Team automata : a formal approach to the modeling of collaboration between system components

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2. Preliminaries

$\subseteq$	set inclusion, 23
$\subset$	proper set inclusion, 23
$\setminus$	set difference, 23
$\#$	cardinality (of a set), 23
$\varnothing$	the empty set, 23
$[n]$	shorthand for $\{1, 2, \dots, n\}$, 23
$\mathbb{N}$	set of positive integers, 23
$\prod$	cartesian product (prefix notation), 23
$\times$	cartesian product (infix notation), 23
proj_j	projection on element j, 23
proj_J	projection on subset J, 23
${\mathrm{proj}_j}^{[2]}$	shorthand for $\mathrm{proj}_j \times \mathrm{proj}_j$, 24
${\mathrm{proj}_J}^{[2]}$	shorthand for $\mathrm{proj}_J \times \mathrm{proj}_J$, 24
$f \upharpoonright C$	restriction of function f to a subset C of its domain, 24
Σ	alphabet, 24
λ	the empty word, 24
$\lvert w \rvert$	length (of a word w), 24
$w(i)$	i-th letter (of a word w), 24
$\#_a(w)$	total number of occurrences of letter a (in a word w), 24
$\mathrm{alph}(w)$	alphabet (of a word w), 25
Σ^*	set of all finite words over Σ, 25
Σ^+	set of all nonempty finite words over Σ, 25
Σ^ω	set of all infinite words over Σ, 25
Σ^∞	set of all words over Σ, 25
$u \cdot v$	concatenation (of words u and v), 25
$K \cdot L$	concatenation (of languages K and L), 25
$\mathrm{pref}(w)$	set of prefixes (of a word w), 26
$w[n]$	prefix of length n (of a word w), 25
$\lim\limits_{n\to\infty} v_n$	limit (of words $v_1 \leq v_2 \leq \cdots$), 26
pres_Γ	function preserving the symbols from Γ (and erasing all other symbols), 27

3. Automata

$\mathcal{A}$	automaton, 29
Q	set of states (of $\mathcal{A}$), 29
Σ	set of actions or alphabet (of $\mathcal{A}$), 29
δ	set of labeled transitions (of $\mathcal{A}$), 29
I	set of initial states (of $\mathcal{A}$), 29
δ_a	set of a-transitions (of $\mathcal{A}$), 30
$\mathbf{C}_{\mathcal{A}}$	set of finite computations of $\mathcal{A}$, 30
$\mathbf{C}_{\mathcal{A}}^{\omega}$	set of infinite computations of $\mathcal{A}$, 30
$\mathbf{C}_{\mathcal{A}}^{\infty}$	set of computations of $\mathcal{A}$, 30
$\mathbf{B}_{\mathcal{A}}^{\Theta,\infty}$	Θ-behavior of $\mathcal{A}$, 31
$\mathbf{B}_{\mathcal{A}}^{\Theta}$	finitary Θ-behavior of $\mathcal{A}$, 31
$\mathbf{B}_{\mathcal{A}}^{\Theta,\omega}$	infinitary Θ-behavior of $\mathcal{A}$, 31
Q_S	set of reachable states (of $\mathcal{A}$), 36
Σ_A	set of active actions (of $\mathcal{A}$), 36
δ_T	set of useful transitions (of $\mathcal{A}$), 36
$\mathcal{A}_1 \sqsubseteq \mathcal{A}_2$	containment (of $\mathcal{A}_1$ in $\mathcal{A}_2$), 36
$\mathcal{A}_A^{\Theta}$	Θ-action-reduced version of $\mathcal{A}$, 37
$\mathcal{A}_T^{\Theta}$	Θ-transition-reduced version of $\mathcal{A}$, 38
$\mathcal{A}_S$	state-reduced version of $\mathcal{A}$, 46
$\mathcal{A}_A$	action-reduced version of $\mathcal{A}$, 50
$\mathcal{A}_T$	transition-reduced version of $\mathcal{A}$, 50
$\mathcal{A}_R$	reduced version of $\mathcal{A}$, 50

