Team Automata: Overview and Roadmap

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Outline

- History of Team Automata
- Team Automata and other Coordination Models
- Recent Results
  - **ICTAC20** Compositionality of Safe Communication in Systems of Team Automata
    Extended Team Automata
  - **FM21** Featured Team Automata
  - **FM23** Can we Communicate? Using Dynamic Logic to Verify Team Automata
    Model Check Team Automata
  - **ICTAC23** Realisability of Global Models of Interaction
    Realisable Team Automata
- Future Work

History of Team Automata

Team Automata

A formalism for interacting component-based systems, whereby multiple sending and receiving actions from concurrent automata can synchronise on certain executions

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Inspired by Input/Output (I/O) automata, inheriting the distinction between internal and external (input and output) actions used for communication with the environment

Technically, an extension of I/O automata, imposing hardly any restrictions on the role of actions in components and composition is not limited to the synchronous product

Selected Publications from 25+ Years

2023	Realisability of Global Models of Interaction	ICTAC'23
2023	Overview on Constrained Multiparty Synchronisation in Team Automata *	FACS'23
2023	Can we Communicate? Using Dynamic Logic to Verify Team Automata	FM'23
2021	Featured Team Automata	FM'21
2020	Compositionality of Safe Communication in Systems of Team Automata	ICTAC'20
2020	Team Automata@Work: On Safe Communication	COORDINATION'20
2017	Communication Requirements for Team Automata	COORDINATION'17
2016	Conditions for Compatibility of Components: The Case of Masters and Slaves	ISoLA'16
2014	On Distributed Cooperation and Synchronised Collaboration	JALC
2013	Compatibility in a multi-component environment *	TCS
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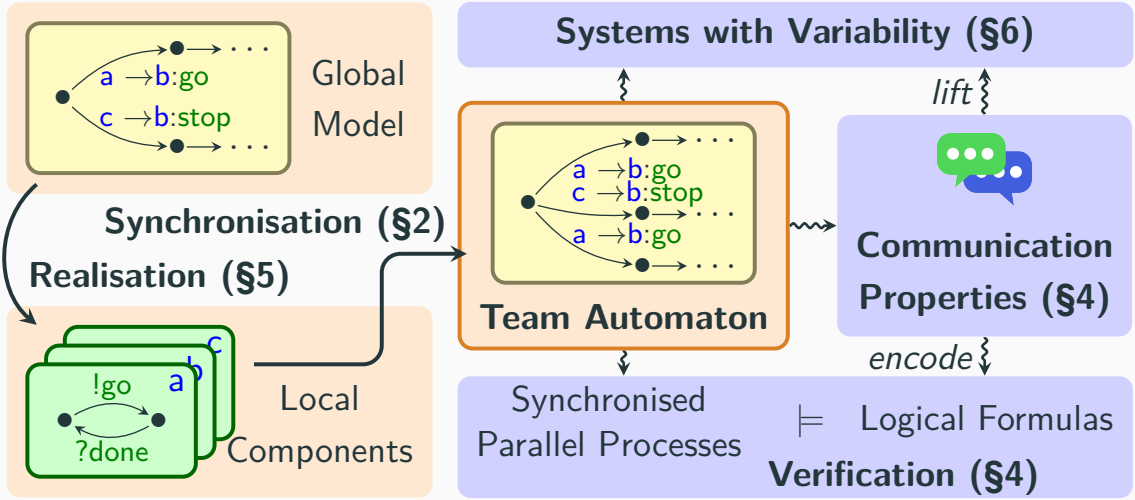
Coordination Formalisms and Aspects Analysed in the Paper

Coordination Formalism (Sections 2 & 3)	Communication Properties (Section 4)	Realisability (Section 5)	Verification (Sections 4 & 4)	Supporting Tools (Sections 3, 4 & 5)	Variability (Section 6)	Data (Section 6)
Team Automata	✓	✓	✓	✓	✓	
Reo via Port Automata			✓	✓	✓	✓
BIP			✓	✓	✓	✓
Contract Automata	✓	✓	✓	✓	✓	
Choreography Automata	✓	✓	✓	✓		
Multi-Party Session Types		✓	✓		✓	✓

Team Automata Aspects Addressed in the Paper



Team Automata by Example

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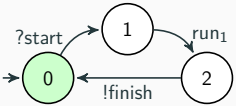

