Supplemental Material for "LWS: A Framework for Log-based Workload Simulation in Session-based SUT"

1. LWS DSL

We design a DSL to describe the workload features in a human-readable way so that the simulated workload can be executed easily even by a non-expert who is not familiar with the LWS framework. We divide the workload features into two categories, namely the user behavior features and the intensity features. The example of DSL input files have been displayed in Table. 1. As we can see from the table, the user behavior features consist of the index, the name, the API detail including the request method (GET/POST/PUT/DELETE) and the request URL, the parameter including the name and values, and the transition probability between two adjacent nodes in the relational model. Specially, two dummy nodes u_s (INITIAL) and u_e (TERMINAL) are defined. In the intensity features, the mandatory information includes the interval δ to represent the time span in seconds and the exact workload intensity modeling method (reproduction/fitting/generation). According to the workload intensity method, the corresponding components of time series to describe $I(t)$ from different perspectives should be provided. The DSL grammar is defined in the Backus Normal Form (BNF) as shown in Figure 1.

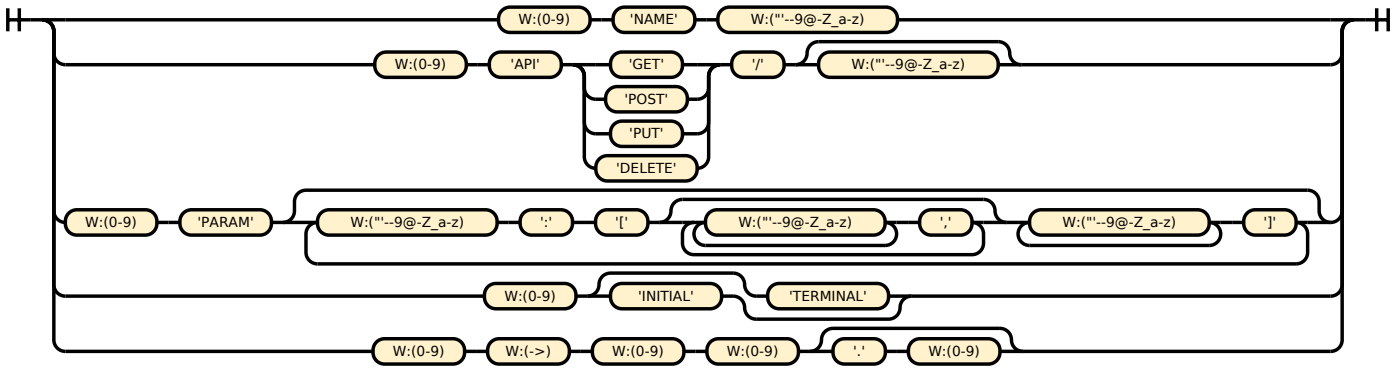
For user behavior features, there are five kinds of line choices as shown in Figure 1a:

- The Name of the User Behavior: For each user behavior, we need to define the name of a user behavior and its ID. For example, "0 NAME adding_to_cart" defines a user behavior "adding_to_cart" whose ID is 0. The first place is always a number and the second constant part is "NAME".
- The API of the User Behavior: For each user behavior, we need to define the concrete request interface and request methods of the user behavior. For example, "0 API POST /cart" defines the request interface and the request method of the user behavior whose ID is 0 (the user behavior is defined as "adding_to_cart" above). The request interface is "/cart" and the request method is "POST" . The first place is always a number, the second place is a constant part "API", the third place is the request method and the fourth place is the request interface. The request method is chosen from "GET", "POST", "PUT" and "DELETE", which can also be extended to other request methods.

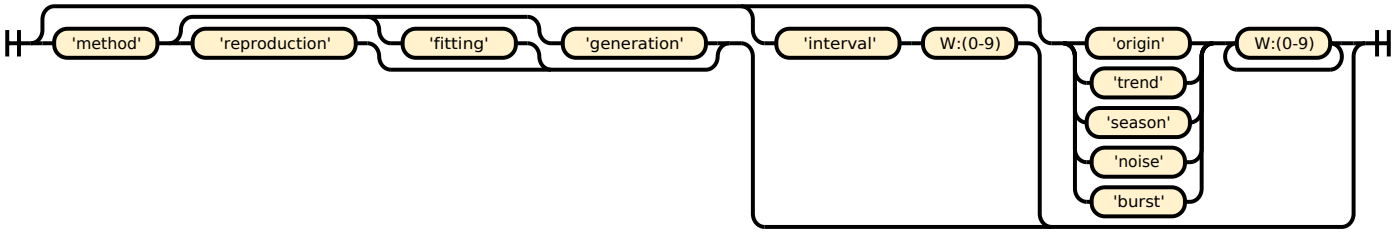
Table 1: The example of DSL input files (The symbol of ... represents omissions to satisfy the space constraints).

