Reset Petri Net Unfolding Semantics for Ecosystem Hypergraphs

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Ecosystems are complex systems still waiting for a convenient and flexible way to model them. This article extends the rule-based discrete-event modeling approach for ecosystems developed by Gaucherel et al. Here, we propose the systematic use of (1-safe) reset Petri nets for the analysis of such systems. For this purpose, we use the translation from RR-systems, and adapt the unfolding methodology of Esparza et al. to provide a consistent and compact semantics in ordinary occurrence nets for 1-safe reset Petri nets. One ecological case study, the evolution of a termite colony (Gaucherel et al.) is carried out to illustrate how important principles deciding between survival and collapse of this ecosystem can be exhibited by structural properties of prefixes of its corresponding unfolding. The modelling of the interaction rules in Petri nets requires, in addition to the usual combination of read and production arcs, also the use of *reset arcs* to capture *side effect* relations, i.e. where a resource is certainly absent after some event but not necessarily present prior to it. In combination with automatizable place replication and complementation procedures, a dedicated unfolding procedure represents the dynamics of a contextual reset net in an ordinary Petri net, taking specificities of both read and reset arcs into account. Unfolding prefixes are computed by the EcoFolder tool developed in this work. Here, we consider as an example of an ecosystem the network of dominant interactions occurring in a termite colony (fig 1), directly inspired from Gaucherel & Pommereau. Our model includes the following variables: **Inhabitants:** Rp: reproductive termites, i.e. the queen, the king, the eggs and the nymphs; Wk: termite workers,

r1:	Rp+	$\gg$	Ec, Rp+
r2:	Rp+, Ec+	$\gg$	Wk+, Rp+, Ec+
r3:	Wk+	$\gg$	Wd+, Te+, Fg+, Ec+, Wk+
r4:	Wk+, Wd+	$\gg$	Sd+, Rp+, Wk+, Wd+
r5:	Wk+, Te+	$\gg$	Wd-, Wk+, Te+
r6:	Wd-	$\gg$	Wk-, Te-, Wd-
r7:	Wk-	$\gg$	Fg-, Sd-, Te-, Wk-
r8:	Wk-, Rp-	$\gg$	Ec-, Wk-, Rp-
r9:	Ac+, Sd-	$\gg$	Wk-, Rp-, Ac+, Sd-

Figure 1: Rule system for the termites colony

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i.e. all termites able to work; Sd: termite soldiers; and Te: *termitomyces*, i.e fungi grown by termites for nutrition.

Structures: Fg: fungal gardens, i.e. chambers for growing fungi; Ec: egg chambers.

Resources: Wd: wood used to build the mound and to grow fungi.

Competitors: Ac: ant competitors that may attack the colony.

Those components can evolve (from an initial state) according to their interactions; we represent the functional presence or absence of any of them by adding '-' or '+' to their respective labels. Their interaction rules can be translated into a Petri net with read and reset arcs, shown on fig 2. Moreover, fig 3 shows the corresponding event structure extracted from the unfolding prefix, both of them created by ECOFOLDER. The schema emphasizes those branches on which the colony collapses (r6, r7, r8, and r9) and survives (r3, r4, r1 and r2), respectively. ⊥ represents the initial cut, causal precedence is indicated by arrows, and dashed lines represent conflict relations. Note that instances of R5 *allow* survival but do not *guarantee* it, as the downfall of the colony always remains possible. The crown at every instance of r5 visualizes this tipping point, and to symbolize a Red Queen. Loosely speaking, workers in the colony have to keep working at a sufficient *rate* to prevent a successful attack by the ants. This phenomenon of *arms race* is suggested by *Red Queen hypotheses* as proposed by L. Van Valen in 1973; it states that species must constantly adapt, evolve and proliferate in the competition with antagonistic species, simply to survive. Therefore, possibilistic approaches like ours allow an exhaustive exploration of the system's trajectory. Our method enables, in the future, to apply finer analysis methods to extract insight about the system's ecology from the study of its dynamics.

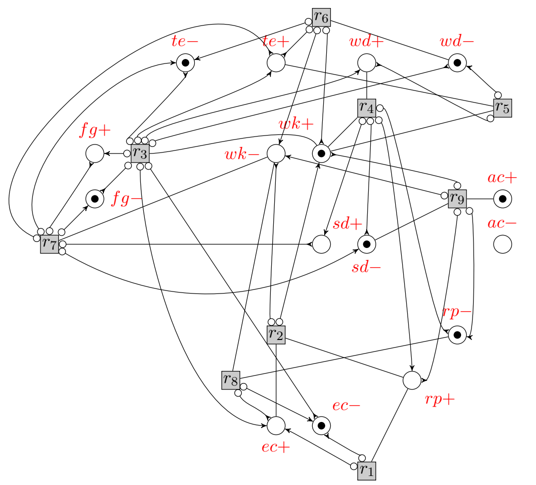

Figure 2: Termites ecosystem using a contextual net with resets.

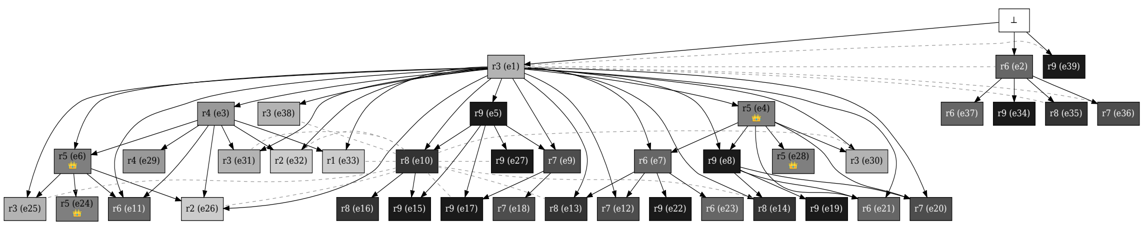

Figure 3: Event structure of the termites ecosystem example.