4. Synchronized Automata

$\mathcal{I}$	index set, 59
$\mathcal{A}_i$	automaton, 59
$\mathcal{S}$	set of automata, 59
$\Delta_a(\mathcal{S})$	complete transition space of a in $\mathcal{S}$, 60
$\mathcal{T}$	synchronized automaton, 60
$SUB_J(\mathcal{T})$	the subautomaton of $\mathcal{T}$ determined by J, 64
SUB_J	the subautomaton (of $\mathcal{T}$) determined by J, 64
$\pi_{\mathcal{A}_j}$	projection on automaton $\mathcal{A}_j$, 70
π_{SUB_J}	projection on subautomaton SUB_J, 70
$\mathcal{D}$	indexed set, 76
$\mathcal{V}(\mathcal{D})$	all finitely nested cartesian products of sets from $\mathcal{D}$, 76
$\mathrm{dom}\,(V)$	domain of an element V, 76
u_V	function unpacking elements v from V, 77

$\langle v \rangle_V$	reordering of an element $v \in V$ relative to the construction of V, 77
$\langle\langle \mathcal{T} \rangle\rangle_{\mathcal{S}}$	reordered version of synchronized automaton $\mathcal{T}$ (w.r.t. $\mathcal{S}$), 81
$\mathcal{T}$	synchronized automaton, 84
$\mathit{Free}(\mathcal{T})$	set of *free* actions of $\mathcal{T}$, 85
$\mathit{AI}(\mathcal{T})$	set of *ai* actions of $\mathcal{T}$, 85
$\mathit{SI}(\mathcal{T})$	set of *si* actions of $\mathcal{T}$, 86
$\mathcal{R}_a^{no}(\mathcal{S})$	predicate *no-constraints*, 88
$\mathcal{R}_a^{free}(\mathcal{S})$	predicate *is-free* for a in $\mathcal{S}$, 88
$\mathcal{R}_a^{ai}(\mathcal{S})$	predicate *is-ai* for a in $\mathcal{S}$, 89
$\mathcal{R}_a^{si}(\mathcal{S})$	predicate *is-si* for a in $\mathcal{S}$, 89
j	element of $\mathcal{I}$, 90
J	subset of $\mathcal{I}$, 90
Θ	arbitrary alphabet disjoint from set Q of states (of $\mathcal{T}$), 90

5. Team Automata

$\mathcal{C}$	component automaton, 116
Σ_{inp}	set of input actions or input alphabet (of $\mathcal{C}$), 116
Σ_{out}	set of output actions or output alphabet (of $\mathcal{C}$), 116
Σ_{int}	set of internal actions or internal alphabet (of $\mathcal{C}$), 116
$\mathrm{und}(\mathcal{C})$	underlying automaton of $\mathcal{C}$, 116
Σ	set of actions or (full) alphabet (of $\mathcal{C}$), 116
Σ_{ext}	set of external actions or external alphabet (of $\mathcal{C}$), 116
Σ_{loc}	set of locally-controlled actions or locally-controlled alphabet (of $\mathcal{C}$), 117
$\mathbf{B}_{\mathcal{C}}^{\Sigma_{inp},\infty}$	input behavior (of $\mathcal{C}$), 117
$\mathbf{B}_{\mathcal{C}}^{\Sigma_{out},\infty}$	output behavior (of $\mathcal{C}$), 117
$\mathbf{B}_{\mathcal{C}}^{\Sigma_{int},\infty}$	internal behavior (of $\mathcal{C}$), 117
$\mathbf{B}_{\mathcal{C}}^{\Sigma_{ext},\infty}$	external behavior (of $\mathcal{C}$), 117
$\mathbf{B}_{\mathcal{C}}^{\Sigma_{loc},\infty}$	locally-controlled behavior (of $\mathcal{C}$), 117
$\mathcal{I}$	index set, 118
$\mathcal{C}_i$	component automaton, 118
Σ_i	set of actions (of $\mathcal{C}_i$), 118
$\mathcal{S}$	set of component automata, 118
$\mathcal{S}$	composable system, 118
$\mathcal{T}$	team automaton, 120
$\mathrm{und}(\mathcal{T})$	underlying synchronized automaton of $\mathcal{T}$, 120
$\mathit{SUB}_J(\mathcal{T})$	the subteam of $\mathcal{T}$ determined by J, 122
SUB_J	the subteam (of $\mathcal{T}$) determined by J, 122