Category	Content
User Behavior Features	0 NAME adding_to_cart 0 API POST /cart 0 PARAM product_id: ['0PUK6V6EV0','6E92ZMYYFZ','2ZYFJ3GM2N',...] quantity: [1,2,3...] 1 NAME home 1 API GET / 1 PARAM 2 NAME placing_order 2 API POST /cart/checkout 2 PARAM email: ['someone@example.com'] ... ... 6 TERMINAL 7 INITIAL 0->5 1.00 1->3 0.33 1->4 0.67 ...
Intensity Features	method generation interval 10 trend 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 season 1 2 3 4 5 1 2 3 4 5 1 2 3 4 5 noise 1 0 2 0 1 0 0 1 1 0 2 0 1 0 1

- The Params of the User Behavior: For each user behavior, we need to define request parameters for real requests. For example, "0 PARAM product_id: ['0PUK6V6EV0','6E92ZMYYFZ','2ZYFJ3GM2N'] quantity: [1,2,3]" define two parameters, "product_id" and "quantity" of the user behavior whose ID is 0. The value of "product_id" is chosen from '0PUK6V6EV0','6E92ZMYYFZ' and '2ZYFJ3GM2N' and the value of "quantity" is chosen from 1,2 and 3. The first place is always a number, the second place is a constant part "PARAM". Then for each parameter, the description consists of two parts: the name of the parameter and its range of values. All possible choices of value is enumerated and listed between "[" and "]".
- The Initial (Terminal) Dummy Node: The initial (terminal) dummy node also needs to be defined for the representation of transition probability. For example, "6 TERMINAL" defines the terminal dummy node whose ID is 6. The first place is always a number and the second place is chosen from "INITIAL" and "TERMINAL", denoting two different dummy nodes.



(a) BNF for user behavior features.



(b) BNF for workload intensity features.

Figure 1: The BNF structures for our DSL grammer.

Table 2: The mathematical expressions of fitting the original intensity in the dataset $\mathcal{B}$.

Method	Component	Mathematical Expression	SSE	R-square	RMSE
Fitting (Origin)	-	$f(x) = a_0 + a_1 \times cos(wx) + b_1 \times sin(wx) + a_2 \times cos(2wx) + b_2 \times sin(2wx) + a_3 \times cos(3wx) + b_3 \times sin(3wx) + a_4 \times cos(4wx) + b_4 \times sin(4wx) + a_5 \times cos(5wx) + b_5 \times sin(5wx) + a_6 \times cos(6wx) + b_6 \times sin(6wx) + a_7 \times cos(7wx) + b_7 \times sin(7wx) + a_8 \times cos(8wx) + b_8 \times sin(8wx), w = 0.04363, a_0 = 34.74, a_1 = -3.123, b_1 = -21.09, a_2 = 7.203, b_2 = -13.5, a_3 = 0.4789, b_3 = -6.229, a_4 = -3.534, b_4 = -3.381, a_5 = -1.036, b_5 = -0.8598, a_6 = -0.4041, b_6 = -0.803, a_7 = 0.1615, b_7 = -0.6252, a_8 = -1.054, b_8 = 0.1594$	2.112×10^4	0.9537	4.319
Fitting (Decomposition)	*trend*	$f(x) = p_1 \times x^8 + p_2 \times x^7 + p_3 \times x^6 + p_4 \times x^5 + p_5 \times x^4 + p_6 \times x^3 + p_7 \times x^2 + p_8 \times x + p_9, p_1 = -3.679 \times 10^{-21}, p_2 = 1.483 \times 10^{-17}, p_3 = -2.332 \times 10^{-14}, p_4 = 1.798 \times 10^{-11}, p_5 = -6.92 \times 10^{-9}, p_6 = 1.19 \times 10^{-6}, p_7 = -7.02 \times 10^{-5}, p_8 = 0.002077, p_9 = 33.61$	79.53	0.9922	0.264
	season	$f(x) = a_0 + a_1 \times cos(wx) + b_1 \times sin(wx) + a_2 \times cos(2wx) + b_2 \times sin(2wx) + a_3 \times cos(3wx) + b_3 \times sin(3wx) + a_4 \times cos(4wx) + b_4 \times sin(4wx) + a_5 \times cos(5wx) + b_5 \times sin(5wx) + a_6 \times cos(6wx) + b_6 \times sin(6wx) + a_7 \times cos(7wx) + b_7 \times sin(7wx) + a_8 \times cos(8wx) + b_8 \times sin(8wx), w = 0.04394, a_0 = 0.001179, a_1 = 0.5394, b_1 = -20.54, a_2 = 11.22, b_2 = -9.706, a_3 = 3.663, b_3 = -4.802, a_4 = -0.2356, b_4 = -4.556, a_5 = 0.134, b_5 = -1.233, a_6 = 0.5156, b_6 = -0.7415, a_7 = 0.6966, b_7 = -0.061, a_8 = -0.2362, b_8 = -0.7853$	296.8	0.9993	0.5121
	noise	$f(x) = a_1 \times exp(-(x - b_1)^2/c_1^2), a_1 = 24.75, b_1 = 1.147 \times 10^3, c_1 = 10.76$	1.403×10^4	0.2838	3.498
	merge	$f(x) = trend + season + noise$	1.405×10^4	0.9692	3.541

