Actions Across Levels (AAL): A Multiple Levels Perspective On What It Means To Make Sense Of Complex Systems

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Furthering our understanding of what it means to make sense of complex systems is becoming a pressing imperative, as educational systems begin incorporating such constructs into standard curricula (Jacobson, 2006; Wilensky, 1999; Levy, Novak & Wilensky, 2006). Work to date on the topic has focused on understanding of the system's structural aspects (Hmelo-Silver & Pfeffer, 2004) or the underlying epistemologies and ontologies (Wilensky & Resnick, 1999; Jacobson, 2001; Chi, 2005). This work builds upon previous work, delineating how people reason about complex systems. We propose a framework, Actions Across Levels (AAL), for understanding and investigating how people reason about complex systems. This framework consists of two dimensions: description levels and mental actions undertaken while interpreting systems (see Figure 1).

Level / Action	Agent	AA* (both)	Aggregate
Rule-making	*Forming agent rules*: agents behaviors depending upon local and internal conditions	*Forming rules* in which (1) local behaviors are impacted by global properties; (2) global behaviors depend on local properties and events.	*Forming rules for the whole system*: impact of global variables upon aggregate states and properties
Paralleling	*Concurrent behaviors of several agents*: Different agent behaviors are dependent on varying local environments; local patterns may emerge.		
Chaining	*Sequencing a chain of agent behaviors* through time: an individual's history	*Sequencing a chain of states* that involve both agent and aggregate description levels.	*Sequencing a chain of systemic states*: the aggregate evolution through time

Figure 1: Actions Across Levels (AAL) – A theoretical framework describing components of reasoning about complex systems.
* AA denotes agent-aggregate complementarity, when both description levels are incorporated into a single explanation or idea.

The notion of *levels* is a central component in agent-based approaches, specifying both *individual agents* and the *overall system*'s emergent and aggregate behavior (Bar-Yam, 1997). Thus, one dimension in the AAL framework is the description level: agent (individuals), aggregate (system) or a mélange of the two (AA, agent-aggregate

complementarity, when both description levels are incorporated into a single explanation; Stroup & Wilensky, 2003).
The second dimension introduces three mental actions, involved in reasoning about systems. *Rule-making*: connecting conditions and actions, which govern agents' behaviors as they respond to their environment or internal states; relating global changes and affected properties; or combinations of the two; *Paralleling*: simulating multiple agents acting and interacting concurrently; *Chaining*: observing or deriving a sequence of states, temporal changes in the system and/or its elements.
In previous work, we investigated ten sixth-grade students' reasoning about ordinary social complex systems, discovering a pervasive strategy: "mid-level construction" (Levy & Wilensky, in press). We have found that students invent intermediate groups in a variety of forms along one of two trajectories: starting from the agents and grouping; or starting from the aggregate and partitioning (Figure 2). This strategy reduces the amount of information in the system, while preserving its multi-component, dynamic and interacting nature, serving explication of the system under scrutiny.

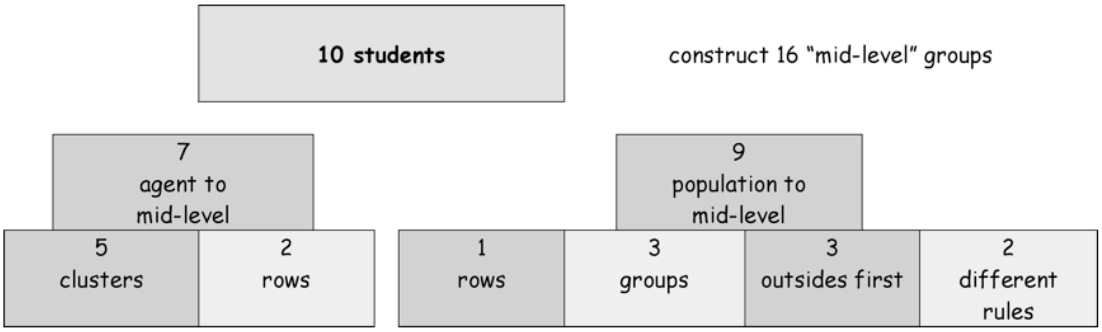

Figure 2: Forms of mid-level construction in ten "Scatter" interviews. Five students constructed more than one kind of mid-level. Trajectory is presented in the bottom part of the figure; specific forms of descriptions are counted.

In this study, we further explicate this strategy by coding the above interviews using the AAL framework. The students' utterances during the interview were coded according to the seven categories (Figure 1) and analyzed for relative frequencies. We have located group-wide strengths regarding the different components of reasoning: while agent rule-making is most commonly exercised, mentally simulating the system's evolution - chaining at all levels is least frequently; paralleling and aggregate rule-making are of intermediate strengths, however with a greater variance among the students (Figure 3).

