Improving the Quality of Supervised Finite-State Machine Construction Using Real-Valued Variables

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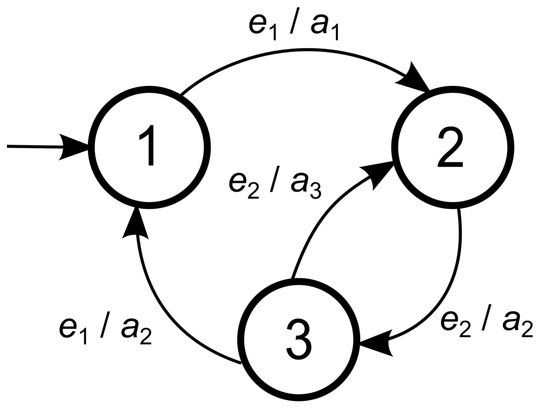
Problem Statement

Finite-State Machine:

- FSM = (S, s_0, E, A, δ, λ)
- S – finite set of states
- s_0 – initial state
- E, A – event and action sets
- δ: $S \times E \to S$ – transition function
- λ: $S \times E \to A$ – output function



Problem:

- Real-valued inputs and outputs
- Tests ($N \approx 20$–30) are the examples of proper control
- Construct an FSM with behavior close to the tests
- Aircraft model is used as a controlled object
- Tests can be written manually in a flight simulator
- Test example:

Values	Description	$t = 1$	...	$t = 10$	...	$t = 235$
in[i, t]$_1$	Pitch angle (°)	3.078	...	3.544	...	4.112
in[i, t]$_2$	Airspeed (knots)	251.42	...	252.29	...	253.20
out[i, t]$_1$	Aileron position	0.000	...	0.032	...	0.073
out[i, t]$_2$	Elevator position	−0.035	...	−0.039	...	−0.037

FSM Learning

- Methodology:

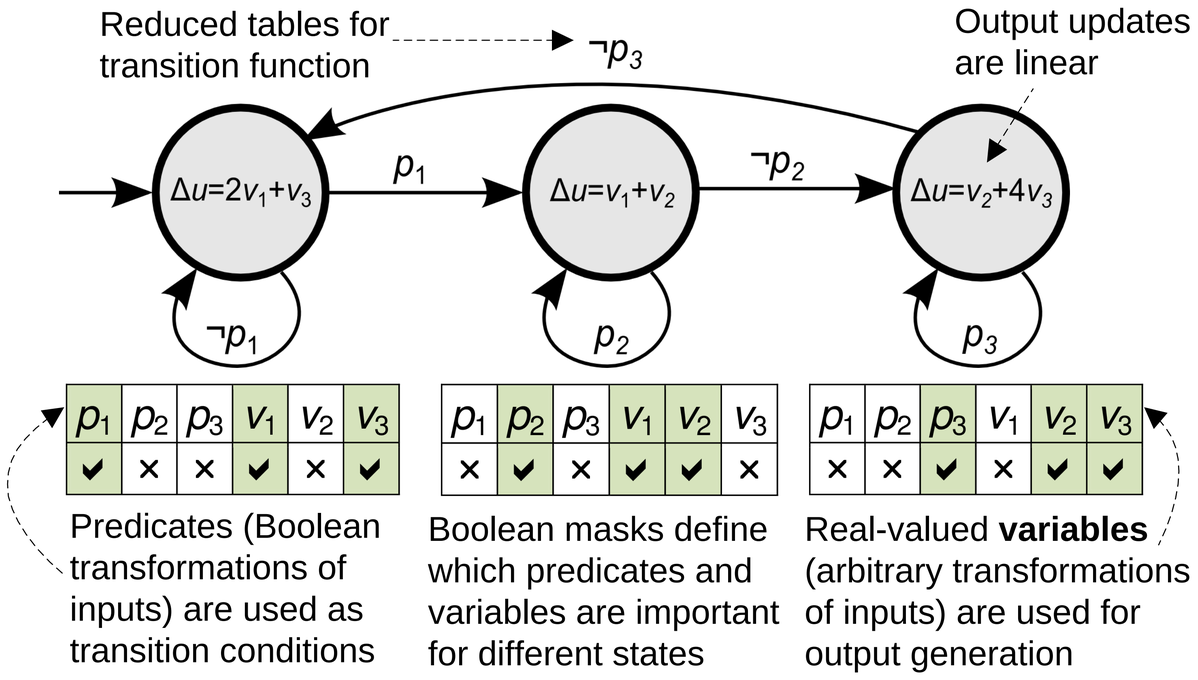
- ACO-based algorithm
- FSMs with undefined output functions are individuals
- Output actions are derived so that the fitness function is maximized
- Fitness function:

$$f = 1 - \sqrt{\frac{1}{N}\sum_{i=1}^{N}\rho^2(\mathrm{ans}[i], \mathrm{out}[i])} - K \cdot \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\max(\tau_i - |S| + 1, 0))^2}$$

$$\rho\left(\mathrm{ans}[i], \mathrm{out}[i]\right) = \sqrt{\frac{1}{\mathrm{len}[i]}\sum_{t=1}^{\mathrm{len}[i]}\frac{1}{C}\sum_{j=1}^{C}\left(\frac{\mathrm{ans}[i,t]_j - \mathrm{out}[i,t]_j}{c_j^{\max} - c_j^{\min}}\right)^2}$$

