Minsky, Mind, and Models: Juxtaposing Agent-Based Computer Simulations and Clinical-Interview Data as a Methodology for Investigating Cognitive-Developmental Theory

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We discuss an innovative application of computer-based simulations in the study of cognitive development. Our work builds on previous seminal contributions to field, in which theoretical models of cognition were implemented in the form of computer programs in attempt to predict human reasoning (Newell & Simon, 1972; Rose & Fischer, 1999). Our computer model can both be a useful vehicle to illustrate the Piagetian theoretical model or to simulate it departing from clinical interview data. We focused in the Piagetian conservation experiment, and collected and analyzed data from actual (not simulated) interviews.
The interviews were videotaped, transcribed, and coded in terms of parameters of the computer simulation. The simulation was then fed with these coded data. We were able to perform different kinds of experiments:
Playback the interview and the computer model side-by-side, trying to identify behavior patterns;
Model validation: investigate whether the child's decision-making process can be predicted by the model.
We conclude that agent-based simulation, activated alongside real data, offers powerful methods for exploring the emergence of self-organized hierarchical organization in human cognition. We are currently exploring the entire combinatorial space of all hypothetical children's initial mental states and activating the simulation per each of these states. From that perspective, our data of real participants become cases out of the combinatorial space.

Introduction

We discuss an innovative application of computer-based simulations in the study of cognitive development. Our work builds on previous seminal contributions to field, in which theoretical models of cognition were implemented in the form of computer programs in attempt to predict human reasoning (Newell & Simon, 1972; Rose & Fischer, 1999). Computers offer powerful methods for exploring the emergence of self-organized hierarchical organization in human cognition. In particular, *agent-based modeling* (ABM; e.g., 'NetLogo,' Wilensky, 1999; 'Swarm,' Langton & Burkhardt, 1997; 'Repast,' Collier & Sallach, 2001) enables theoreticians to assign rules of behavior to computer "agents," whereupon these entities act independently *but* with awareness to local contingencies, such as the behaviors of other agents. ABM has been used to illustrate aspects of cognitive development (see Abrahamson & Wilensky, 2005, for a previous JPS paper on Piagetian–Vygotskiian perspectives on individual learning in social contexts). We, too, propose to use ABM to simulate human reasoning, yet we move forward by *juxtaposing our simulation with real data*. We chose the theory of Minsky (1985), the *Society of Mind*, because it is dynamical, hierarchical, and emergent; we chose a Piagetian conservation task, because Minsky modeled this task with his theory; finally, we worked with children in both transitional and stable phases so as to elicit richer data. Our full paper and presentation provide step-by-step hybrid narratives – computer simulation vs. videography – of children's performance on a conservation task. In the remainder of this paper, we will introduce Minsky's theory, explain our experiment (a variation on the classical conservation-of-volume task, Piaget, 1952), and present case studies where simulation and real data are juxtaposed.

Minsky's model of Piagetian experiments stresses the importance of *structure* to cognitive evolution, especially its reorganization. Younger children, for instance, would have 'one-level' priority-based structures: one aspect would always be more dominant (*tall* would take priority over *thin* and over *confined* - see Figure 1) and compensation is inexistent.

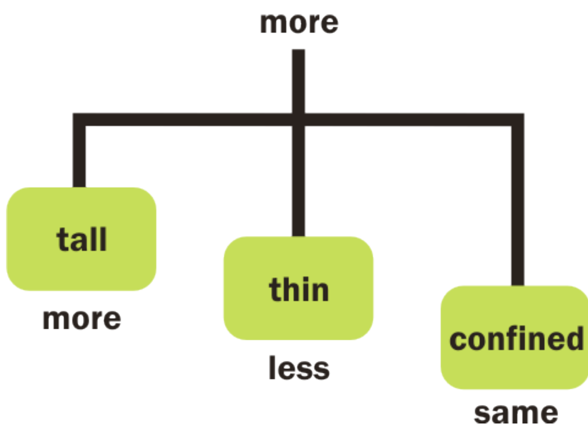


Figure 1 – A one-level model for evaluating "who has more".

