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METHODOLOGICAL PRINCIPLES FOR SUBSTANTIATING THE INTERRELATIONSHIPS OF A MULTI-LEVEL APPROACH AT THE MICRO, MESO AND MACRO LEVELS AND FORMING A MODEL ARCHITECTURE

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Abstract

This article provides a theoretical and methodological basis for the multi-level approach, which examines the interconnections at the micro-meso-macro levels, and develops principles for forming a model architecture taking these interconnections into account. The micro level represents the behavior and local interactions of agents (individuals, business entities, community members); the meso level represents institutions, networks, organizations, technological regimes, and "rule sets"; and the macro level represents a slowly changing context (culture, political-economic landscape, global trends). It is shown that without a clear formalization of inter-level connections (bottom-up, top-down, and co-evolutionary), "inter-dimensional" errors (micro-macro gap, ecological fallacy) arise in explaining and predicting real systems. The article argues that the hierarchical structure and the idea of " near-decomposability " in systems theory serve as a methodological basis for modularizing the model, identifying interfaces and connecting mechanisms. It also proposes an architecture that combines multilevel concepts of social systems, sociotechnical changes and socio-ecological systems.

Keywords

multilevel approach; micro-meso-macro; interlevel mechanisms; modular architecture; hierarchy; near-decomposable system; agent-based modeling; sociotechnical regime; system dynamics; validation.

INTRODUCTION

In explaining complex social, economic, technological and socio-ecological processes, analysis that is "locked" to a single level is often insufficient. For example, relying only on the micro level (the behavior of individuals or firms) loses the limiting/directing role of institutions and context; relying only on macro indicators (GDP, inflation, general trends) does not show how real decisions of agents and local interactions "create" macro outcomes. For this reason, multi-level approaches have been developed in various fields in modern scientific literature: the ecological model of human development describes the micro–meso–macro structure as "inside-out" systems [Bronfenbrenner, 1979, 23]; the theory of sociotechnical change presents the "niche–regime–landscape" triad as a nested (inside-out) hierarchy [Geels, 2002, 1261]; The general framework for socio-ecological systems (SES) also distinguishes interconnected subsystems and levels [Ostrom, 2009, 420].

The problem, however, is that simply mentioning "micro–meso–macro" is not enough: unless the mechanisms of inter-level linkages are clearly expressed in practical modeling, the explanation will be weak. Agent-based models (ABM) strongly impose this "generative" requirement: the macro order (norm, price equilibrium, segregation) must be "grown" by micro agents and local interactions [Epstein, 1999, 41]. At the same time, in real systems there is also a top-down effect: institutions, norms and rules reshape micro behavior; hence, the micro and macro often co-evolve [Epstein, 1999, 41].

The purpose of this article is:

1. methodological substantiation of the connections between micro - meso-macro levels ;
2. Formulating architectural principles that serve to represent inter-level mechanisms in a model ;
3. Provide tables and conceptual drawings operationalizing the proposed architecture .

The research questions are as follows :

- Under what conditions do micro outcomes stabilize or erode mesostructures (network, institution, regime)?
- How does the meso level constrain or encourage micro decisions (rules, information flows, resource access)?
- Through what mechanisms does the macro landscape (slowly changing factors) exert "pressure" on the meso regime and micro niches?
- What kind of architecture is needed to combine all of this in one model?

LITERATURE ANALYSIS AND METHODS

1. Theoretical basis: levels and internal hierarchy

a multilevel approach, "level" refers not only to size, but also to differences in mechanism and structure . Bronfenbrenner's ecological approach defines a microsystem as a model of activities, roles, and relationships in which an individual is directly involved [Bronfenbrenner, 1979, 23]. Importantly, he sees the environment as "internally concentric structures" : micro–meso–exo–macro layers are located on top of each other [Bronfenbrenner, 1979, 23]. Here, the meso level is the connection between microsystems , the inter-institutional connections, the "bridge" role.

In the multilevel perspective (MLP) on sociotechnical change , the concepts of niche (micro), regime (meso), and landscape (macro) are presented in the form of a "nested hierarchy" [Geels, 2002, 1261]. According to Geels , the regime explains the stability of the existing development trajectory, the landscape is a slowly changing set of external factors that exert pressure on the regime, and niches are "incubators" of radical innovations [Geels, 2002, 1261]. This concept also shows the time scale difference between micro–meso–macro : macro changes slowly, meso changes moderately, and micro changes relatively quickly.

Ostrom's SES framework for social-ecological systems distinguishes subsystems such as resource systems, resource units, management systems, users, and their interactions , emphasizing the nonlinear interrelationships among variables [Ostrom, 2009, 420]. This allows for a multilevel approach to be used not only in the social but also in human-nature integration.