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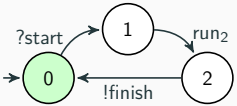

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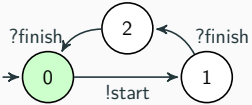

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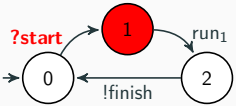

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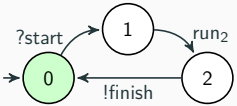

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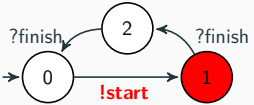

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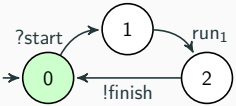

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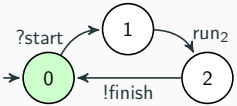

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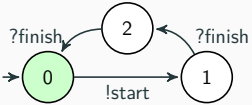

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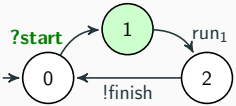

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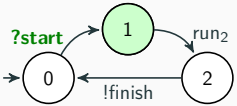

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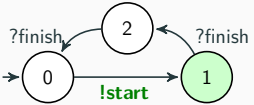

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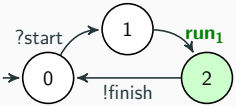

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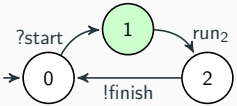

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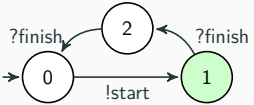

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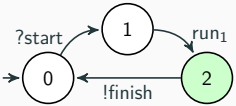

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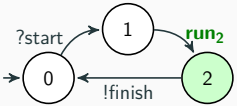

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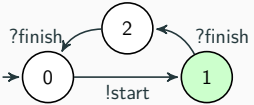

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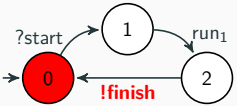

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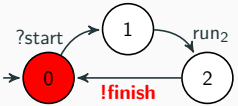

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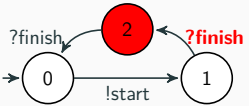

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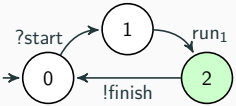

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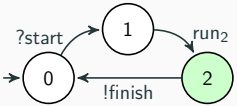

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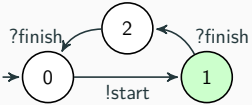

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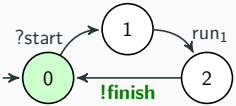

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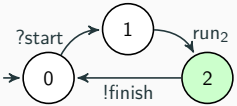

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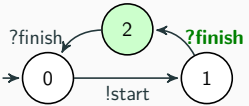

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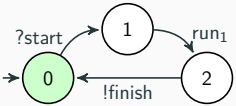

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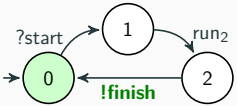

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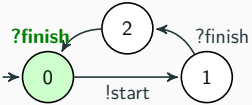

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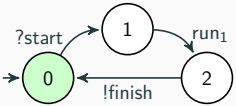
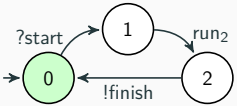
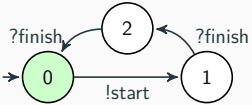
Extended Team Automata: Constrained Multiparty Synchronisations



$\mathcal{R}unner_1$



$\mathcal{R}unner_2$

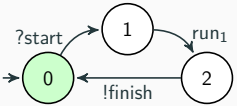


Controller

Extended TA synchronisations:

[CSCW'01'03] [FM'03,'21,'23] [TCS'12'13]
[COORDINATION'17,'20] [ICTAC'20,'23]

Extended Team Automata: Constrained Multiparty Synchronisations



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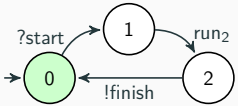
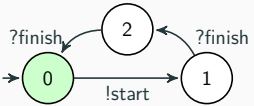


$\mathcal{R}unner_2$



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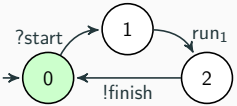
multiparty

