EMERGENCE OF HUMAN LANGUAGE: A DEVS-BASED SYSTEMS APPROACH

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ABSTRACT

Active-passive compositions provide a class of systems from which we can draw intuition and examples for generalizations about system emergence at the fundamental level. In this paper, we will employ the modeling and simulation framework based on system theory focusing on its concepts of iterative specification and the Discrete Event Systems Specification (DEVS) formalism. Our approach to emergence of human language formulates the problem as an instance of a set of components that must be coupled to form a system with innovative inter-component information exchange. We show that passive/active alternation interaction of a cross-coupled pair can satisfy the conditions required for well-defined systems.

Keywords: Active-passive compositions, DEVS, Emergence, Modeling and Simulation, well-defined systems.

1 INTRODUCTION

The Discrete Event Systems Specification (DEVS) formalism based on systems theory, provides a framework and a set of modeling and simulation tools to support Systems concepts in application to SoS engineering (Zeigler et al 2000). A DEVS model is a system-theoretic concept specifying inputs, states, outputs, similar to a state machine. Critically different however, is that it includes a time-advance function that enables it to represent discrete event systems, as well as hybrids with continuous components, in a straightforward platform-neutral manner. DEVS provides a robust formalism for designing systems using event-driven, state-based models in which timing information is explicitly and precisely defined. Hierarchy within DEVS is supported through the specification of atomic and coupled models. Atomic models specify behavior of individual components. Coupled models specify the instances and connections between atomic models and consist of ports, atomic model instances, and port connections. The input and output ports define a model's external interface, through which models (atomic or coupled) can be connected to other models.

Based on Wymore's Systems Theory (Wymore 1967) the DEVS formalism mathematically characterizes:

- DEVS Atomic and Coupled Models specify Wymore Systems (Oren and Zeigler 2012).
- Composition of DEVS Models: component DEVS and coupling result in a Wymore system, called the resultant, with structure and behavior emerging from their interaction (Mittal and Martin 2013).
- Closure under coupling: the resultant is a well-defined DEVS just like the original components (Zeigler et al 2000).
- Hierarchical Composition – closure of coupling enables the resultant coupled models to become components in larger compositions (Oren and Yilmaz 2015).

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Components and couplings in complex system models must include representation of decision making in natural and artificial environments. DEVS has the universality (Zeigler et al 2000) to represent the discrete (for agent models) and continuous (for natural environments) as well as hybrid (for artificial environments) formalism types needed for adequate complex system model construction. DEVS supports dynamic structure for genuine adaption and evolution (Park and Hunt 2006, Steineger and Uhrmacher 2016.) Strong dynamic structure capabilities are needed to specify and flexibly control the changes in components and their coupling to be able to adequately model adaptation, evolution and emergence (Mittal 2013) in ways that include the possibility of genuine surprise (Muzy and Zeigler 2014).

1.1 Active-Passive Compositions

An interesting form of the interaction among components may take on a pattern found in numerous information technology and process control systems. In this interaction, each component system alternates between two phases, active and passive. When one system is active the other is passive - only one can be active at any time. The active system does two actions: 1) it sends an input to the passive system that activates it (puts it into the active phase), and 2) it transits to the passive phase to await subsequent re-activation. For example, in a Turing Machine (TM), the TM control starts a cycle of interaction by sending a symbol and move instruction to the tape system then waiting passively for a new scanned symbol to arrive. The tape system waits passively for the symbol/move pair. When it arrives it executes the instruction and sends the symbol now under the head to the waiting control.

Such active-passive compositions provide a class of systems from which we can draw intuition and examples for generalizations about system emergence at the fundamental level. We will employ the modeling and simulation framework based on system theory formulated in (Zeigler et al 2000) especially focusing on its concepts of iterative specification and the DEVS formalism (Zeigler et al 2000). Zeigler and Muzy (2016) employed the pattern of active-passive compositions to illuminate the conditions that result in ill-definition of deterministic, non-deterministic and probabilistic systems. They provided sufficient conditions, meaningful especially for feedback coupled assemblages, under which iterative system specifications can be composed to create a well-defined resultant and that moreover can be expressed and studied within the DEVS formalism.