Later the child develops a new "administrative" layer that allows for more complex decisions: in Figure 2, for example, if *more tall* and *less thin* are in conflict, the *history* administrator can take over the decision.

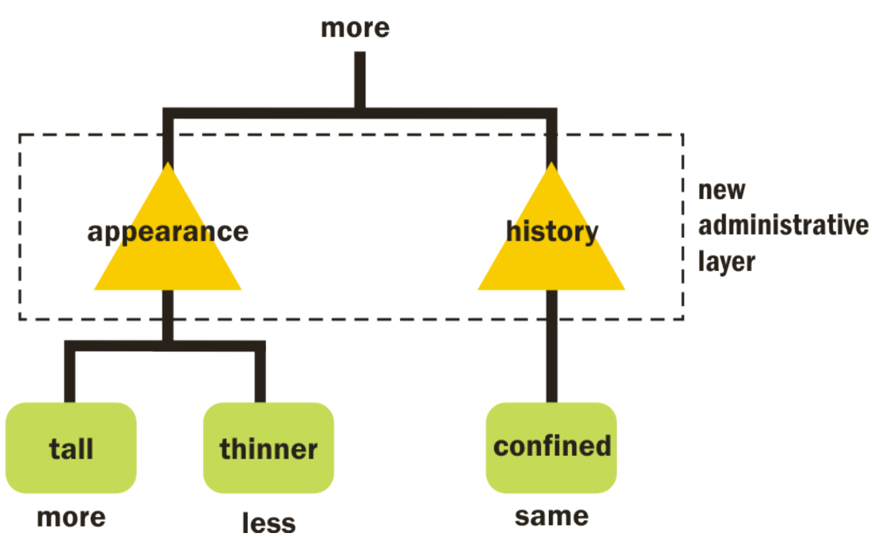


Figure 2 – New administrative layer

The Experiment

Two elongated blocks of clay of same shape but different color are laid before the child. One is "the child's," and the other is "the experimenter's." After the child agrees that both are the same size, the experimenter cuts one block in two, lengthwise, and joins the two parts so as to form a block twice as long, then cuts the other block in two, widthwise, to form a block twice as thick as before. The child is asked whether the blocks are still "the same" or whether either person has more than the other. According to the child's response, the interaction then becomes semi-clinical, with the experimenter pursuing the child's reasoning and challenging him/her with further questions.

The interviews were videotaped and transcribed, and the data were coded in terms of parameters of the computer simulation (see below). The simulation was then fed with these coded data. We were able to perform different kinds of experiments:

1) **Playback the interview** and the computer model side-by-side, trying to identify behavior patterns and couch them in terms of the simulated model;
2) **Model validation:** investigate whether the child's decision-making process can be predicted by the model. We set the model with the child's initial responses, "run" it through to completion, and try to identify whether the simulated cognitive development matches processes observed.

Below, we demonstrate option #1, using hybrid data (computer simulation alongside human behavior). We will show how the different models (programmed with data from the interviews with three children) yield a surprisingly similar probabilistic cluster of responses as the interviews themselves.