$\mathcal{S}$	composable system, 123
$\langle\langle\mathcal{T}\rangle\rangle_{\mathcal{S}}$	reordered version of team automaton $\mathcal{T}$ w.r.t. $\mathcal{S}$, 125
$\mathcal{T}$	team automaton, 126
Σ_{inp}	set of input actions (of $\mathcal{T}$), 126
Σ_{out}	set of output actions (of $\mathcal{T}$), 126
Σ_{int}	set of internal actions (of $\mathcal{T}$), 126
Σ	set of actions (of $\mathcal{T}$), 126
Σ_{ext}	set of external actions (of $\mathcal{T}$), 126
Σ_{loc}	set of locally-controlled actions (of $\mathcal{T}$), 126
$\mathcal{I}_{a,inp}(\mathcal{S})$	input domain of a in $\mathcal{S}$, 126
$\mathcal{I}_{a,out}(\mathcal{S})$	output domain of a in $\mathcal{S}$, 126
$\mathcal{I}_{a,inp}$	input domain of a (in $\mathcal{S}$), 127
$\mathcal{I}_{a,out}$	output domain of a (in $\mathcal{S}$), 127
$SUB_{a,inp}(\mathcal{T})$	input subteam of a in $\mathcal{T}$, 127
$SUB_{a,out}(\mathcal{T})$	output subteam of a in $\mathcal{T}$, 127
$SUB_{a,inp}$	input subteam of a (in $\mathcal{T}$), 127
$SUB_{a,out}$	output subteam of a (in $\mathcal{T}$), 127
$SIPP(\mathcal{T})$	set of *sipp* actions of $\mathcal{T}$, 129
$WIPP(\mathcal{T})$	set of *wipp* actions of $\mathcal{T}$, 129
$SOPP(\mathcal{T})$	set of *sopp* actions of $\mathcal{T}$, 129
$WOPP(\mathcal{T})$	set of *wopp* actions of $\mathcal{T}$, 129
$MS(\mathcal{T})$	set of *ms* actions of $\mathcal{T}$, 131
$SMS(\mathcal{T})$	set of *sms* actions of $\mathcal{T}$, 131
$WMS(\mathcal{T})$	set of *wms* actions of $\mathcal{T}$, 132
$\mathcal{I}_{a,inp}$	input domain of a (in $\mathcal{S}$), 141
$\mathcal{I}_{a,out}$	output domain of a (in $\mathcal{S}$), 141
$\mathcal{R}_a^{sipp}(\mathcal{S})$	predicate *is-sipp* for a in $\mathcal{S}$, 141
$\mathcal{R}_a^{wipp}(\mathcal{S})$	predicate *is-wipp* for a in $\mathcal{S}$, 141
$\mathcal{R}_a^{sopp}(\mathcal{S})$	predicate *is-sopp* for a in $\mathcal{S}$, 142
$\mathcal{R}_a^{wopp}(\mathcal{S})$	predicate *is-wopp* for a in $\mathcal{S}$, 142
$\mathcal{R}_a^{ms}(\mathcal{S})$	predicate *is-ms* for a in $\mathcal{S}$, 144
$\mathcal{R}_a^{sms}(\mathcal{S})$	predicate *is-sms* for a in $\mathcal{S}$, 144
$\mathcal{R}_a^{wms}(\mathcal{S})$	predicate *is-wms* for a in $\mathcal{S}$, 144
$\Sigma_{i,ext}$	set of external actions (of $\mathcal{C}_i$), 150
$\Sigma_{i,loc}$	set of locally-controlled actions (of $\mathcal{C}_i$), 150
j	element of $\mathcal{I}$, 150
J	subset of $\mathcal{I}$, 150
$\Sigma_{J,ext}$	set of external actions (of SUB_J), 150
$\Sigma_{J,loc}$	set of locally-controlled actions (of SUB_J), 150

