Stateflow to Extended Finite Automata Translation

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Abstract—Stateflow, a graphical interface tool for Matlab, is a common choice for design of event-driven software and systems. In order for their offline analysis (testing/verification) or online analysis (monitoring), the Stateflow model must be converted to a form that is amenable to formal analysis. In this paper, we present a systematic method, which translates Stateflow into a formal model, called Input/Output Extended Finite Automata (I/O-EFA). The translation method treats each state of the Stateflow model as an atomic module, and applies composition/refinement rules for each feature (such as state-hierarchy, local events) recursively to obtain the entire model. The size of the translated model is linear in the size of the Stateflow chart. Our translation method is sound and complete in the sense that it preserves the discrete behaviors as observed at the sample times. Further, the translation method has been implemented in a Matlab tool, which outputs the translated I/O-EFA model that can itself be simulated in Matlab.

I. INTRODUCTION

Simulink/Stateflow is a popular commercial model-based development tool for many industrial domains, such as power systems, aircraft, automotives and chemical plants. Simulink is much better for handling continuous systems, whereas Stateflow is much better for handling state based problems. Owing to the correctness, safety, security, etc. requirements of such systems, methods to analyze the system designs are needed. Simulink/Stateflow however has originally been designed for the simulation of the designs, and does not provide a model that makes it amenable for formal analysis such as verification and validation.

In our previous work [1], we introduced a recursive modeling method to translate Simulink diagram to Input/Output Extended Finite Automata (I/O-EFA), which is a formal model of a reactive untimed infinite state system, amenable to formal analysis. This paper completes the modeling approach by extending it to allow the translation of Stateflow charts that are event-driven blocks.

Stateflow, which has been adopted from StateChart, allows hierarchical modeling of discrete behaviors consisting of parallel and exclusive decompositions, with tedious semantics, which makes it challenging to capture and translate into formal models. Several authors have attempted different forms of Stateflow translation. Scaife et al. [2] translated a subset of Simulink/Stateflow into Lustre and verified the model using a model checking tool called Lestat. Gadkari et al. [3] proposed a translation from Simulink/Stateflow to Symbolic Analysis Laboratory (SAL). However, few of the prior works have considered the translation from Stateflow to an automaton, which preserves the discrete behaviors (behaviors observed at discrete time steps when the inputs are sampled and the outputs are computed).

In this work, we continue to use I/O-EFA as the target model for translation so as to retain consistency with our previous work that translated the Simulink diagrams. In order to have our modeling process recursive, we treat the individual states of a Stateflow chart to be the most elementary constructs for modeling, and define the atomic models for them. Next, two composition rules are defined to interconnect the simpler models to form the more complex models for the “AND” versus “OR” states, preserving their state execution and transition behaviors. By viewing the Stateflow chart’s hierarchical structure as a tree, we recursively apply the two composition rules in a bottom-up algorithm to obtain the overall I/O-EFA model. Finally, the additional Stateflow features, such as event broadcasting and interlevel transitions, are incorporated by refining the model at locations where the features reside. Furthermore, a composition rule between Stateflow and Simulink models is introduced to combine them into a single complete model.

We have also implemented our algorithm into an automated translation tool SS2EFA, written in the Matlab script. A counter and a complex motor control system have been used as the case studies for the proposed translation method and the tool. The simulation results show that the translated model simulates correctly the original Simulink diagram at each time step. The contributions of this paper include:

- We have developed a recursive method to translate a Stateflow chart into an I/O-EFA that preserves the discrete behaviors. The overall model of a Stateflow chart has the same structure as the model of a Simulink diagram proposed in our previous work, which makes the two models integrable.
- The translated model shows different paths to represent all the computational sequences, which makes it easier for formal analysis.
- We have developed an automated translation tool that is ready for use. The translated I/O-EFA model can itself be simulated in Matlab (by treating it as a “flat” Stateflow model).

II. INTRODUCTION TO I/O-EFA

An I/O-EFA is a symbolic description of a reactive untimed infinite state system in form of an automaton, extended with discrete variables of inputs, outputs and data.