- The Transition Probability: We need to define the transition probability for final user behavior sequence sampling. Each edge is enumerated by "ID1->ID2 *prob*", which means the transition probability from the user behavior whose ID is ID1 to the user behavior whose ID is ID2 is *prob*.

Then for intensity features, there are three kinds of line choices as shown in Figure 1a:

- The Method of Workload Intensity Modeling: First the method of workload intensity modeling method

Table 3: The parameters of *Generation*.

Method	Component	Parameter	Value
Generation(LIMBO)	*trend*	η_1	1
		η_2	1296
		c_1	27.263
		c_2	40.207
		c_3	26.494
		g_1	linear
	season	η_2	1296
		η_3	9
		η_4	1152
		c_4	-24.975
		c_5	-24.975
		c_6	17.596
		c_7	19.723
		g_2	quadratic
	burst	η_5	104
		η_6	160
		η_7	32
		c_8	32
		g_3	quadratic
	noise	η_8	0
		η_9	6
Generation(TSAGen)	*trend*	θ_1	31.550
		θ_2	0.005
	season	θ_3	65
		θ_4	144
		θ_5	8
		k_1	0
		k_2	0
		d_1	10
		d_2	2
	noise	θ_6	0.206
		θ_7	0.139
		θ_8	4.057

is defined which decides the following defined components. The method is chosen from "reproduction", "fitting", and "generation". The first place is a constant part "method" and the second place is the chosen method. If the method is "reproduction", the final intensity consists of the "origin" component. If the method is "fitting", the final intensity consists of the "trend" component, the "season" component, the "noise" component. If the method is "generation", the final intensity consists of the "trend" component, the "season" component, the "noise" component, and the "burst" component.

- The Interval Denoting the Bucket Length: The interval is defined which is the bucket length described in Section 4.4 in the original paper. The first place is a constant part "interval" and the second place is the value of the interval.
- The Value of Each Component: For each component, the value sequence is specified. The first place is a constant part chosen from "trend", "season", "noise", and "burst". Then the value sequence is separated by spaces. After all components corresponding to the intensity modeling method are given, the final intensity is calculated by adding values in the same position of all components.

2. Fitting Mathematical Expressions

Table 2 shows the detailed mathematical expressions and evaluation metrics including the sum of squares error (denoted by SSE), R-squared value (denoted by R-square), and the root mean square error (denoted by RMSE) of fitting the original intensity. Each mathematical expression is the most suitable one automatically chosen based on RMSE.

3. Generation Parameters

Table 3 shows the parameters and interpolation functions adopted in *Generation(LIMBO)* and *Generation(TSAGen)*.