Ctr $\rightarrow \{R1, R2\}$: start

Extended Team Automata: Constrained Multiparty Synchronisations



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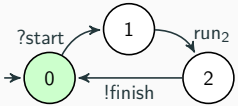
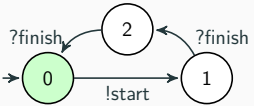


$\mathcal{R}unner_2$



Controller

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multiparty

Ctr $\rightarrow \{R1, R2\}$: start

constrained

start: $1 \rightarrow 2$
finish: $1 \rightarrow 1$

Extended Team Automata and other Coordination Models

Overview on Constrained Multiparty Synchronisation in Team Automata

and other coordination models:

J. Proença, Overview on Constrained Multiparty Synchronisation in Team Automata @ FACS'23

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Runners with orchestrators

- Reo
- BIP

↳ S.-S.T.Q. Jongmans and F. Arbab, Overview of thirty semantic formalisms for Reo. *Scientific Annals of Computer Science* 22 (2012)

S. Bliudze and J. Sifakis, The algebra of connectors: structuring interaction in BIP. *IEEE Transactions on Computers* 57 (2008)

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Runners with choreographies

- Choreography Automata
- Multiparty Session Types

↳ F. Barbanera, I. Lanese, and E. Tuosto, Choreography Automata @ COORDINATION'20

S. Ghilezan, S. Jakšić, J. Pantović, A. Scalas, and N. Yoshida, Precise subtyping for synchronous multiparty sessions. *JLAMP* 104 (2019)

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. . . with both

- Contract Automata

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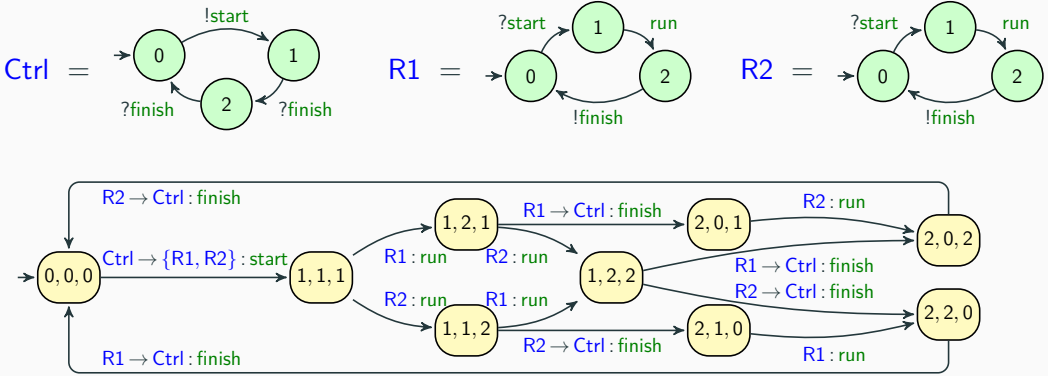
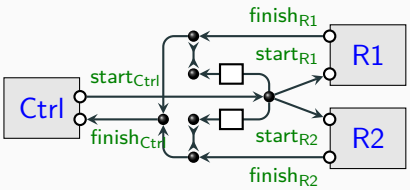
In the paper we discuss for each formalism (1) the definition, means of (2) composition (via synchronisation), (3) a model of the Race example, (4) a brief relation with team automata, and (5) tool support

Team Automata

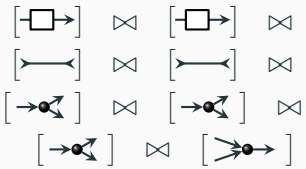
In the paper we discuss for each formalism (1) the definition, means of (2) composition (via synchronisation), (3) a model of the Race example, (4) a brief relation with team automata, and (5) tool support



Reo via Port Automata



- Focus on connectors (not on components)
- Connectors built compositionally
- Components should be flexible/compatible



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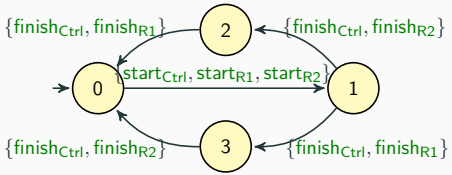
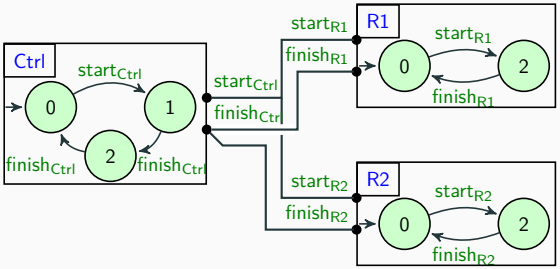