Definition 1: An I/O-EFA is a tuple \( P = (L, D, U, Y, \Sigma, \Delta, L_0, D_0, L_m, E) \), where
- \( L \) is the set of locations (symbolic-states),
- \( D = D_1 \times \cdots \times D_n \) is the set of data (numeric-states),
- \( U = U_1 \times \cdots \times U_m \) is the set of numeric inputs,
- \( Y = Y_1 \times \cdots \times Y_p \) is the set of numeric outputs,
- \( \Sigma \) is the set of symbolic-inputs,

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\( \Delta \) is the set of symbolic-outputs,
- \( L_0 \subseteq L \) is the set of initial locations,
- \( D_0 \subseteq D \) is the set of initial-data values,
- \( L_m \subseteq L \) is the set of final locations,
- \( E \) is the set of edges, and each \( e \in E \) is a 7-tuple, \( e = (o_e, t_e, \sigma_e, \delta_e, G_e, f_e, h_e) \), where
  - \( o_e \in L \) is the origin location,
  - \( t_e \in L \) is the terminal location,
  - \( \sigma_e \in \Sigma \cup \{\varepsilon\} \) is the symbolic-input,
  - \( \delta_e \in \Delta \cup \{\varepsilon\} \) is the symbolic-output,
  - \( G_e \subseteq D \times U \) is the enabling guard (a predicate),
  - \( f_e : D \times U \to D \) is the data-update function, and
  - \( h_e : D \times U \to Y \) is the output-assignment function.

I/O-EFA \( P \) starts from an initial location \( l_0 \in L_0 \) with initial data \( d_0 \in D_0 \). When at a state \((l, d)\), a transition \( e \in E \) with \( o_e = l \) is enabled, if the input \( \sigma_e \) arrives, and the data and input \( u \) are such that the guard \( G_e(d, u) \) holds. \( P \) transitions from location \( o_e \) to location \( t_e \) through the execution of the enabled transition \( e \) and at the same time the data value is updated to \( f_e \), whereas the output variable is assigned the value \( h_e(d, u) \) and a discrete output \( \delta_e \) is emitted. In what follows below, the data update and output assignments are performed together in a single action.

### III. Atomic Model for States

States are the most basic components in a Stateflow chart in that a simplest Stateflow chart can just be a single state. Stateflow allows states to be organized hierarchically by allowing states to possess substates, and same holds for substates. A state that is down (resp., up) one step in the hierarchy is termed a substate (resp., superstate). We represent the most basic components of a Stateflow chart as atomic models, which are the smallest modules that are interconnected (following the semantics of the hierarchy and other Stateflow features as described in the following sections) to build the model of an overall Stateflow chart.

Consider a Simulink diagram of a counter system shown in Figure 1. The counter itself is a Stateflow chart, which gets the input from the signal source “pulse generator” to switch between the “count” and the “stop” mode. The simulation is a Simulink block that sets the lower and upper bounds for the output values. The Stateflow chart consists of six states with two parallel top-level states and two exclusive substates for each of them. This hierarchical structure of the states is shown in a tree format in Figure 2. Each node of the tree can be modeled as an atomic I/O-EFA model, which we describe below in this section.

The behavior of a Stateflow state comprises of three phases: entering, executing and exiting, where
- Entering phase marks the state as active and next performs all the entry actions;
- Executing phase evaluates the entire set of outgoing transitions. If no outgoing transition is enabled, the during actions, along with the enabled on-event actions, are performed;
- Exiting phase performs all the exit actions and marks the state inactive.

According to the above behaviors, an individual state \( s \) of a Stateflow can be represented in the form of an I/O-EFA of Figure 3.

![Fig. 1. Simulink diagram of a Counter system (top) and the Stateflow chart of the counter (below)](image)

![Fig. 2. Hierarchical Structure of Counter’s Stateflow chart](image)

![Fig. 3. Atomic Model a Stateflow state](image)

As can be seen from the figure, the atomic I/O-EFA model has three locations \( l_0^a, l_1^a, l_m^a \) for differentiating the activation versus the deactivation process, where the transition
- \( l_0^a \to l_1^a \) captures the activation process, including the state entry and during actions, and the transition
- \( l_1^a \to l_m^a \) captures the deactivation process, including the state exit actions and the transitions to higher/lower level.

The atomic model has internal data-variables \( d_0^a, d_1^a \), \{\( d_0^a \) | \( o_e = s \)\} for controlling the execution flow, where
- \( d_0^a \) is to determine if the particular state is inactive/active/newly active as captured by the three values (0/1/2),
- \( d_1^a \) is to determine the direction of flow in the hierarchy: down/same/up as captured by the three values (-1/0/1), and
- \( d_1^a \) is to determine if the outgoing transition \( e \) is active or not (0/1).