2 WELL-DEFINITION OF SYSTEMS

Before proceeding to review the more fundamental issues, we need to start with a primitive and perhaps more intuitive notion of a system. As in Figure 1, consider a concept of an input-free system (or autonomous, i.e., not responding to inputs) with outputs not considered and with states, transitions, and times associated with transitions. Then we have a transition system

$$M = < S, \delta, ta >, \text{ where } \delta \subseteq S \times S, \text{ and } ta : S \times S \to R_0^\infty$$

Here we are allowing the transition system to be *non-deterministic* so that rather than δ and ta being functions they are presented as relations.

For example, in Figure 1, we have

$$S = \{S1, S2, S3, S4, S5, S6, S7\},$$
$$\delta = \{(S1, S3), (S3, S4), \ldots\}$$
$$ta(S1, S3) = 1, ta(S3, S4) = 1, \ldots$$

For example there are transitions from state S1 to state S3 and from S3 to S4 which each takes1 time unit and there is a cycle of transitions involving S4…S7 each of which take zero time. There is a self-transition involving S2 which consumes an infinite amount of time (signifying that it is passive, remaining in that state forever.) This is distinguished from the absence of any transitions out of S8. A state trajectory is a sequence of states following along existing transitions, e.g., S1, S3, S4 is such a trajectory.

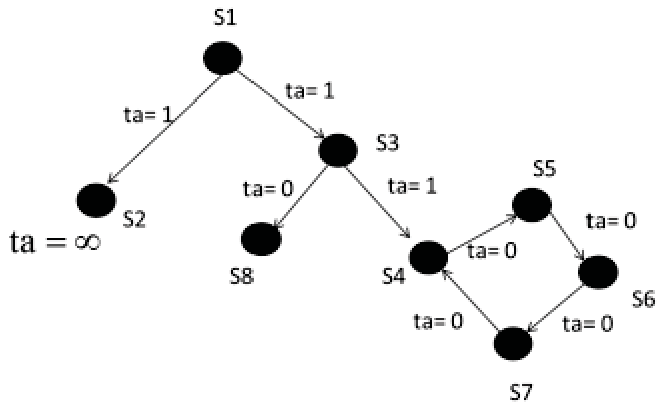

Figure 1: System with tuned transitions.

This example gives us a quick understanding of the conditions for system existence at the fundamental level:

We say that the system is

- *not defined* at S8 because there is no trajectory emerging from it, i.e., because there is no transition pair with S8 as the left member in δ
- *non-deterministic* at S1 because there are two distinct outbound transitions defined for it, i.e., because S1 is a left member of two transition pairs (S1,S2) and (S1,S3)
- *deterministic* at S2 and S4 because there is only one outbound transition for each, i.e., because there is only one transition pair involving each one as a left member.

We say that the system is *well-defined* if it is defined at all its states. These conditions are relative to static properties, i.e., they relate to states not how the states follow one another over time. In contrast, state trajectories relate to dynamic and temporal properties. When moving along a trajectory we keep adding the time advances to get the total traversal time, e.g., the time taken to go from S2 to S4 is 2. Here a trajectory is said to be *progressive* in time if time always advances as we extend the trajectory. For example, the cycle of states S4…S7 is not progressive because as we keep adding the time advances the sum never increases. Conceptually, let's start a clock at 0 and, starting from a given state, we let the system evolve following existing transitions and advancing the clock according to the time advances on the transitions. If we then ask what the state of the system will be at some time later, we will always be able to answer if the system is well-defined and progressive. A well-defined system that is not progressive signifies that the system gets stuck in time and after some time, it becomes impossible to ask what the state of the system is in after that time. Zeno's paradox offers a well-known metaphor where the time advances diminish so that time accumulates to a point rather than continue to progress and offers an example showing that the pathology does not necessarily involve a finite cycle. Our concept of progressiveness generalizes the concept of legitimacy for DEVS (Zeigler et al 2000) and characterizes the "zenoness" property.