(semantics as a port automaton, after hiding internal ports shared among sub-connectors)

BIP without Priorities



$$\mathbb{N} = \{\mathsf{Ctrl}, \mathsf{R1}, \mathsf{R2}\}$$

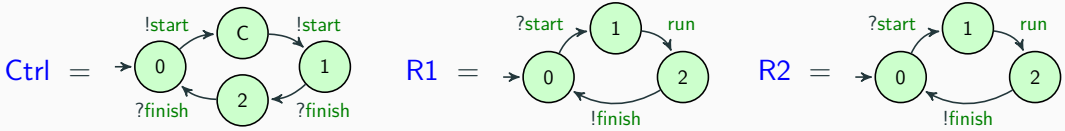
$$BP = (\{B_{\mathsf{Ctrl}}, B_{\mathsf{R1}}, B_{\mathsf{R2}}\}\ ,\ I)$$

$$I = \left\{ \begin{array}{l} \{\mathsf{start}_{\mathsf{Ctrl}}, \mathsf{start}_{\mathsf{R1}}, \mathsf{start}_{\mathsf{R2}}\}, \\ \{\mathsf{finish}_{\mathsf{Ctrl}}, \mathsf{finish}_{\mathsf{R1}}\}, \\ \{\mathsf{finish}_{\mathsf{Ctrl}}, \mathsf{finish}_{\mathsf{R2}}\} \end{array} \right\}$$

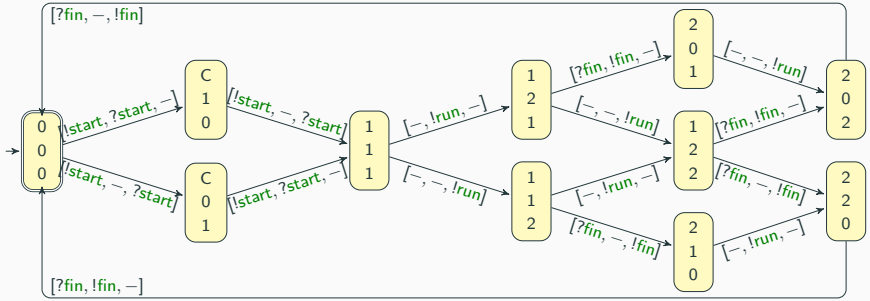
- Components expose ports
- Interactions restrict which ports can fire
- Constructors using unicast (●) and broadcast (▲) can be used to restrict interactions
- Dataflow can be added

(individual components labelled by actions, restricted to the interactions allowed by I)

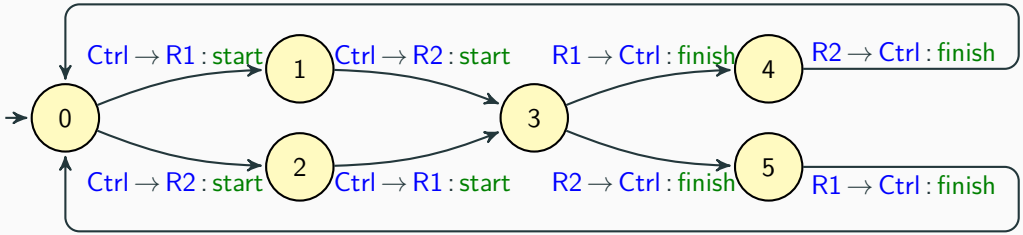
Contract Automata



(**C**ommitted states: whenever the intermediate state of two concatenated transitions is committed, the two transitions are executed atomically)



Choreography Automata



(without internal run actions)

