truth Tables

Logical Minimization Procedure

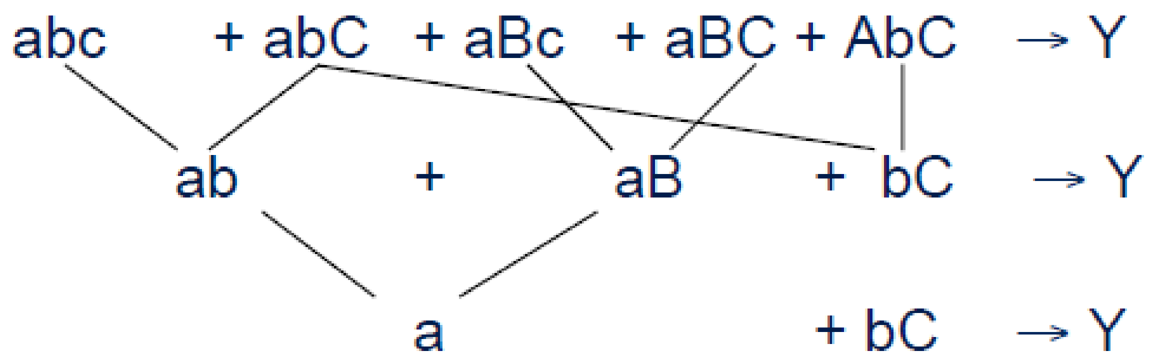
- How to analyze a truth table?
  - Aim
    - Which (combinations of conditions) are linked to the outcome?
    - Which combinations are sufficient for the outcome?

    → All rows that display the outcome

    Most complex answer/solution term
- How to get a more parsimonious solution?
  - By hand
  - By computer

Truth Tables

Logical Minimization Procedure



Primitive expression – Prime Implicants – Minimal solution

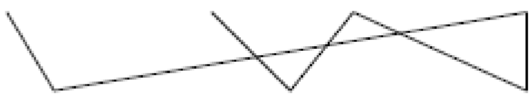
- **Comprise same truth value contained in truth table**
- **Are logically equivalent**
- **Should be reported in publications**
- **Which one to focus on most depends on research aims**

Truth Tables

Logical Minimization Procedure

- Not always does the above minimization strategy lead to the most parsimonious solution
- (Ragin 1986: Table 5)

AbC + aBc + ABc + ABC → S



AC + Bc + AB → S

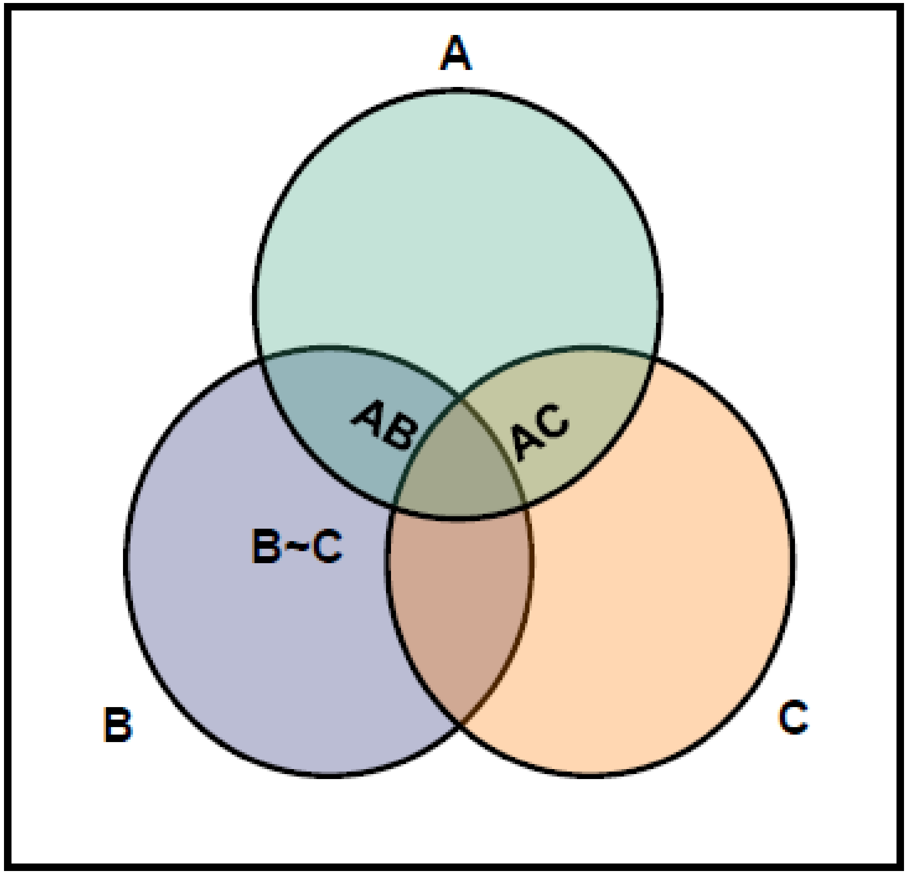
<u>Computer</u>

AC + Bc → S

- Why is the implicant 'AB' logically redundant?

Truth Tables

Logical Minimization Procedure



Our solution:

AC + B~C + AB → S

Computer:

AC + B~C → S

AB is covered by (AC + B~C)

AB is thus logically redundant (no additional information)

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