A formal description of this atomic model is given in the following algorithm.

**Algorithm 1:** A Stateflow state \( s \) can be represented as an I/O-EFA \((L^s, D^s, -, -, -, -, \{l_0^s\}, D_0^s, -, E^s)\), where
- \( L^s \) is the set of states \( \{l_0^s, l_1^s, l_m^s\} \),
- \( D^s \) is the set of data variable consisting \( \{d_0^s, d_1^s\} \cup \{d^s | o_e = s\} \),
- \( D_0^s \) is the set of initial data values, and
- \( E^s \) is the set of enabled transition, where
  \( \{l_0^s, l_1^s, [d_0^s = 2], \{e_{n_a}, d_0^s := 1, d_1^s := -1 \text{ (if s has a substate) or } 1 \text{ (otherwise)}\} \) \cup \{l_0^s, l_1^s, [d_0^s = 1 ] \land -\{\{e_{c_a} = s\} g_e\}, \{du_a, d_1^s := -1 \text{ (if s has a substate) or } 1 \text{ (otherwise)}\} \) \cup \{l_1^s, l_m^s, [d_1^s = 0], \{ex_a\}\}, where
- \( e_{n_a} \) is the entry actions of \( s \),
– $du_s$ is the during actions of $s$,
– $ex_s$ is the exit actions of $s$, and
– $ge$ is the guard of the transition $e$.

The above atomic model captures a Stateflow state’s behavior as follows:

- When the Stateflow state $s$ is newly activated and the location is transitioned to $l_0^n$, $d_u^n$ is set to 2 (as described later). Accordingly, initially the transition labeled “entry” is enabled, and the state entry action $e_{in}$ is executed, and also $d_u^n$ is set to 1 to note that the state has already been activated; $d_l^n = -1$ (if $s$ has a substate and so the execution flow should be downward into the hierarchy to a substate) or 1 (if $s$ has no substate and so the execution flow can only be upward to a superstate) to indicate that the state has finished executing in this time step, and execution flow should go to another state;
- Once the state has been activated, $d_u^n$ equals 1 and upon arrival at $l_0^n$ if none of the outgoing transitions is enabled, the transition labeled “during” is executed causing the state during action $du_s$ to be executed; $d_u^n$ remains unchanged since the state is still in the execution phase; $d_l^n$ is set to -1 or 1 as described above in the previous bullet;
- When leaving the state, $d_l^n$ is set to 0 (as discussed later), so upon arrival to $l_0^n$ the transition labeled “exit” is executed, causing the execution of the state exit action $ex_s$.

### IV. Modeling State Hierarchy

Stateflow provides for hierarchical modeling of discrete behaviors by allowing a state to possess substates which can be organized into a tree structure. The root node of the tree is the Stateflow chart, the internal nodes are the substates of the Stateflow chart, and the leaves are the bottom-level states with no substates of their own. As described in the previous section, each state, which is a node of the tree, is modeled as an atomic model of the type shown in Figure 3. The next step in the modeling is to connect these atomic models according to the type (AND vs. OR) of the children nodes.

In case of AND substates, all states must be active simultaneously and must execute according to their execution order at each time step, whereas in case of OR substates, at most one of the substates can be active at each time step, and one of the substates is deemed default substate which gets activated at the first time step its superstate becomes active. For the execution order of a state with substates, two rules must be followed: 1) The substates can be executed only when their superstate is activated, and 2) A state finishes execution only when all its substates have been evaluated for execution.

After the execution of a transition labeled “entry” or “during” of a state, all its outgoing transitions are evaluated for enablement (if no outgoing transition is enabled, another execution of “during” action is performed). The enabled transition with the highest priority is selected for execution, and the particular transition is activated. Also the exit phase of the state is initiated. Exit phase generally has the following execution sequence: The condition action of the activated transition, the exit actions of the leaving state, the transition action of the activated transition and the entry action of the entering state. Furthermore, if there are multiple exit actions to be executed (i.e. the leaving state has substates), then those are ordered according to the following rule: The leaving state, along with all its substates, exits by starting from the last-entered state’s exit action, and progressing in reverse order to the first-entered state’s exit action.

With the above knowledge of the semantics of the AND/OR hierarchy, we can now model the hierarchical behaviors by defining the corresponding composition rules. We first introduce a few notation to make the presentation clearer.