- C – number of outputs
- ans[i] – FSM's output for the i-th test
- τ_i – number of state changes on the i-th test

FSM Representation



More complex example (one state):

Predicate significance mask			
p_1	p_2	p_3	p_4
✔	×	✔	×

Transition table (from the current state)			
$\neg p_1 \wedge \neg p_3$	$\neg p_1 \wedge p_3$	$p_1 \wedge \neg p_3$	$p_1 \wedge p_3$
2	4	1	1

Variable significance mask for output 1			
$v_{1,1}$	$v_{1,2}$	$v_{1,3}$	$v_{1,4}$
×	✔	×	✔

Variable significance mask for output 2				
$v_{2,1}$	$v_{2,2}$	$v_{2,3}$	$v_{2,4}$	$v_{2,5}$
✔	×	×	×	✔

Output action 1			
$r_{s,1,1}$	$r_{s,2,1}$	$r_{s,3,1}$	$r_{s,4,1}$
0	**1.2**	0	**0.3**
$\Delta u_1 =$ **1.2** $v_{1,2}$ + **0.3** $v_{1,4}$			

Output action 2				
$r_{s,1,2}$	$r_{s,2,2}$	$r_{s,3,2}$	$r_{s,4,2}$	$r_{s,5,2}$
3.7	0	0	0	**−0.3**
$\Delta u_2 =$ **3.7** $v_{2,1}$ − **0.3** $v_{2,5}$				

Experiments & Results

- Quad-core Intel Core i7–2670QM processor
- 3 test sets, number |S| of states: 3..5
- Method execution time: about 10 minutes
- Comparison with the previous representation
- Fitness values:

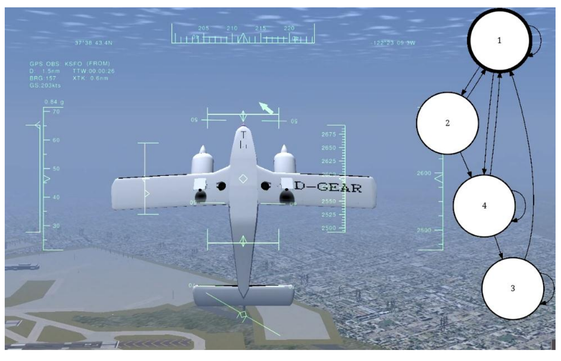
$\lvert S\rvert$	FSM Representation	Loop	Barrel roll	Turn
3	Proposed	**0.9856**	**0.9854**	0.9892
	Previous	0.9812	0.9832	0.9894
4	Proposed	**0.9866**	**0.9863**	0.9898
	Previous	0.9836	0.9856	0.9901
5	Proposed	**0.9873**	**0.9868**	0.9901
	Previous	0.9842	0.9858	0.9902

- Roll/pitch errors (°) in simulation:

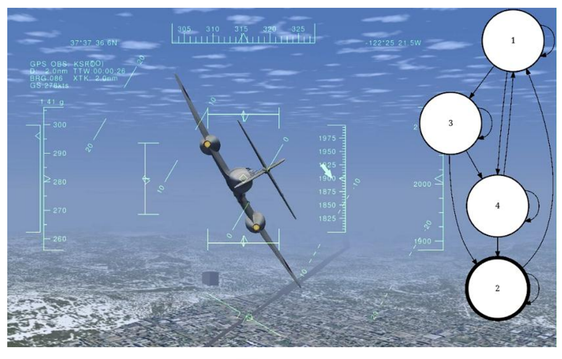
$\lvert S\rvert$	FSM Representation	Loop	Barrel roll	Turn
3	Proposed	**1.71/17.21**	**16.52/3.20**	**4.80/1.95**
	Previous	6.37/20.54	18.56/4.44	50.29/7.58
4	Proposed	2.41/23.04	**15.35/2.51**	**4.10/1.42**
	Previous	6.32/22.11	21.86/4.08	57.04/6.79
5	Proposed	3.21/25.27	**14.74/2.43**	**4.07/1.36**
	Previous	9.54/24.44	22.99/4.68	45.83/7.83

✓ Quality is improved
✓ Now it is possible to construct FSMs performing the turn

Screenshots (FlightGear simulator)



Loop



Turn

Publications

- Buzhinsky I., Ulyantsev V., Chivilikhin D., Shalyto A. Inducing Finite State Machines from Training Samples Using Ant Colony Optimization. Journal of Computer and Systems Sciences International, 2014, Vol. 53, No. 2. P. 256–266.
- Buzhinsky I., Ulyantsev V., Tsarev F., Shalyto A. Search-Based Construction of Finite-State Machines with Real-Valued Actions: New Representation Model. Genetic and Evolutionary Computation Conference (GECCO 2013) Companion. P. 199–200.

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