2. Methodological "base" for architectural principles: hierarchy and quasi-decomposability

The most important question in the methodology for forming a model architecture is: how can a complex system be described in terms of its components (modularization) while maintaining its overall behavior?

that many complex systems have a hierarchical structure and that hierarchy is a "construction method" for managing complexity [Simon, 1962, 470]. He also distinguishes "nearly decomposable systems"—that is, systems in which the parts are relatively strong and the connections between the parts are relatively weak [Simon, 1962, 476]. This idea translates into modeling as follows:

- Within a micro module, agents interact with each other in a very local way;
- Institute/network rules are strong in the meso module;
- In the macro module, landscape parameters change slowly ;
- and interfaces between module(s) are connected via specific, limited channel(s).

This approach makes the model (1) more understandable, (2) easier to calculate, and (3) allows for verification/validation to be carried out step-by-step by modules.

3. The micro–macro " bridge " issue and the generative approach

the multilevel approach is to explain the mechanism of transition from micro to macro without a "gap". In Coleman's "boat" image, macro conditions affect micro actions, and micro actions in turn produce macro results [Coleman, 1990, 8]. This structure, in fact, represents a chain of top-down → micro mechanism → bottom-up .

posed the central question in generative social science as follows : "How does the decentralized local interaction of heterogeneous agents produce a given macro regularity?" [Epstein, 1999, 41]. This requirement implies that there must be simulational consistency between micro rules (agent algorithms) and macro indicators (order, trend, equilibrium) in a multi- level model architecture .

4. Research methods (within the article)

This article is conceptual-methodological and was written in a combination of the following methods:

1. Theoretical analysis and synthesis : bringing micro–meso–macro concepts from different directions into general architectural principles [Weaver, 1948, 66].
2. Design-methodological approach : design the model architecture based on the chain "requirements → module → interface → verification " .
3. Operationalization : Representing indicators and verification criteria for levels, variables , and mechanisms through a table/figure.
4. Systems thinking : interpreting leverage points (information flow, rules, goals, paradigm) across levels [Meadows, 1999, 2].

DISCUSSION

1. Functional definitions of micro, meso and macro levels

For practical modeling, it is convenient to define the levels in a working definition as follows:

• Micro level (agents and local interactions) Unit: individual, family, firm, farmer, student, consumer, user, etc. Mechanism: decision rules, limited information, habits and motives; interaction with "neighbors"; adaptation through experience. According to the generative requirement, macro regularity should "grow" precisely from these local interactions [Epstein, 1999, 41].

• Meso level (institutions, networks, organizations, regimes) Unit: inter-organizational network, market segment, educational institution, set of norms, technological regime, management system. Mechanism: rules, standards, resource allocation, monitoring and sanctioning, cooperation/competition configuration. In MLP, it is the meso regime that is seen as a source of stability and trajectory [Geels, 2002, 1261].

• Macro level (landscape/context) Unit: cultural values, demographic trends, global market conditions, geopolitical factors, environmental constraints. Mechanism: slowly changing parameters, "background" conditions, mega-trends that put pressure on the system. In MLP, the landscape changes more slowly than the regime [Geels, 2002, 1261].

2. Types of inter-level connections : bottom-up, top-down, co-evolution

the multilevel model are three types of connections:

2.1. Bottom-up (micro → meso/macro)

this sense , the aggregation of micro-behavior "creates" or reinforces meso-institutions. For example:

• local collaboration creates networks;

• recurring choices shape market norms;

• many agents creates the possibility of transition from niche to regime [Geels, 2002, 1261].

Generative criterion: macro-specifications arise from micro-specifications and recur in simulation [Epstein, 1999, 42].

2.2. Top-down (macro/meso → micro)

redefines the micro-decision set through "rules, information flow, incentives , and constraints." This is also present in Bronfenbrenner's internal structure of the environment: individual development involves the interactions and influences of "larger contexts" [Bronfenbrenner, 1979, 21]. It is also common within ABM for there to be feedback from macrostructures to microstructures [Epstein, 1999, 41].

2.3. Co-evolution (mutual adaptation cycle)

In most real systems, micro-agents change institutions , and institutions re-educate agents; as a result, the levels "walk" together. Ostrom's framework emphasizes that variables interact nonlinearly, and the effect of one factor depends on the value of another [Ostrom, 2009, 420]. Therefore, the architecture should be feedback rather than "one- way flow " .

3. Methodological principles for forming model architecture

The following principles make multi- level model architecture stable and testable:

Principle 1. Hierarchical modularity and near-decomposability

strong coupling within the model modules and limited interfaces between the modules [Simon, 1962, 476]. This architecture:

• to place levels "inside by side",

• to control the number of parameters,

• serves to reduce computational complexity.

Principle 2. Clearly define inter-level interfaces

An "interface" is a minimal set of information/resources that are exchanged between modules : for example, a tax rate or price signal from a macro module to a micro one, rules and sanctions from a meso to a micro one, and aggregate indicators (demand, trust, innovation rate) from a micro to a meso one. Leaving the interfaces "vague" reinforces the micro–macro narrative.

