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Refining the causal loop diagram

A tutorial for maximizing the contribution of domain expertise in computational system dynamics modeling

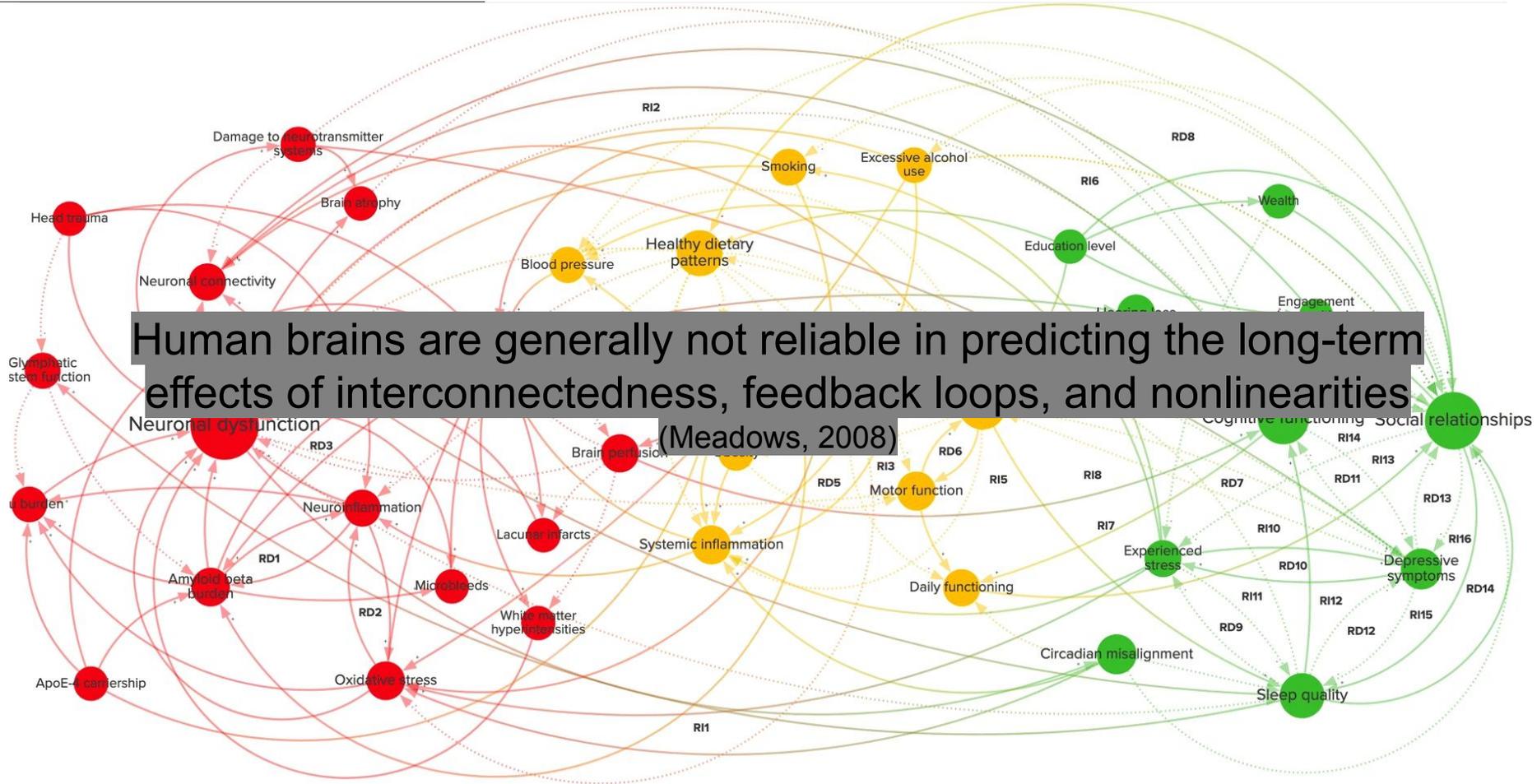
Introduction

- Complexity science ...
 - Studies “the way in which large groups of individual components behave collectively by adapting to each other and the environment they create themselves” (Sloot, 2020)
 - Is relevant to study prevailing problems **where biology, psychology, and socio-environmental factors interact**
 - Mental health (Borsboom, 2017), depression (Wittenborn, 2016)
 - Public health (Luke, 2012), obesity epidemic (Allender, 2015)
 - Planetary health (Swinburn, 2019), climate change (Dunn, 2017)
 - Social dynamics (Castellano, 2009), polarisation (Feliciani, 2017)

Introduction

- Complexity science ...
 - Aims to model the spatio-temporal dynamics of a system to explore its inherent patterns (Plisek, 2001)
- Step 1: **conceptual model**
 - Makes causal hypotheses, knowledge, and assumptions explicit (Kenzie, 2018; Uleman, 2020)
 - Causal loop diagram