3 EMERGENCE OF LANGUAGE CAPABILITIES IN HUMAN EVOLUTION

Following Ashby (1956) and Foo and Zeigler (1985), *emergence* is conceived as global behavior of a model that might be characterized as: components + interactions (computation) + higher-order effects where the latter can be considered as the source of emergent behaviors (Kubik 2003, Mittal and Zeigler 2014a, Szabo and Teo 2015). In a fundamental characterization of emergence, Mittal and Rainey (2016) contrast positive emergence (which fulfils the Systems of Systems (SoS) purpose (Boardman and Sauser 2006) and keeps the constituent systems operational and healthy in their optimum performance ranges) from negative emergence (which to does not fulfill SoS purposes and manifests undesired behaviors such as load hot-swapping, cascaded failures.) Some perspectives on the role of modeling and simulation in study of emergence are presented in Mittal (2013), Zeigler and Muzy (2016) and Zeigler (2016a,b.)

Speech acts involve humans speaking to one another in order to change their knowledge or behavior or to otherwise affect them. Questions concern the evolution of motivations and mechanisms and how such speech acts could have emerged in early hominids. According to Everett (2012), humans' interest in interacting with fellow humans differs from that of other apes for reasons such as:

1. The discovery of fire and management of fire technology,
2. Improving the efficiency of securing and preparing food (accelerated by fire (cooking)), and
3. Emerging sense of community.

Everett asserts that evolution had to prepare early hominids to develop instances of multi-media channels in order to communicate with one another laying the foundation for language, the ultimate communicative tool. The media for conveying messages could have been whistles, humming, or physical signing predating the use of the modern vocal apparatus to produce today's speech sounds. An early speech act may have been spontaneous grunting and pointing vigorously to a serendipitously appearing prey. "Theory of mind" – recognizing others as having the same mental propensities as oneself– may be prerequisite to shared symbols in messages. The range of employed speech acts is governed by general principles by which all members of the culture recognize that a speech act of a certain kind has taken place. Thus culture sets the channel symbol size and response of senders and receivers. While syntax concerns message formation, and semantics concerns message meaning, pragmatics concerns a speaker's ability to understand another's intended meaning (Zeigler and Hammonds 2007). Mutual comprehension requires speaking the same language with a shared ontology.

4 FUNDAMENTAL SYSTEMS APPROACH

Our approach to emergence of language starts with this background but formulates the problem as an instance of a set of components that must be coupled to form a system with the ability to communicate that does not exists initially. We note that standard languages and principles for computer agent to agent communications are being researched (Chopra et al 2016). However, from the systems composition perspective, agent communication research assumes *existing* linguistic competence. Also while evolutionary theory speculates on how such competence could have developed, it does not do so as an instance of emergence from a formal M&S perspective.