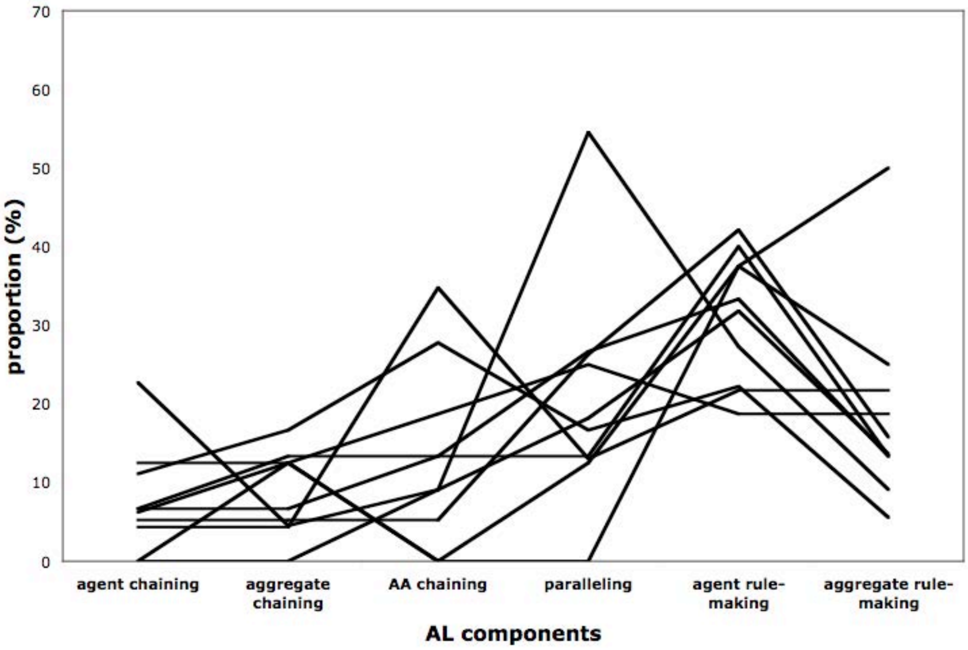

Figure 3: Individual student profiles across the different AAL actions and levels. Each student is a line. The proportion of utterances (%) for a single action out of all utterances is graphed. Note the range between the lowest and the highest value.

Moreover, we have found associations between individual students' strengths and the specific forms of "mid-levels" they create (Table 2). For example, strong paralleling is associated with a pattern involving several groups acting concurrently ("groups"), but not with a pattern in which groups' actions are staggered over time ("outsides first").

AAL / Mid-level	N	Agent chaining	Aggregate chaining	AA chaining	Paralleling	Agent rule-making	Aggregate rule-making
Clustering	5	10	7	18	20	30	14
Groups	3	10	5	12	32	26	14
Outsides first	3	7	12	4	8	38	29

Table 2: Mean proportions of utterances (%) related to actions for the dominant kinds of mid-levels. Dark gray signifies the dominant proportions (proportion is over 28%). White signifies low proportions (under 18%). Light gray signifies intermediate proportions (18% to 27%).

DISCUSSION

We discuss these findings with respect to support for the AAL framework, reported difficulties and possible supports in learning and teaching complex systems.

In the introduction, we proposed a two-dimensional framework for describing how people explain emergent phenomena: "Actions across Levels" (AAL).

We have presented evidence to support the utility of the AAL framework by locating instances of each component in the students' utterances, as well as diverse strengths and their association with different reasoning strategies.

We have found that for all the students, agent rule-making was prominent. Chaining (or sequencing events) was the least dominant. This confirmed our assumption that the task was well suited to students' everyday agent-based reasoning. As a group, the students' main resource was agent rule-making. Mentally simulating the unfolding of events was a challenge.

Mid-level construction was used to test the framework. Given the small sample, we do this carefully, and claim only to trends. We found that variation among the AAL components is related to the particular forms of mid-levels; stronger actions were used to construct mid-levels. "Clustering" in an individual-to-mid-level trajectory was related to stronger Paralleling or AA chaining, central features of agent-based reasoning. The other patterns were formed in a population-to-mid-level trajectory. The "groups" pattern, a parallel detachment of groups from the central cluster was related to stronger Paralleling, while lacking the Chaining features that access the system's evolution; staggering the groups ("outsides-first") was related to stronger Aggregate chaining and Aggregate rule-making, which support such temporal patterns, but lack the systems' parallel interactions.

Educational implications of this research point a way to analyzing both strengths and difficulties encountered by students while reasoning about complex systems, as related curricula become more prevalent.

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