Introduction

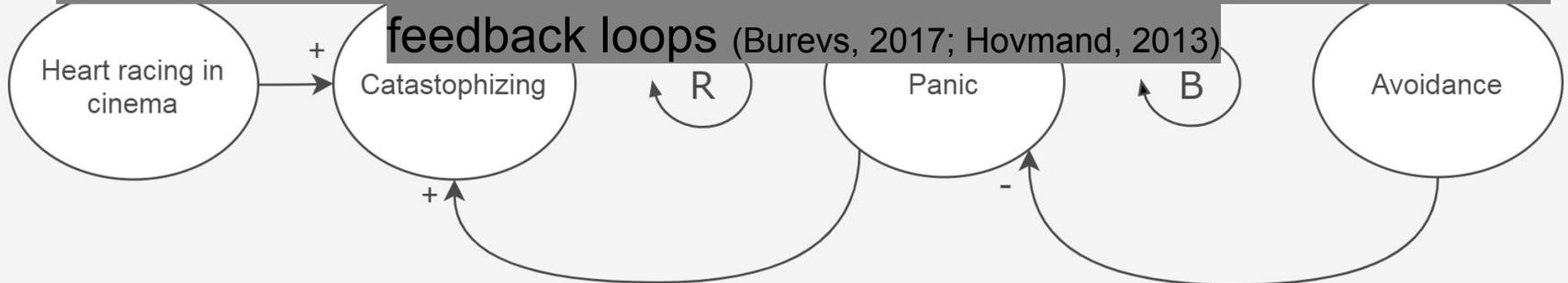
- Step 2: **computational model**
 - Less prevalent in biopsychosocial domains because of ...
 - Infeasibility of experimental research
 - Difficulty to obtain rich data
 - Rapid changes in underlying system
 - Relevant variables on many spatial and temporal scales
 - Difficulty to replicate a controlled environment
 - Unclear system boundaries
 - ... But necessary if we want to explore, interpret, and manipulate *in silico* the emergent dynamics of a system

Introduction

- Need to identify **methods** to build computational models from conceptual models using the sparse available data in the biopsychosocial domains
 - Documented protocols lack steps that would allow for subsequent conversion to a validated, executable computational model (Serman, 2001; Littlejohns, 2018; Martinez, 2018)

Current state-of-the-art CLD

Contains variables, causal links in the forms of arrows, and identified feedback loops (Burevs, 2017; Hovmand, 2013)