6. Behavior of Team Automata

pREG	family of prefix-closed regular finitary languages, 164

REG	family of regular languages, 164
FIN	family of finite languages, 164
CA	$\{\, \mathbf{B}^{\Sigma}_{\mathcal{C}} \mid \mathcal{C}$ is a finite component automaton with alphabet $\Sigma \,\}$, 164
CA^{alph}	$\{\, \mathbf{B}^{alph}_{\mathcal{C}} \mid \mathcal{C}$ is a finite component automaton $\}$ (with $alph \in \{inp, out, int, ext, loc\}$), 165
$\mathcal{I}$	index set, 166
$\mathcal{C}_i$	component automaton, 166
Σ_i	set of actions (of $\mathcal{C}_i$), 166
$\mathcal{S}$	composable system, 166
$\mathcal{T}$	team automaton, 166
Σ	set of actions (of $\mathcal{T}$), 166
Θ	arbitrary alphabet disjoint from set Q of states (of $\mathcal{T}$), 166
j	element of $\mathcal{I}$, 166
$uAI_j(\mathcal{T})$	set of useful j-ai actions (of $\mathcal{T}$), 169
$\|\|$	shuffle, 183
$\|\|\|$	fair shuffle, 183
$\|\| d \|\|$	norm (of decomposition d), 198
$\|\|\|_{i\in[n]}$	n-ary fair shuffle, 205
$\|\|_{i\in[n]}$	n-ary shuffle, 205
$\|\|^{\Gamma}$	S-shuffle on Γ, 207
$\|\|\|^{\Gamma}$	fair S-shuffle on Γ, 207
$\mathrm{alph}(L)$	alphabet (of a language L), 208
${}_{\Sigma_1}\underline{\|\|}_{\Sigma_2}$	fS-shuffle w.r.t. Σ_1 and Σ_2, 208
${}_{\Sigma_1}\underline{\|\|\|}_{\Sigma_2}$	fair fS-shuffle w.r.t. Σ_1 and Σ_2, 208
${}_{\Sigma_1}\underline{\|\|}^{\Gamma}_{\Sigma_2}$	rS-shuffle on Γ w.r.t. Σ_1 and Σ_2, 209
${}_{\Sigma_1}\underline{\|\|\|}^{\Gamma}_{\Sigma_2}$	fair rS-shuffle on Γ w.r.t. Σ_1 and Σ_2, 209
$\|\|\|^{\Gamma}_{i\in[n]}$	n-ary fair S-shuffle on Γ, 227
$\|\|^{\Gamma}_{i\in[n]}$	n-ary S-shuffle on Γ, 227
$\underline{\|\|\|}_{\bigcup_{i\in[n]}\Sigma_i}$	n-ary fair fS-shuffle w.r.t. $\bigcup_{i\in[n]}\Sigma_i$, 228
$\underline{\|\|}_{\bigcup_{i\in[n]}\Sigma_i}$	n-ary fS-shuffle w.r.t. $\bigcup_{i\in[n]}\Sigma_i$, 228
$\underline{\|\|\|}^{\Gamma}_{\bigcup_{i\in[n]}\Sigma_i}$	n-ary fair rS-shuffle on Γ w.r.t. $\bigcup_{i\in[n]}\Sigma_i$, 228
$\underline{\|\|}^{\Gamma}_{\bigcup_{i\in[n]}\Sigma_i}$	n-ary rS-shuffle on Γ w.r.t. $\bigcup_{i\in[n]}\Sigma_i$, 228

7. Team Automata, I/O Automata, Petri Nets

$\mathcal{I}$	index set, 233
$\mathcal{C}_i$	component automaton, 233
Σ_i	set of actions (of $\mathcal{C}_i$), 233
$\mathcal{S}$	composable system, 233
$\mathcal{T}$	team automaton, 233