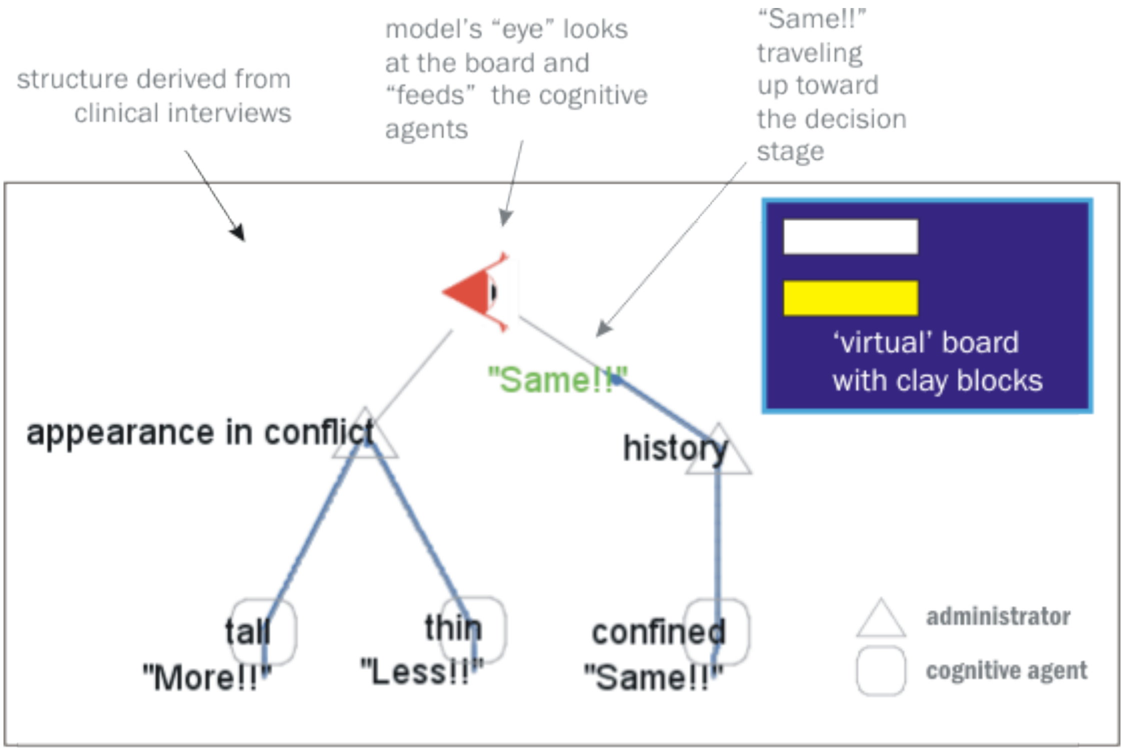
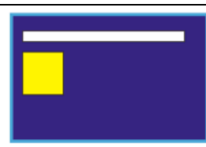
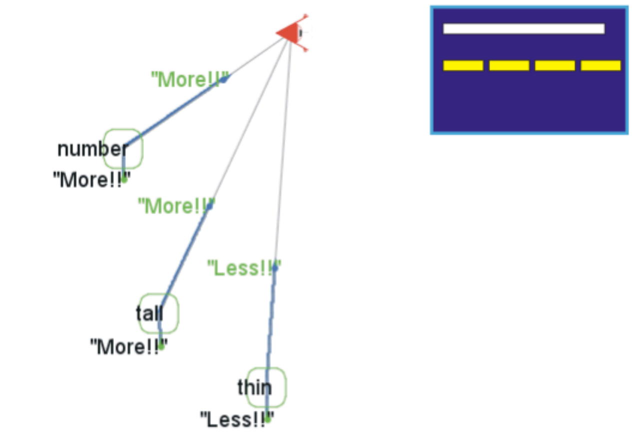


Figure 3. A screenshot of the computer model and its main components. Similar to the child, the computer 'sees' blocks of clay and tries to determine which block is 'more.'

Computer model (screen captures)	Transcriptions/pictures
Child 1	
From Child1's **(6yo)** interview, we inferred the simple model below. Cognitive agents presumed to be active are marked with a green outline. Dominance is represented in the model by the vertical distance to top. For this child, whenever **Number** -- the cardinal dimension of the stimulus -- is contextually salient, it dominates the decision-making process. Also **Tall** appears to dominate **Thin**.	"Because you cut in half, so there **is two pieces**, but… It's **not as fat as that**. This is kind of fat, but this is taller. I have more".
 	 
Number is absent from this second interaction. Even when two other measurements conflict, one is always dominant. In this case, **tall** is more salient.	*Researcher: Who has more?* *Child1: It's hard to tell now. [tries to measure the fat one with his fingers, then compares his fingers with the thin and tall one]. This one [the taller].*
 	 

In the third interaction, the experimenter reintroduces **Number** by cutting his piece in four: as predicted by the model, **number** takes priority again over **tall** and **thin.**

“You have more, because you have four quarters, I have only two halves.”