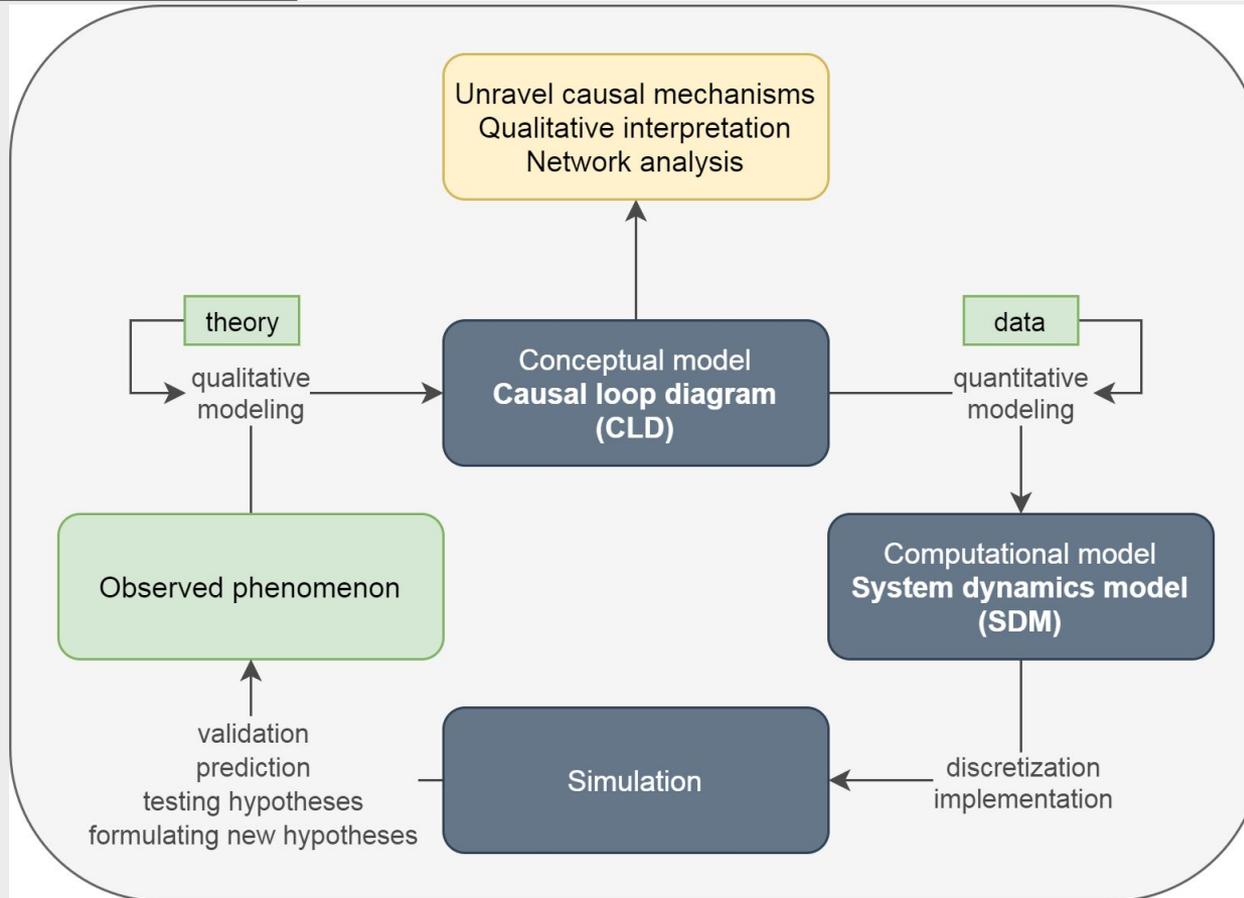


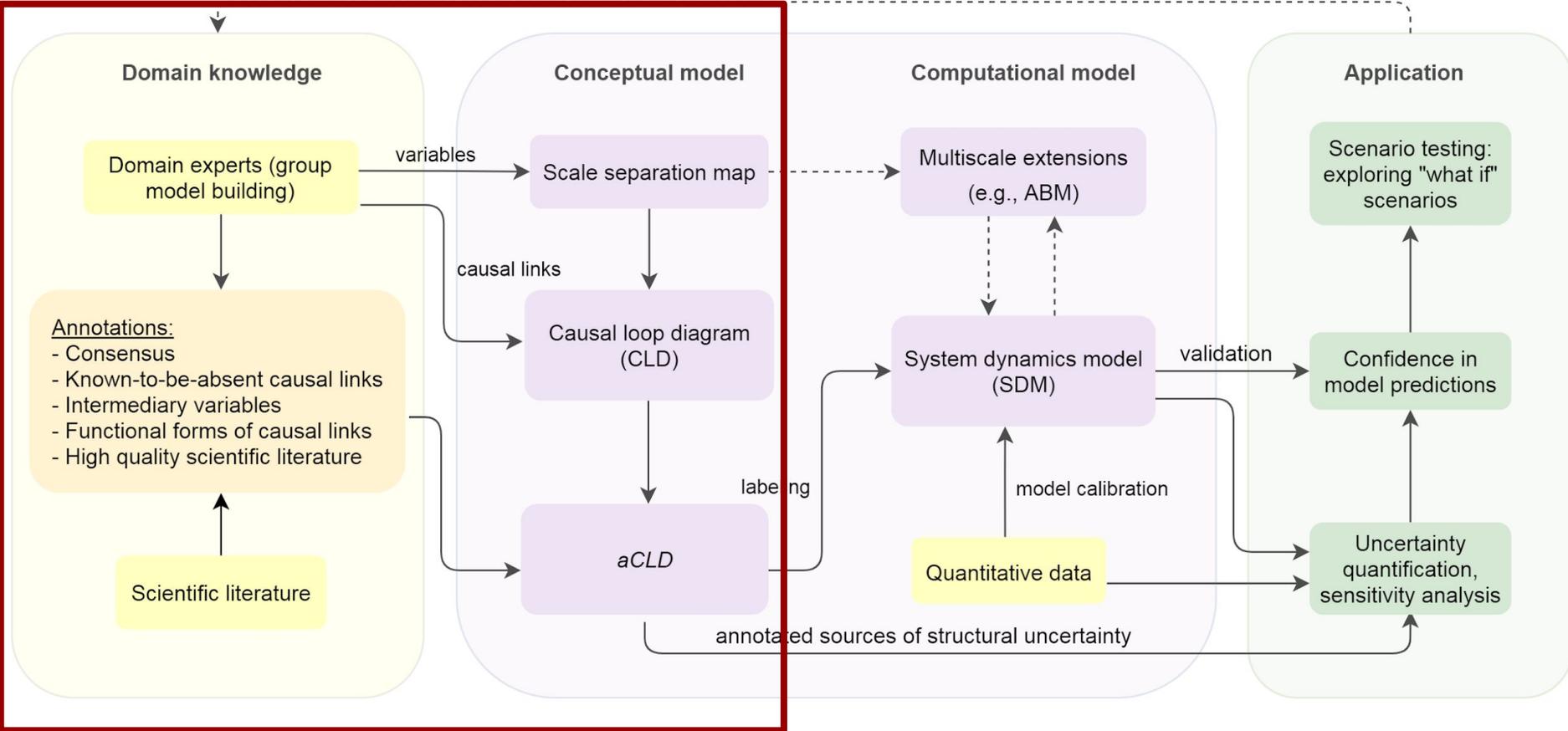
Introduction

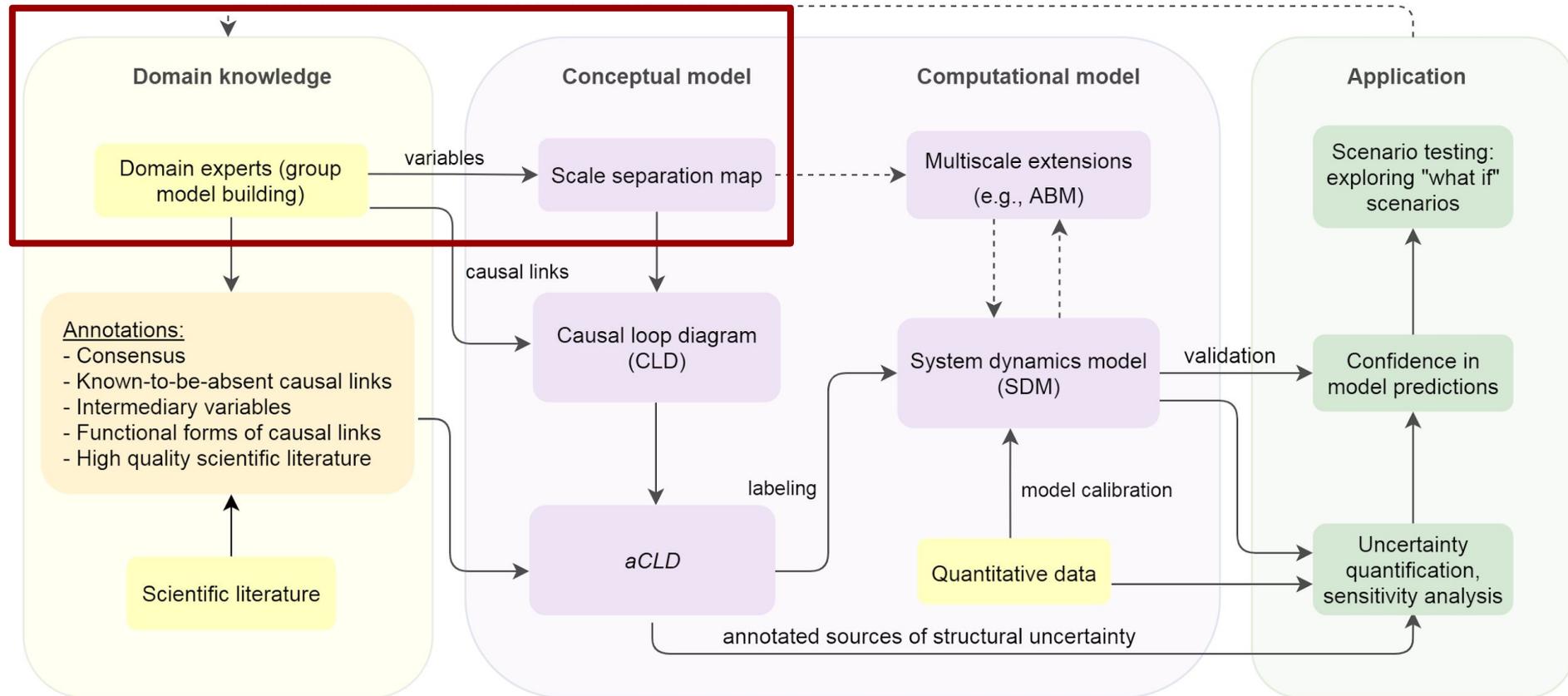
- Ask the experts for more than that!
- Paper describes steps required for capturing expert knowledge in a conceptual model such that it may result in a computational model
 - Draw on the experience of the IAS community
- Focus on causal loop diagrams (CLDs) as conceptual models and **system dynamics models (SDMs)** as computational models
 - **Annotated causal loop diagram (aCLD)**