- Similar to contract automata
- Several results over the language of CA
- Realising = Projecting the language of CA

$$\mathcal{G} = \mathsf{Ctrl} \to \mathsf{R1} : \mathsf{start}.\mathsf{Ctrl} \to \mathsf{R2} : \left\{ \begin{array}{l} \mathsf{start}_1.(\mathsf{R1} \to \mathsf{Ctrl} : \mathsf{finish}.\mathsf{R2} \to \mathsf{Ctrl} : \mathsf{finish}.\mathcal{G}), \\ \mathsf{start}_2.(\mathsf{R2} \to \mathsf{Ctrl} : \mathsf{finish}.\mathsf{R1} \to \mathsf{Ctrl} : \mathsf{finish}.\mathcal{G}) \end{array} \right\}$$

$$\mathcal{S} = \mathsf{Ctrl} \rhd \mathcal{L}_{\mathsf{Ctrl}} \parallel \mathsf{R1} \rhd \mathcal{L}_{\mathsf{R1}} \parallel \mathsf{R2} \rhd \mathcal{L}_{\mathsf{R2}}$$

$$\mathcal{L}_{\mathsf{Ctrl}} = \mathsf{R1}!\mathsf{start}.\mathsf{R2}!\left\{\mathsf{start}_1.(\mathsf{R1}?\mathsf{finish}.\mathsf{R2}?\mathsf{finish}.\mathcal{L}_{\mathsf{Ctrl}})\,,\ \mathsf{start}_2.(\mathsf{R2}?\mathsf{finish}.\mathsf{R1}?\mathsf{finish}.\mathcal{L}_{\mathsf{Ctrl}})\right\}$$

$$\mathcal{L}_{\mathsf{R1}} = \mathsf{Ctrl}?\mathsf{start}.\mathsf{Ctrl}!\mathsf{finish}.\mathcal{L}_{\mathsf{R1}}$$

$$\mathcal{L}_{\mathsf{R2}} = \mathsf{Ctrl}?\left\{\mathsf{start}_1.\mathsf{Ctrl}!\mathsf{finish}.\mathcal{L}_{\mathsf{R2}}\,,\ \mathsf{start}_2.\mathsf{Ctrl}!\mathsf{finish}.\mathcal{L}_{\mathsf{R2}}\right\}$$

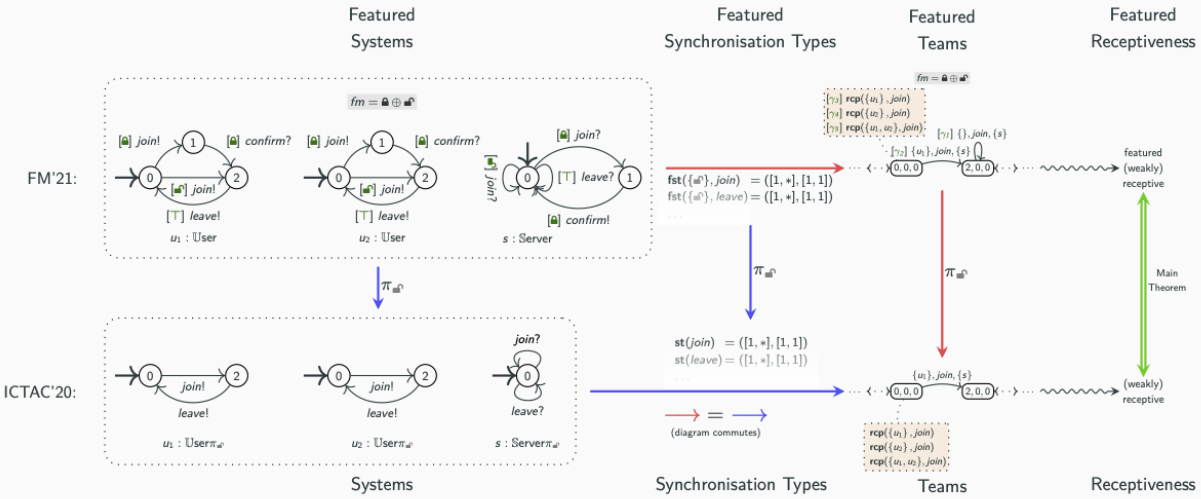
(using only binary synchronisation and
using distinct start_1 and start_2 to differentiate the choice in the branch)

- Use projections for realisation
- Often impose syntactic restrictions on global types

Recent Results

Featured Team Automata

Featured Extended Team Automata (fETA)