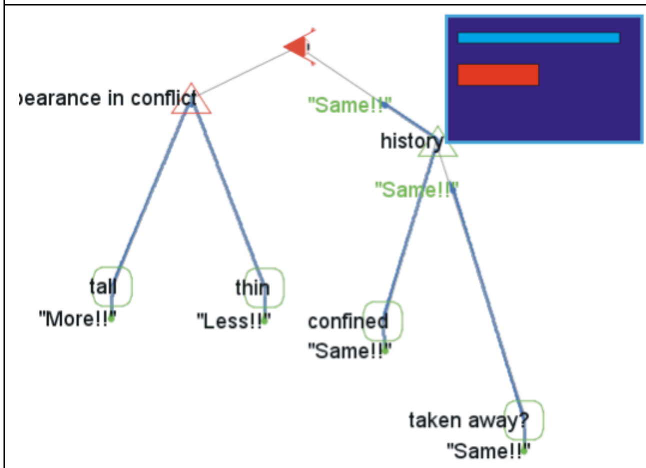


Interpretation: The ‘priority’ model can account for the responses of Child1: he cannot coordinate two or more measures. In the computer model, also, two measures cannot be coordinated. Given the same inputs, the computer model and the interview data yield comparable results.

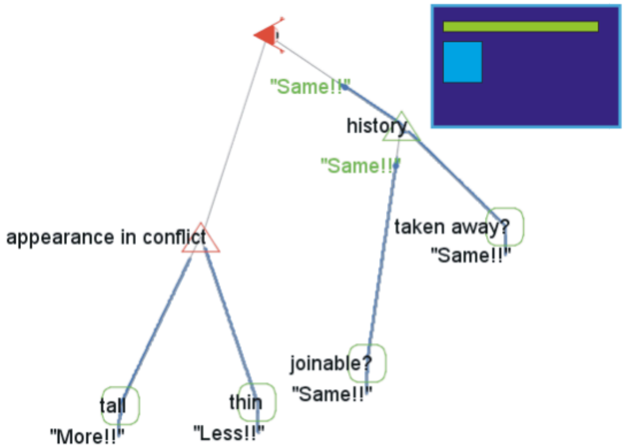
Child 2

Child 2 **(8yo)** has a model with Minsky’s “administrators” (**appearance** and **history of the transformations**). With one in conflict, the other takes control. If the **Tall** agent reports ‘more’ and the **Thin** agent reports ‘less’, then the **Appearance** administrator will say nothing - it is in conflict and cannot decide.

“If you put them back together, you’ll have the same”



Child 2 has a new level of **administrators**, which enables him to background the **appearance** and focus on the **history** of the objects. The blue is ‘re-joinable’, so both blocks are the same. During the interview, Child 2 occasionally said that nothing was added or taken away. The model, again, correctly determines the combinatorial space and predicts response frequency distribution.

<table>
<tr><td colspan="2">Child 3</td></tr>
<tr><td>For Child 3 (10yo), material taken away? was far more dominant that joinable? or appearance.</td><td>“It’s the same, because you still have the same amount, even if you cut in half in different ways, because it’s still in half.”</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Child 3 backgrounds appearance from the start (see, in the model, that these agents are lower than others) and focuses on confinement (nothing was taken away or added), and thus concludes that the blocks are still the same.</td></tr>
</table>

Conclusions

The computer model can be a useful vehicle both to illustrate the Piagetian theoretical model and to simulate it departing from interview data. Through the lens of agent-based models, new properties of Minsky’s model are revealed. Namely, the mature, hierarchical structure of the cognitive model is stochastically determined, in the sense that across combinatorial initial conditions, and over sufficient interactions, the same meta-structures ultimately emerge. Collecting and analyzing data from actual (not simulated) interviews is an essential phase in the ongoing improvement of the computer simulation of a theoretical model, such as Minsky’s model: The data sensitize us to the crucial components and dimensions of the interactions and to the nature of the transformations. We are currently exploring the entire combinatorial space of all hypothetical children’s initial mental states and activating the simulation per each of these states. From that perspective, our data of real participants become cases out of the combinatorial space. At the conference, we will demonstrate the several strands of our methodology, including simulation, prediction, and stochastic exploration of combinatorial spaces.

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