System dynamics model (SDM)

- A coupled set of differential or difference equations (Homer, 2006)
- Intuitive computational implementation of expert knowledge combined with data (Forrester, 2009)
- Architecture can incorporate other computational models
 - Leading to modular construction of a multiscale model (Borgdorff, 2013; Hoekstra et al. 2019; Hoekstra et al. 2019)

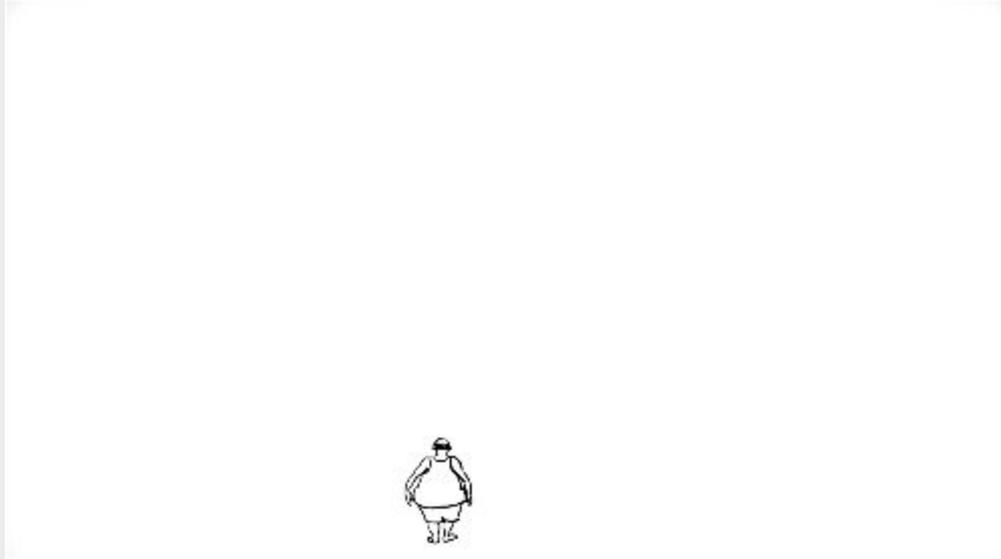






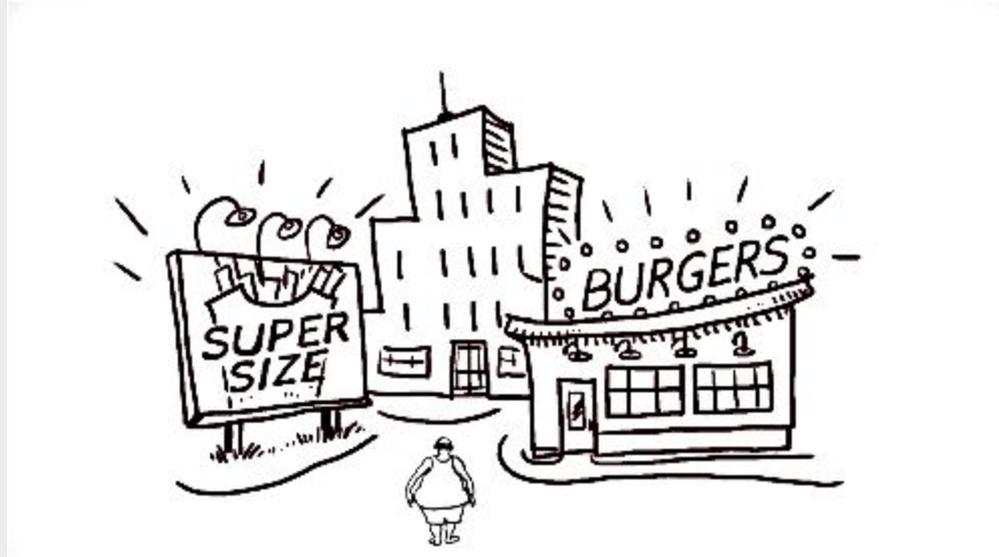
Research question and context of validity