**Definition 2**: A complex state $\tilde{s}$ is the state system consisting of the state $s$ and all its immediate substates. $\tilde{s}$ is said to be an AND- (resp., OR-) complex state if it possesses AND (resp., OR) substates. We define $|\tilde{s}|$ to indicate the number of substates in the complex state $\tilde{s}$.

#### A. Modeling state with OR-substates

Following the state transition semantics, the modeling rule for a state with OR-substates can be defined by the following algorithm. For an OR-complex state $\tilde{s}$ we use $s^*$ to denote its default state.

**Algorithm 2**: An OR-complex state $\tilde{s}$ can be represented as an I/O-EFA $(L_\tilde{s}, D_\tilde{s}, \cdot, \cdot, \cdot, \{l_0^n\}, D_0^n, E, E^*)$, where

- $L_\tilde{s} = \bigcup_{s \in E} L_s^*$,
- $D_\tilde{s} = \prod_{s \in E} D_s^*$,
- $D_0^* = \prod_{s \in E} D_0^s$,
- $E^* = \bigcup_{s \in E} E_s^*$, where $E$ is all newly introduced edges as shown in Figure 4.

\[
\begin{align*}
\cup \{l_0^n, [d_i^n := 1 \land d_i^n > 0], \} \\
\cup \{l_0^n, [d_i^n := 1 \land (\forall s \in E) (d_s := 0)], \} \quad (\forall s \in s^*, d_s := 2) \\
\cup \{l_0^n, [d_i^n := 0], \} \quad (\forall s \in s^*, d_s := 0; d_l := -1 \text{ (if } s \text{ has a substate) or 0 (otherwise)}) \\
\cup \{l_0^n, [d_i^n := 0], \} \quad (\forall s \in s^*, d_s := 0; d_l := -1 \text{ (if } s \text{ has a state) or 0 (otherwise)}) \\
\cup \{l_0^n, [d_i^n := 1], \} \quad (\forall s \in s^*, d_s := 0; d_l := -1 \} \\
\cup \{l_0^n, [d_i^n := 0], \} \quad (\forall s \in s^*, d_s := 0; d_l := -1 \} \}
\end{align*}
\]

- $ge$ is guard condition of the transition $e$,
- $ca_i$ is condition action of the transition $e$.
- $ta_e$ is transition action of the transition $e$, and
- $oe_i$ (resp., $te$) is the origin (resp., terminal) state of edge $e$.

**Fig. 4.** OR-Complex state modeling. $\forall s \in \tilde{s} \setminus \{s\}: sEx_s \equiv [d_s := 0] \quad (\forall s \in \tilde{s} \setminus \{s\}: subConEx_s \equiv [d_s := 1 \land ge \land d_i^n > 0] \quad (\forall s \in \tilde{s} \setminus \{s\}: subTransCA_s \equiv [d_s := 1 \land ge \land d_i^n > 0] \quad (\forall s \in \tilde{s} \setminus \{s\}: subTransAE_s \equiv [d_s := 0 \land de = 1] \quad \{ta_e; d_i^n := 2; d_i^n := -1\} \}.

#### B. Modeling state with AND-substates

For an AND-complex state $\tilde{s}$, its substates, although simultaneously active, are executed in a certain order. With a
slight abuse of notation we use \( r \) to denote the state whose execution order is \( r \) among all the substates of \( \tilde{s} \). Also for simplicity of notation let \( k = |\tilde{s}| \). The modeling rule for a state with AND-substates is defined as follows.

**Algorithm 3:** An AND-complex state \( \tilde{s} \) can be represented as an I/O-EFA \((L^\tilde{s}, D^\tilde{s}, \neg, -: -, -, \{t_0\}, D_0^\tilde{s}, \neg, E^\tilde{s}\), where

- \( L^\tilde{s} = \bigcup_{s \in \tilde{s}} L^s \)
- \( D^\tilde{s} = \prod_{s \in \tilde{s}} D^s \)
- \( D_0^\tilde{s} = \prod_{s \in \tilde{s}} D_0^s \)
- \( E^\tilde{s} = E \bigcup_{s \in \tilde{s}} E^s \), where \( E \) is all newly introduced edges as shown in Figure 5:

\[
\begin{align*}
\{t_i^s, t_i^s, [d_i^s = 1 \land d_k^s > 0 \land d_\neg^s > 0], \} & \{\forall r \in \tilde{s} - \{s\} : d_a^s := 2\} \\
\{t_i^s, t_i^s, [d_i^s = 1 \land d_a^s = 0], \} & \{\forall r \in \tilde{s} - \{s\} : d_a^s := 1\} \\
\{t_i^s, t_i^s, [d_i^s = 1], \} & \{d_i^s := 1\} \\
\{t_i^s, t_i^s, [d_i^s = 1], \} & \{d_i^s := 0\} \\
\{t_i^s, t_i^s, [d_i^s = 1], \} & \{d_i^s := 0\} \\
\{t_i^s, t_i^s, [d_i^s = 1], \} & \{d_i^s := 0\} \\
\end{align*}
\]