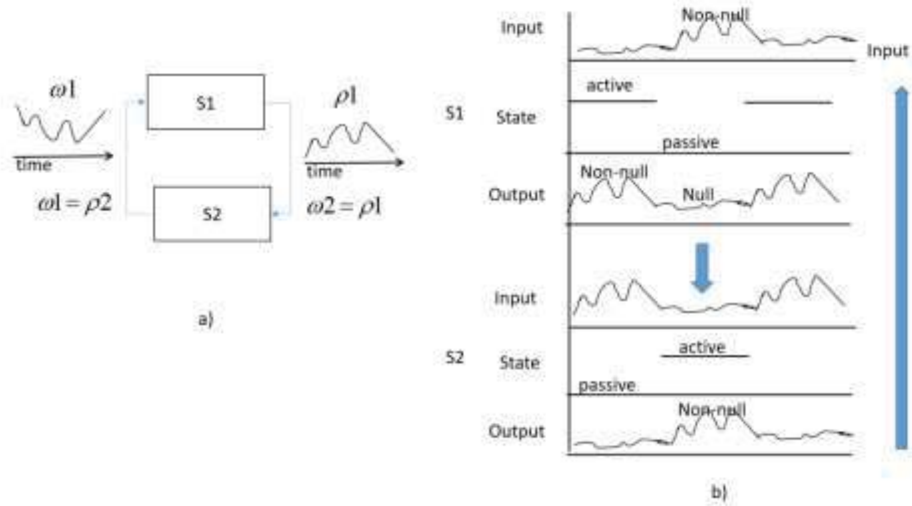

Figure 2: Interaction of two components attempting to form a composite system.

We examine the problem of emergence of a well-defined system from a coupling of a pair of component systems (the smallest example of the multi-component case). As in Figure 2, the time base is a critical parameter to take into account on which input and output streams (functions of time) are happening. The cross-coupling imposes a pair of constraints as shown that the output time function of one component must equal the input time function of the other. The problem is given that the system components have fixed input/output behavior how can the constraints be solved so that their composition forms a well-defined system? We must recognize that inputs and outputs are occurring simultaneously in continuous time so that the constraints must be simultaneously satisfied at every instant. One step toward a solution is to break the time functions into parts or segments that allow restricting the problem to segments rather than complete streams. This approach was formalized within the mechanism of iterative specification of systems (Zeigler and Muzy 2016) and a complete review is beyond the scope of this paper. However, the way that active-passive compositions help can be explained as in Figure 2b. In this interaction, each component system alternates between two phases, active and passive. When one system is active the other is passive - only one can be active at any time. The active system does two actions: 1) it sends an input to the passive system that activates it (puts it into the active phase), and 2) it transits to the passive phase to await subsequent re-activation. Moreover, during any one such segment, only the active component sends a non-null output segment to the passive component. The input/output constraints are satisfied as long as this output segment is accepted by the passive component and the component outputs only null segments while passive.

4.1 DEVS Agent Modeling

Assuming that both pre-linguistic agents have the necessary basic components – motivation and theory-of-mind basis for communication and Shannon audio-visual mechanisms to create signs for encoding/decoding messages. They must set up a channel – first two half-duplex channels then perhaps one full duplex channel. Example: A wants to inform B: “wild boar there, grab it” A needs to get B to attend to this audio-visually encoded message thus setting up the channel whereby B needs to decode this message and interpret it as information and urge to action. The situation might be depicted as in Figure 3 a) where a unidirectional channel emerges from one agent to another. DEVS enables formal modeling – and subsequent simulation – of this dynamic structure change as depicted in Figure 3 a) where ports provide potential points of input and output information/energy flow among component models and couplings from specific output ports to input ports determine the actual flow paths. The addition of a new component and associated couplings is mediated by dynamic structure transformation that can be induced when a model satisfies the requisite conditions (Barros 2002,Uhrmacher 2001).