Σ	set of actions (of $\mathcal{T}$), 233
Σ_{ext}	set of external actions (of $\mathcal{T}$), 233
Σ_{loc}	set of locally-controlled actions (of $\mathcal{T}$), 233
Θ	arbitrary alphabet disjoint from set Q of states (of $\mathcal{T}$), 233
$\mathcal{S}$	compatible system, 237
$\mathcal{T}$	team I/O automaton, 239
IOCA	$\{\mathbf{B}_{\mathcal{C}}^{\Gamma} \mid \Gamma$ is an alphabet and $\mathcal{C}$ is a finite input-enabling component automaton with alphabet $\Gamma\}$, 240
IOCA^{alph}	$\{\mathbf{B}_{\mathcal{C}}^{alph} \mid \mathcal{C}$ is a finite input-enabling component automaton$\}$ (with $alph \in \{inp, out, int, ext, loc\}$), 240
$\Delta_a^v(\mathcal{S})$	complete vector transition space (of a in $\mathcal{S}$), 245
$\underline{a}$	vector action a, 245
$\mathcal{T}^v$	vector team automaton, 245
δ^v	set of labeled vector transitions (of $\mathcal{T}^v$), 245
$\delta_{\underline{a}}^v$	set of vector $\underline{a}$-transitions (of $\mathcal{T}^v$), 245
$SUB_J(\mathcal{T}^v)$	the subteam of $\mathcal{T}^v$ determined by J, 246
$\mathcal{T}_F^v$	the flattened version (of $\mathcal{T}^v$), 247
$tFree(\mathcal{T}^v)$	set of truly *free* actions (of $\mathcal{T}^v$), 250
$tAI(\mathcal{T}^v)$	set of truly *ai* actions (of $\mathcal{T}^v$), 250
$tSI(\mathcal{T}^v)$	set of truly *si* actions (of $\mathcal{T}^v$), 250
Λ	empty word vector, 252
$\mathrm{tot}\,(\{\Delta_j \mid j \in J\})$	total vector alphabet (over $\{\Delta_j \mid j \in J\}$), 252
Δ^u	subset of uniform vector letters of vector alphabet Δ, 252
$v \circ w$	component-wise concatenation (of two n-dimensional vector letters v and w), 252
coll	collapse of a sequence of vector letters into a word vector, 252
$\mathrm{und}(\mathcal{T}^v)$	underlying vector automaton (of $\mathcal{T}^v$), 253
$\mathbf{V}_{\mathcal{T}^v}$	finitary vector behavior (of $\mathcal{T}^v$), 253
$\mathbf{V}_{\mathcal{T}^v}^{\omega}$	infinitary vector behavior (of $\mathcal{T}^v$), 253
$\mathbf{V}_{\mathcal{T}^v}^{\infty}$	vector behavior (of $\mathcal{T}^v$), 253
$\mathcal{N}$	n-VLITN, 254
P	finite set of places (of $\mathcal{N}$), 254
T	finite set of events (of $\mathcal{N}$), 254
O	finite set of n integers, called tokens (of $\mathcal{N}$), 254
F	flow function (of $\mathcal{N}$), 254
V	vector alphabet of vector labels (of $\mathcal{N}$), 255
ℓ	event labeling homomorphism (of $\mathcal{N}$), 255
$\mathrm{use}\,(t)$	set of tokens used (by event t), 255
$\mathbf{M}_{\mathcal{N}}$	set of all markings of $\mathcal{N}$, 255
$\mu[t\rangle_{\mathcal{N}}$	enabled (an event t of $\mathcal{N}$ at a marking μ of $\mathcal{N}$), 256
$\mu[t\rangle_{\mathcal{N}}\nu$	fires (an event t of $\mathcal{N}$ from a marking μ of $\mathcal{N}$ to a marking ν of $\mathcal{N}$), 256

$\mu_0[t_1t_2\cdots t_m\rangle_{\mathcal{N}}$	firing sequence (of events $t_1, t_2, \ldots, t_m$) of $\mathcal{N}$ starting from μ_0, 256
$\mu_0[t_1t_2\cdots t_m\rangle_{\mathcal{N}}\mu_m$	firing sequence (of events $t_1, t_2, \ldots, t_m$) of $\mathcal{N}$ starting from μ_0 and leading to μ_m, 256
$\mu_0[t_1t_2\cdots\rangle_{\mathcal{N}}$	infinite firing sequence (of events $t_1, t_2, \ldots$) of $\mathcal{N}$ starting from μ_0, 256
$\mathcal{K}$	n-ITNC, 256
und($\mathcal{K}$)	underlying n-VLITN (of $\mathcal{K}$), 256
$\mathcal{M}_0$	set of initial markings (of $\mathcal{K}$), 256
$\mathcal{M}_f$	set of final markings (of $\mathcal{K}$), 256
$\mathbf{FS}_{\mathcal{K}}$	set of all firing sequences (of $\mathcal{K}$), 257
$\mathbf{M}_{\mathcal{K}}$	the set of all reachable markings (of $\mathcal{K}$), 257
$\mathbf{B}_{\mathcal{K}}$	behavior of $\mathcal{K}$, 257
$\mathbf{V}_{\mathcal{K}}$	vector behavior of $\mathcal{K}$, 257
carrier ($\underline{a}$)	carrier (of $\underline{a}$), 260
$PN(\mathcal{T}^v)$	ITNC obtained from $\mathcal{T}^v$, 261
$SUB_J(\mathcal{K})$	the subnet (of $\mathcal{K}$) determined by J, 270

8. Applying Team Automata

$\mathcal{I}$	index set, 278
$\mathcal{C}_i$	component automaton, 278
$\Sigma_{i,ext}$	set of external actions (of $\mathcal{C}_i$), 278
$\mathcal{S}$	composable system, 278
$\mathcal{T}$	team automaton, 278
Σ	set of actions (of $\mathcal{T}$), 278
Σ_{ext}	set of external actions (of $\mathcal{T}$), 278
$\mathcal{C}_H^{\Delta}$	the Δ-hiding version (of $\mathcal{C}$), 278
Σ_{com}	set of communicating actions (in $\mathcal{S}$), 279
$\boxed{\mathcal{T}}$	(communication) closed version (of $\mathcal{T}$), 279
$\mathcal{C}_N^h$	h-renamed version (of $\mathcal{C}$), 280

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