- Predetermined context of validity (spatial and temporal scales) and research question agreed upon by experts (Velten, 2009; DeTombe 2015)
- **“the purpose of the computational model provides the anchor”** (Burton, 1995)
 - Otherwise no defined boundary to accept/reject proposed variables and causal links
 - Result: mix of model components for a set of different contexts, while not valid for any of them
- Model should never be used outside of the context for which it was developed without careful consideration and enhancement (Cellier, 1991)



Physiology of overweight (micro-level, months)





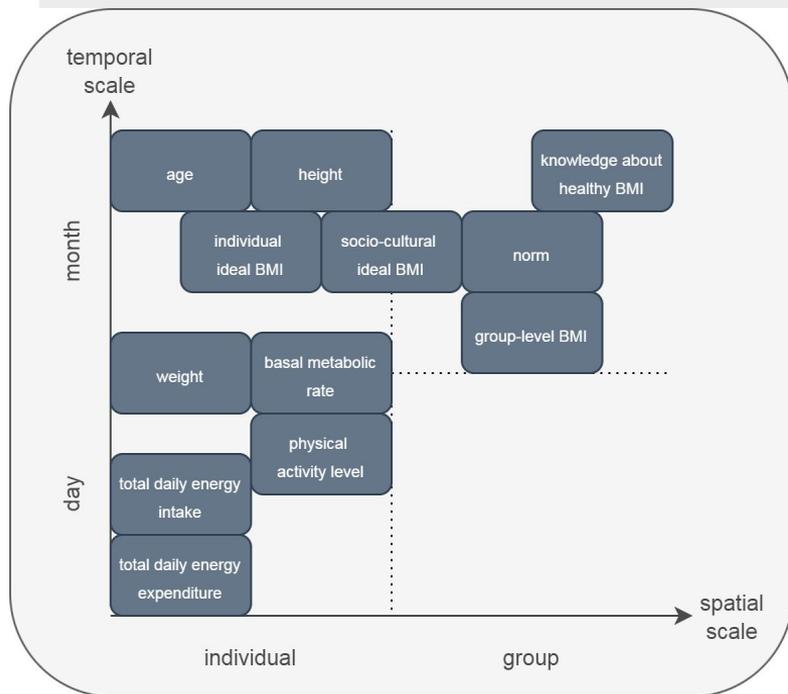
Influence of local built environment on overweight (macro-level, years)



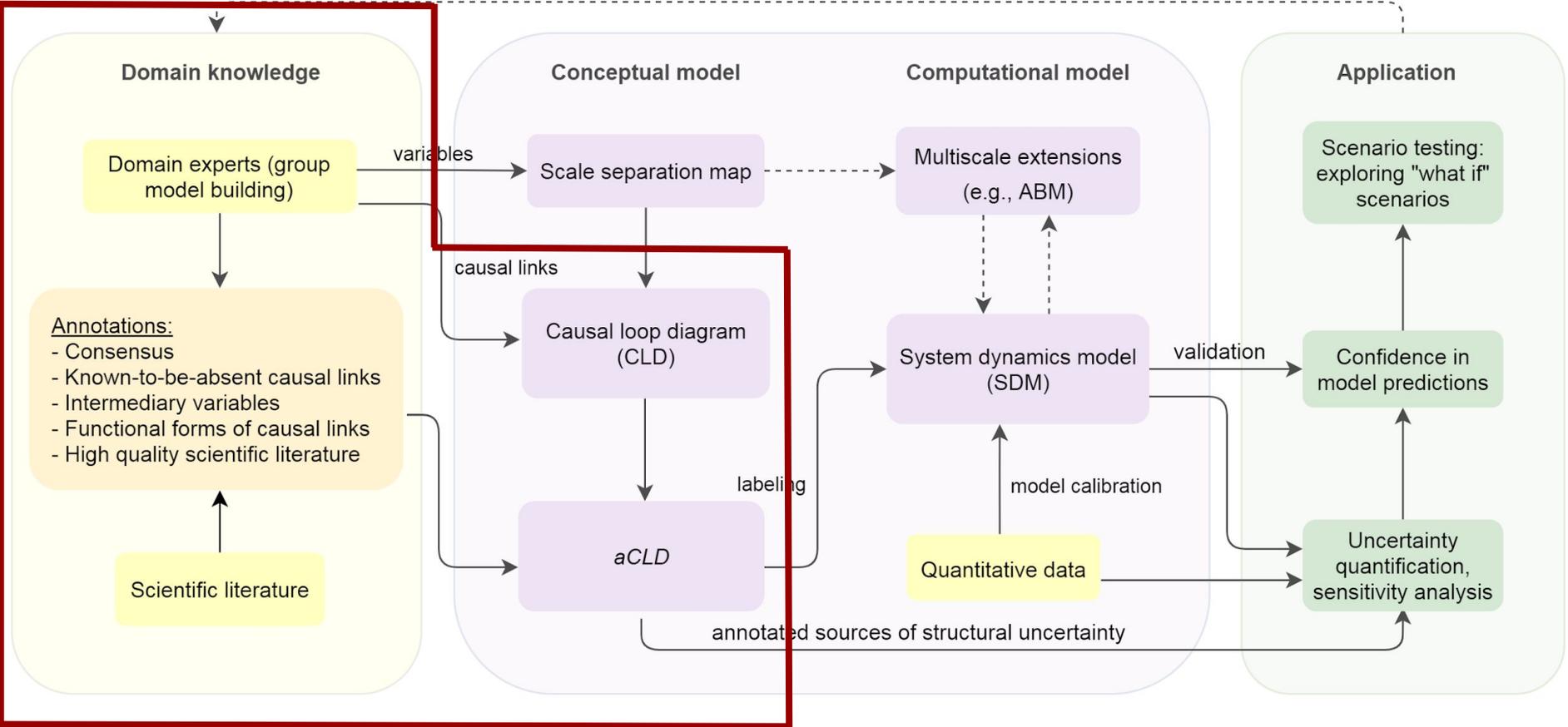
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- aCLD is “a reflection of the knowledge and assumptions held by a person or group - a shared mental model” (Kenzie, 2018; Jones, 2011)
- Group model building (Rouwette, 2016; Richardson, 1995, Andersen, 2007; Hovmand, 2012, Luna-Reyes 2006)
- “all models are wrong” (Box, 1976): **reflection of the collective understanding of a specific group of experts**
- Diverse yet overlapping selection of domains (Richardson, 1995)
- Expert-domain cross table to prove diversity and overlap (Uleman, 2020)