Principle 3. Mechanism -oriented operationalization

Each link should be written as a "mechanism": (condition) → (action rule) → (result). This turns the Coleman chain into a practical "bridge " [Coleman , 1990, 8].

Principle 4. Harmony of time scales

Slow changes in macro factors should be represented in the model as slow parameters (or scenarios); micro steps should be handled with fast iterations. In MLP, the landscape changes slowly, the regime changes moderately , and the niche changes faster [Geels, 2002, 1261].

Principle 5. Build traceability and validation into the architecture

be verifiable, not just a "beautiful explanation ." In the generative approach, it is not enough for micro-rules to yield macro-regularities; if there are competing micro-specifications , empirical tests at the micro-level must distinguish them [Epstein, 1999, 42].

Principle 6. Allocation of leverage points by level

In systems thinking, leverage points are often not at the "parameter" level, but at the information flow, rules, goals, and paradigm levels [Meadows, 1999, 2]. Translating to a multi- level architecture: meso (rules), macro (goals/paradigm), and micro (decision rules) leverage points are seen as separate modules.

RESULTS

operationalizing the multi-level approach and designing the model architecture.

Table 1. Micro–meso–macro levels: units, variables , and sources of observation

Level	Basic unit (unit)	Typical bles	Mechanism	Observation/infor on source

Micro	Agent vidual/firm/user)	choice, habit, ırce, trust, tation	local interaction, based learning	query, log-data, actions, experience
Meso	Organization/network/r e	rules, standard, toring, network ture	institutional raint, lination, sanction	regulations, stry metrics, institute mation
Macro	Landscape/context	trend, ographics, global s, values	slow neters, ure/pulses	statistics, scenarios, o indicators

Note: The "mechanism" column in the table serves not only to classify levels but also to identify model interfaces. This, in turn , helps to build a micro–macro bridge based on the mechanism [Coleman, 1990, 8].

Table 2. Architecture principles and verifiable indicators

Principle	**Architectural requirement**	**Control indicator (minimum)**	**Source/scientific basis**
Hierarchical modulation	Strong coupling within modules, limited coupling between modules	the number of interface variables is "small"; the internal module coupling is "strong"	[Simon, 1962, 476]
Interface accuracy	Clear entry/exit for each level	There is an "input-output" list and units of measurement.	[Geels, 2002, 1261]
Orientation to the mechanism	(condition → rule → result) record	there is a mechanism card for each link	[Epstein, 1999, 41]
Time scale	Macro is slow, micro is fast iterated	time step and parameter update rate match	[Geels, 2002, 1261]
Validation is "built in"	Observable macro indicators and micro tests	generative compatibility + micro empirical compatibility	[Epstein, 1999, 42]
Leverage allocation	Parameter–Rules–Goal–Paradigm Layers	There is a module for each leverage type.	[Meadows, 1999, 2]

Table 3. Matrix of inter-level connections (mechanism map)

Link direction	**Mechanism name**	**Interface signal**	**Expected result**
Micro → Meso	Endogenous formation of the norm	agents behavior frequency	emergence of a rule/standard
Meso → Micro	Institutional restriction	sanction, incentive, permission	decision set narrowing
Macro → Meso	Horizontal pressure	trend, shock, resource	decrease in regime

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		constraint	stability
Micro → Macro	Aggregation	total demand/trust/innovation share	macro indicator change
Macro ↔ Micro	Co-evolution	norm/institution ↔ behavior	new equilibrium or cycle

Figure 1. Micro–meso–macro internal-internal model (conceptual diagram)

CONCLUSION

The article argues that the multi-level approach to the interrelationship of micro–meso–macro layers is not a "classification" but rather a problem of mechanism and architecture . Key conclusions:

1. There are three main connections between the micro, meso, and macro levels: bottom - up , top-down , and co-evolution . Without explicitly formalizing them, the micro–macro explanation is broken.
2. The idea of hierarchical organization and almost decomposable systems as the methodological basis of model architecture facilitates modularization, interface constraints, and validation [Simon, 1962, 476].
3. The MLP (niche–regime–landscape) and SES frameworks provide a strong conceptual basis for explaining inter-level time scales and nonlinear interactions [Geels, 2002, 1261; Ostrom, 2009, 420].

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4. The generative approach provides a powerful test for multilevel models: macro regularity must "grow" through micro rules and competing micro specifications must be empirically disentangled [Epstein, 1999, 42].

5. The tables and figures proposed in the Results section serve as a basic "constructor" for the practical design of a multi-level architecture (module–interface–indicator).

In future work, it is desirable to test this methodological architecture with empirical data in a specific domain (e.g., education system, risk in the banking sector, innovation diffusion, or resource management), optimize the minimum set of interface signals, and strengthen it with sensitivity/robustness analyses.

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