With the above two composition rules, an overall model of a Stateflow chart, capturing only the state hierarchy feature, can be obtained by applying the rules recursively, over the tree structure of the state hierarchy, in a bottom-up fashion.

**V. MODEL REFINEMENT FOR OTHER FEATURES**

Besides the state hierarchy, Stateflow provides many additional features, such as events, historical node and interlevel transitions. We capture these features into our model by refining the I/O-EFA model obtained by recursively applying Algorithms 1-3. We illustrate the model refinement by modeling one of the important features of Stateflow, namely a local event which is a commonly used event type.

A local event is triggered at a certain source state as part of one of the actions, where along with the event name, the destination states for the event broadcast are also specified. When an event is triggered, it is immediately broadcast to its destination state for evaluation. At this point, the destination state, including all of its substates, is executed by treating the event condition to be true in all of the guard conditions where it appears. Then the execution flow returns to the breakpoint where the event was triggered and resumes the execution.

The Stateflow event semantics permits an infinite chaining of events since each event can cause an action in its destination state that triggers a new or the same event. Such recursive behavior cannot be captured in the I/O-EFA modeling framework. However, practical systems avoid infinite chaining of events by way of satisfying the following requirements [3], which we assume to hold:

- Local events can be sent only to parallel states,
- Transitions out of parallel states are forbidden,
- Loops in broadcasting of events are forbidden, and
- Local events can be sent only to already-visited states.

For local event \( ev \) that is triggered in some source state \( src \) of a Stateflow chart, let \( ev^s \in E \) be an edge that broadcasts the event \( ev \). The model refinement step for modeling the local event behavior requires replacing the event-triggering edge \( ev^s \) with a pair of edges between the event source state \( src \) and the event destination state \( des \), one in each direction (see Figure 6 for illustration). Also letting \( E^\tilde{ev} \) denote the set of edges in the destination state’s I/O-EFA model where the event \( ev \) is received, then for each edge \( e \in E^\tilde{ev} \), its event label \( \sigma_e (= ev) \) is replaced by the guard condition \( [d_e^s = 1] \), where the binary variable \( d_e^s \) captures whether or not the event \( ev \) has been triggered.

**Algorithm 4:** Given an I/O-EFA model \((L, D, -, -, -, L_0, D_0, -, E)\) obtained from recursive application of Algorithms 1-3, an edge \( ev^s \in E \) that broadcasts an event \( ev \) to the destination state \( des \), and a set of edges \( E^\tilde{ev} \) in the destination state that receive the event (i.e., \( \forall e \in E^\tilde{ev} : \sigma_e (= ev) \)), the refined I/O-EFA model is given by \((L, D, -, -, -, L_0, D_0, -, E^\tilde{ev})\), where

\[
E^\tilde{ev} = \begin{cases} E \setminus E^e & \text{if } e \in E^\tilde{ev} \\ E^\tilde{ev} & \text{otherwise} \end{cases},
\]

where \( E^e \) denotes all the guard conditions and actions appearing on the event-triggering edge prior to (resp., after) the event-broadcast label, and \( E^\tilde{ev} \) is the set of edges obtained by replacing the event label \( \sigma_e (= ev) \) of each edge \( e \in E^\tilde{ev} \) by the guard condition \([d_e^s = 1]\) (no relabeling is done for the remaining edges in \( E - E^\tilde{ev} \)).
VI. Final Touches: Finalizing the Model

At the top level, a Stateflow chart is also a Simulink block (the distinction being that it is event-driven as opposed to time-driven). So to be consistent, at the very top level, the model of a Stateflow chart ought to resemble the model of a time-driven Simulink block as introduced in [1]. Accordingly, the model of a Stateflow chart obtained from applying Algorithms 1-4 is adapted by adding another layer as shown in Figure 7. As is the case with the model of a time-driven Simulink chart, the final model of a Stateflow chart is composed of two I/O-EFAs connected through succession edges as shown in Figure 7. Finally, the I/O-EFA model for the Stateflow chart of a counter is combined with the I/O-EFA model of Simulink block (of saturation) using the connecting rule introduced in [1]. The result is shown in Figure 8.