Variable selection and the scale separation map

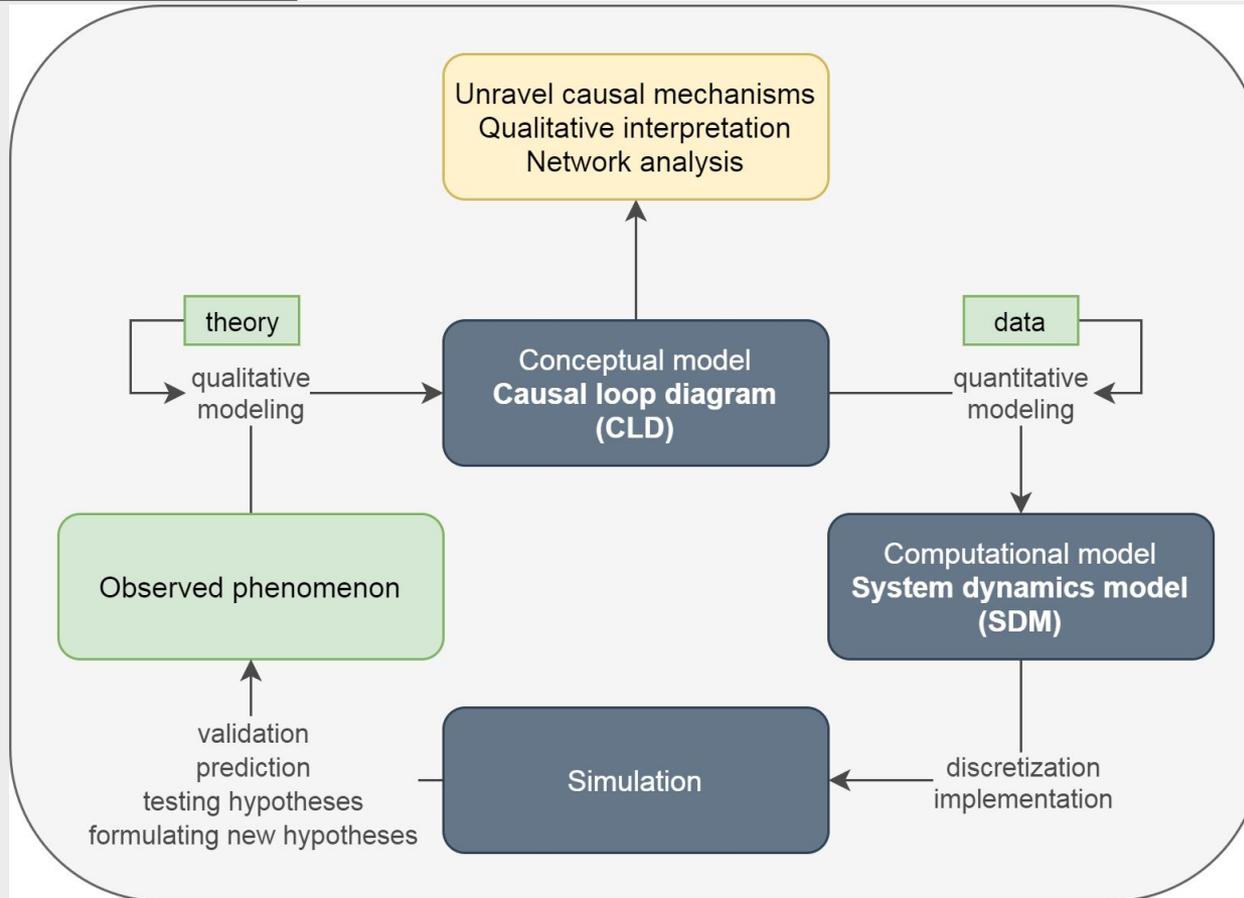


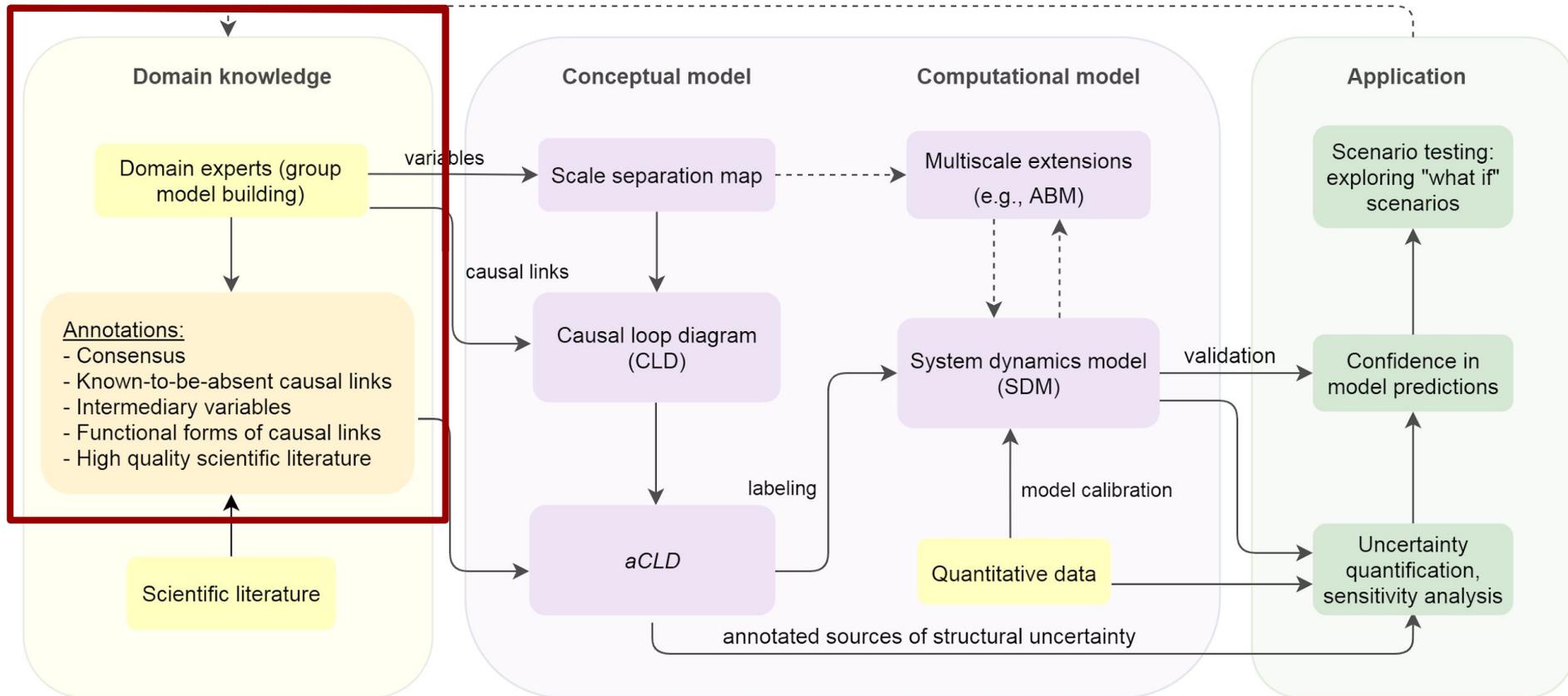
- Scale separation map (Sloot, 2010)
 - Smaller temporal scale: average out (physical activity level)
 - Larger temporal scale: keep constant (age, height)
- Define variables unambiguously (diet → total daily energy intake) (Haraldsson, 2004)
- Define variables neutrally (unhealthy ideal BMI → ideal BMI) (Haraldsson, 2004)



Uncertainty in modeling

- **Structural uncertainty**, in topology of the aCLD and equations used in the SDM, leads to uncertainties in the corresponding simulation results
- Ignored or simply decided one way or another creates bias, overstates predictive power, and may lead to wrong conclusions (Babtie, 2014)
 - Uncertainties should be made explicit and annotated in the aCLD during conceptual modeling
 - Structural uncertainty can be reduced by maximizing the domain knowledge used in development of the CLD (Roy, 2011)





Recording consensus

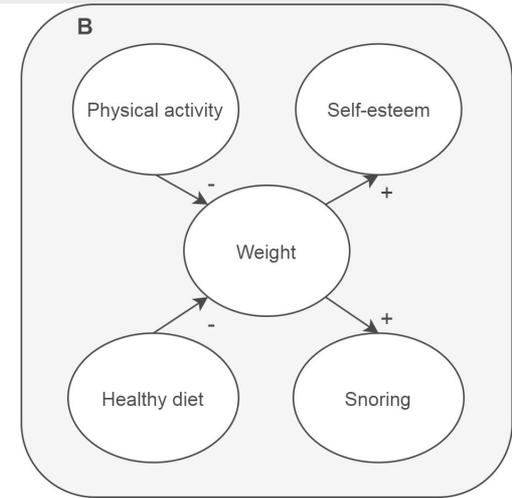
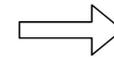
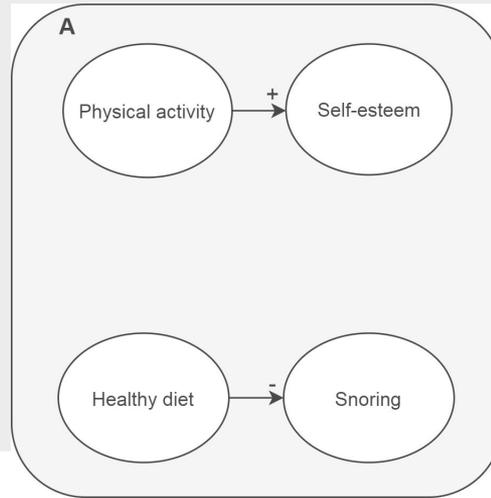
- If aCLD is result of consensus between experts, it strengthens certainty regarding its structure (Vennix, 1996)
- Conversely, disagreement among experts increases structural uncertainty
- **Uncertain causal links** result in multiple possible models
- **Votes** (Gustafson, 1986) as a measure of certainty for the existence of an uncertain causal link (prior probability)

Recording known-to-be-absent causal links

- Known not to be a direct cause-and-effect
- Now: if causal link is not present in CLD, it remains unrecorded whether this is because it is ...
 - Known to be unknown (should not be excluded)
 - Unknown to be unknown (simply not discussed)
 - **Known-to-be-absent**
- Assuming that unrecorded causal link is known-to-be-absent: leads to underestimation of the structural uncertainty
- Adding annotation of known-to-be-absent causal links enables bringing the structural uncertainty to a manageable level while reducing bias