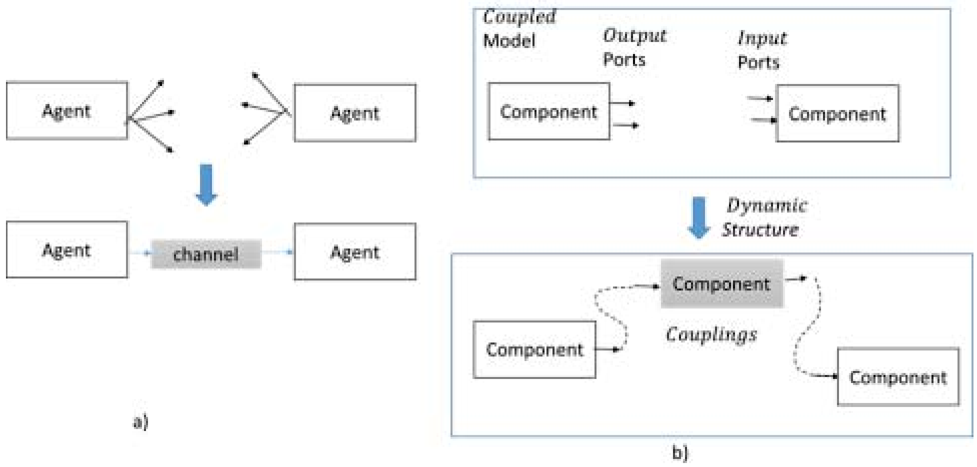

Figure 3: Hypothetical DEVS modeling of emergence of language capabilities in human evolution.

The next step in emergence of language might have been the addition of a second channel allowing bi-directional communication (or the same channel with duplex capacity.) Conceptually, this would be a second instance of the process in Figure 3 b). However, the establishment of a discipline or protocol for when to speak and when to listen may be more novel and problematic. The problem might be suggested by talking with a friend on the phone (perhaps a successful instance) or pundits from opposite sides of the political spectrum attempting to talk over each other (a negative instance,)

5 PERSPECTIVES

We outline two perspectives - application domain and system modeling - and show how they may converge to provide a solution.

5.1 Evolution Domain Perspective

From the evolution domain perspective, we can recognize that two Shannon components are needed – thinking (e.g., encoding, decoding, interpreting, etc.) and production/transduction (vocalizing, auditioning, etc.) Limited cognitive capabilities would bound the number and level of activities that could command attention simultaneously (single-tasking more likely than multi-tasking,) Thus agents would likely be in either speaking or listening mode - not both, Conversational interaction might ensue as the talker finishes and the listener now has motivation to speak, e.g., “Let’s grab it” stimulates the listener to take action. The discipline of alternation between speaking and listening might then become institutionalized. Appendix A provides more evidence that apes cannot develop the required alternation of discourse discipline.

5.2 System Modeling Perspective

From the system modeling perspective, we return to the problem, illustrated in Figure 2, that components with cyclic (looped) – as opposed to acyclic – coupling face in forming a well-defined system. Solutions do exist to satisfy the simultaneous input/output constraints imposed by such coupling (sufficient conditions are known for particular classes of systems (Zeigler et al 2000) However, as mentioned before, such solutions are difficult to realize due to the concurrency of interaction and must overcome the potential to get stuck in zeno-like singularities. On the other hand, we see that the passive/active alternation interaction for a cross-coupled pair can more easily support the conditions for a well-defined system. Identifying *listening* with *passive* (although mental components are active, they do not produce output) and *speaking* with *active* (output production) we see that alternation between speaking and listening would satisfy the conditions for establishing a well-defined coupled system from a pair of hominid agents. Figure 4 illustrates a simplified DEVS representation of such a speak-listen active-passive system. The active agent transitions from thinking to talking and outputting a command that starts the passive agent listening. The receiving agent must detect the end of the command and commence with an associated action. Although not shown, the reverse direction would have the roles reversed with the second agent transmitting a reply and the first agent receiving it.