Example 1: Consider the counter system of Figure 1. It can be translated into an I/O-EFA model as follows:

1. Modeling states: We first construct atomic model for each of the seven states (including the Stateflow root) of Figure 2.
2. Modeling state hierarchy: We apply OR Complex State Composition Rule (Algorithm 2) on the models obtained in step 1 of the two bottom-level OR complex states, and AND Complex State Composition Rule (Algorithm 3) on models obtained in step 1 of the top-level AND complex state.
3. Modeling local events: Each edge in the model obtained in step 2 containing the event “count” or “stop” is replaced with a pair of edges to connect the source state “outputAssignment” and the destination state “dataUpdate”, in each direction. At the same time the evaluation of “count” (resp., “stop”) is modified to \(d_{ev1} = 1\) (resp., \(d_{ev2} = 1\)).
4. Obtaining final model: The model obtained in step 3 is augmented by applying Algorithm 5 to obtain a final model (this step introduces four extra locations, and a few extra edges as shown in Figure 7). Finally, the I/O-EFA model for Stateflow chart (of counter) is combined with the I/O-EFA model of Simulink block (of saturation) using the connecting rule introduced in [1]. The result is shown in Figure 8.

VII. Validation of Stateflow Modeling

The Stateflow modeling approach described above, along with the Simulink modeling method of our previous work [1], written in the Matlab script, has been implemented in an automated translation tool SS2EFA. Upon specifying a source Simulink/Stateflow model file, the tool can be executed to output the corresponding I/O-EFA model in form of a “flat” Stateflow chart, which can itself be simulated in Matlab. The result of simulating the I/O-EFA is the same as that of simulating the source Simulink/Stateflow model.

Example 2: The simulation result comparison between the I/O-EFA model of the counter (see Figure 8) and the original counter system (see Figure 1) is shown in Figure 9. The simulation (using Intel Core 2 Duo P8400 2.27GHz, 2GB RAM) time is 4 seconds with sampling period of 0.03 seconds, and the results are consistent with the behaviors of the counter.

Example 3: This example is of a servo velocity control system consisting of a controller, a fault monitor (both written in Stateflow), and a motor (written in Simulink). The Simulink/Stateflow diagram of the servo velocity control system is translated by our translation tool. The CPU time (using Intel Core 2 Duo P8400 2.27GHz, 2GB RAM) for the translation is 45.1 seconds and the translated model has
Fig. 8. Complete I/O-EFA model (some edges whose guards are never satisfied are omitted for simplicity) for counter system of Figure 1. The model contains 382 locations and 646 edges. The simulation result of the translated model (shown in Figure 11) is identical to the discrete behaviors of the original Simulink/Stateflow model.

Fig. 10. Simulink/Stateflow model of servo velocity control

Fig. 11. Simulation results for the velocity set point and actual servo velocity (top) and residue (bottom); left (resp., right) figures are for translated I/O-EFA model (resp., original Simulink/Stateflow model of servo system)

VIII. CONCLUSION

We presented a translation approach from Stateflow chart to Input/Output Extended Finite Automata (I/O-EFA). A Stateflow state, which is the most basic component of Stateflow chart, is modeled as an atomic model. The composition rules for AND/OR hierarchy are defined to connect the atomic state models. An overall I/O-EFA model is obtained by recursively applying the two composition rules in a bottom-up fashion over the tree structure of the state hierarchy. Rules for further refining the model to incorporate other Stateflow features such as events, historical information, interlevel transitions, etc. have been developed. Finally, the Stateflow model is adapted to resemble a Simulink model, since at the highest level a Stateflow chart is a block in the Simulink library. The size of the translated model is linear in the size of the Stateflow chart. Both the Stateflow and Simulink translation approaches have been implemented in an automated translation tool SS2EFA. The translated I/O-EFA models are validated to preserve the discrete behaviors of the original Simulink/Stateflow models. The translated I/O-EFA models can be used for further formal analysis such as verification and test generation. Generally, for test generation, certain set of the computational paths within one time step are extracted according to the coverage criterion, and checked for their feasibility. The input sequences that can achieve the feasible paths are the test cases. We will discuss these in our future work.

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