Recording intermediary variables

- Only direct causal links should be added (relative to all variables included in the aCLD)
- If mediators remain unrecorded, it has to be assumed that the intermediary variables underlying the causal links are **independent**



Describing the functional form of causal links

- Mathematical equation that best describes the causal relationship
- Refine the initial polarity used for a causal link
- Draw selection of **mathematical relationships** for experts to choose from
- Any information can help reduce the uncertainty about the functional form (e.g., “monotonically increasing”, “eventually converging to zero”)



Describing interaction terms

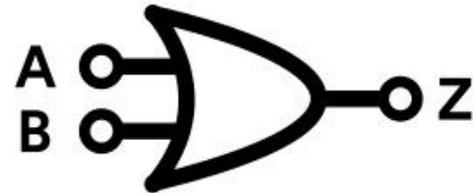
- Many-to-one causal link in which multiple variables collectively bring about a change in another variable: **interaction** (Hayward, 2014)
 - Logical AND gate
 - Logical OR gate

AND gate



A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

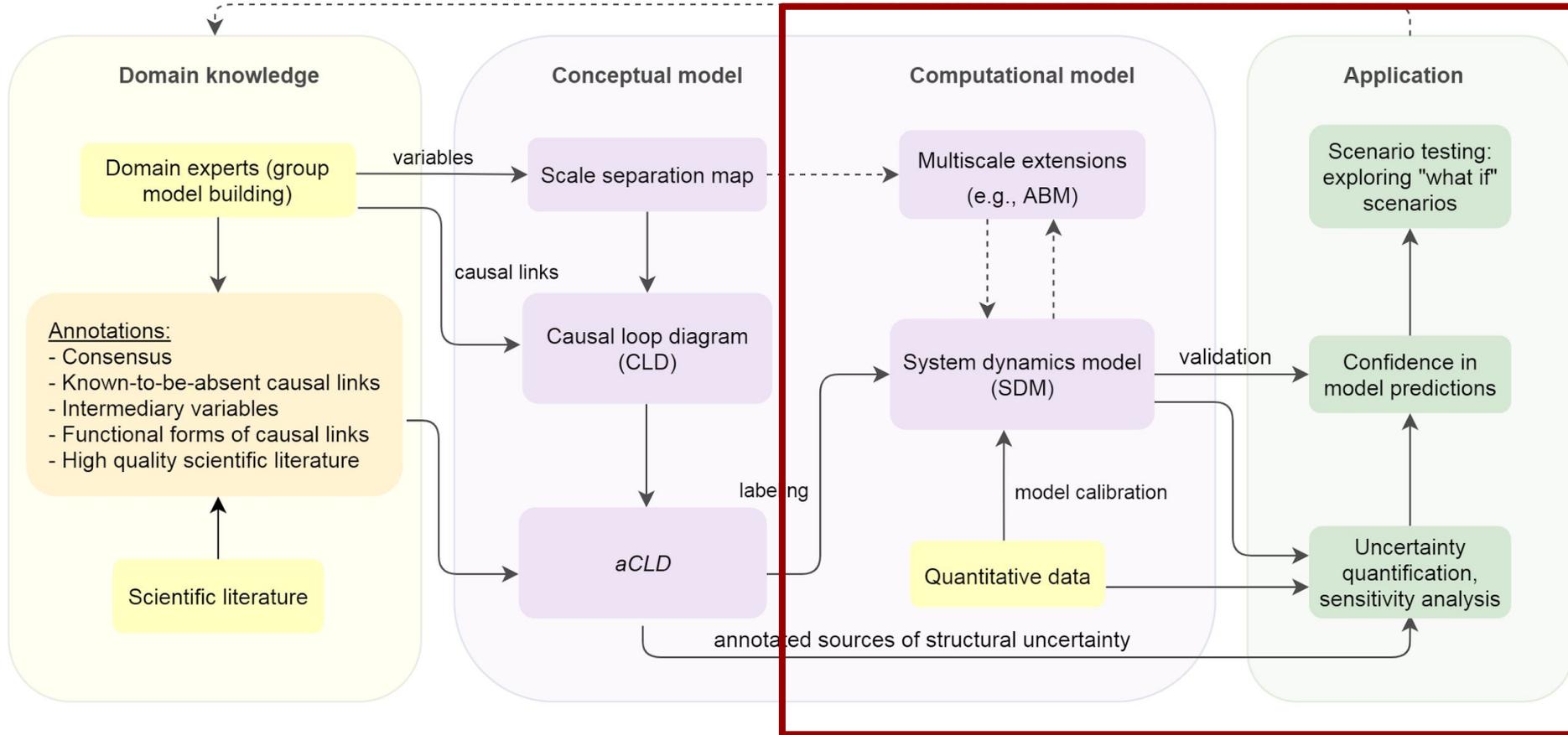
OR gate



A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

Providing high quality literature evidence

- Empirical evidence is often provided implicitly (Wittenborn, 2016; Vins, 2015; Tucker, 2017)
- Should be explicitly specified for each variable and causal link (Kenzie, 2018)
 - Allows for **iterative development**
 - Provides a concrete basis for **discussion** among experts
 - Evidence can be deciding factor (although known to be unknown should be included) according to quality of evidence (Grade, 2004; Guyatt, 2011)



All the confidence in the world

- Testing “what if” scenarios
- Test effects of hypothetical interventions
- Quantify causal pathways





Questions?

- Any uncertainties you'd want to share?