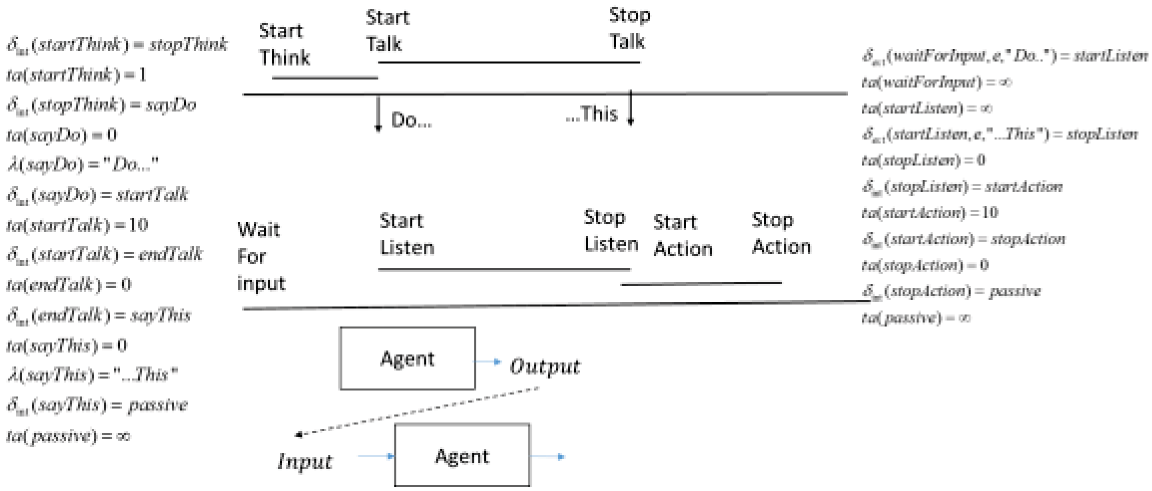

Figure 4: DEVS modeling of one-way agent-agent communication.

6 CONCLUSIONS AND FURTURE WORK

DEVS has a number of features that enable the representation of systems components and couplings that can change dynamically as needed for genuine adaptation and evolution and therefore provides the concepts and formalisms needed for modeling and simulation of emergent behavior. Active-passive compositions provide a class of systems from which we can draw intuition and examples for generalizations about system emergence at the fundamental level. Here we employed the modeling and simulation framework based on system theory with particular focus on its concepts of iterative specification. Earlier development formulated sufficient conditions for feedback coupled assemblages under which iterative system specifications can be composed to create well-defined systems that also can be represented in the DEVS formalism. Our approach to emergence of human language here has formulated the problem in terms of a set of components that must be coupled to form a system with innovative inter-component information exchange. We showed that passive/active alternation interaction of a cross-coupled pair can satisfy the required conditions for well-definition. The implication is that learning to alternate between speaking and listening may have been a necessary pre-condition for a pair of hominid agents to establish a well-defined symbol-based information exchange system. Evolutionary studies indicated that language should be regarded as a means to coordinate behaviors and requires management of shared attention (Appendix A)). Future research can address multiple issues along these lines left not fully developed in this paper. One interesting connection relates to the activity-based monitoring paradigm developed by Mittal and Zeigler (2014a) and the emergent property of attention-focusing in such resource-constrained activity-based complex dynamical intelligent systems (Mittal and Zeigler 2014b). There may be a fundamental property of systems in that their ability to obtain useful information from the world is related to the ability to suppress activity unrelated to current goals and thereby to satisfy the requirements for well-definition of self as system.

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A APPENDIX Limitations of non-human primates wrt alternation of discourse

Observations indicate that apes point only for humans and not for one another (Kinneally 2008). Even apes trained to communicate with humans don't exhibit this behavior with each other. The reason seems to be that humans respond to apes' gestures while other apes are oblivious to such gestures. Perhaps, apes don't recognize that they are being addressed (Tomasello 2008). Kinneally (2008) relays the account of two apes that had successfully acquired many signs and used them effectively. However when one day they were asked to converse, there resulted a sign-shouting match; ***neither ape was willing to listen***.

Savage-Rumbaugh (2004) provides an analysis that strongly supports our system theoretic-based emergence approach. She says that "language coordinates behaviors between individuals by a complex process of exchanging behaviors that are punctuated by speech." At its most fundamental, language is an act of ***shared attention***, and without the fundamentally human willingness to listen to what another person is saying, language would not work. Symbols like words are devices that coordinate attention, just as pointing does. They presuppose a general give-and-take that chimpanzees don't seem to have (Tomasello 2008.)

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