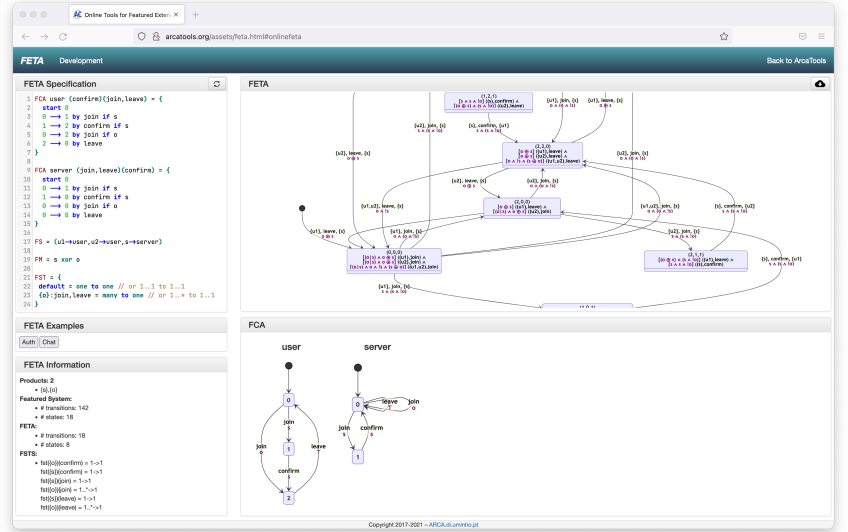


Online prototype: `http://arcatools.org/feta`

Online Prototype: `http://arcatools.org/feta`

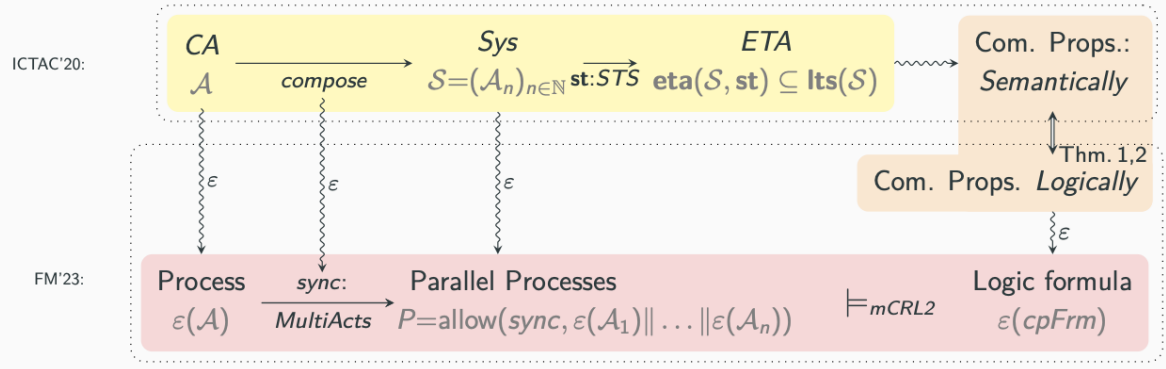
- Specify
- Generate*
- Visualise
- Statistics

*SAT solver to solve *fm*



Model Check Team Automata

Safe communication: receptiveness (*no message loss*) & responsiveness (*no indefinite waiting*)



Online Prototype: https://github.com/arcalab/team-a

ETA Specification

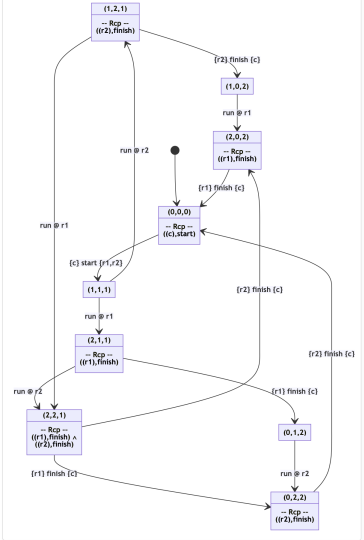
```
1  //Race example
2  CA runner (start)
3                (finish) = {
4    start 0
5    0 --> 1 by start
6    1 --> 2 by run
7    2 --> 0 by finish
8  }
9  CA controller (finish)
10                 (start) = {
11   start 0
12   0 --> 1 by start
13   1 --> 2 by finish
14   2 --> 0 by finish
15 }
16 S = (r1:runner, r2:runner,
17      c:controller)
18 STS = {
19   default = 1 to 1
20   start = 1 to 2
21 }
```

Race example

ETA Examples

Simple | Race | Chat

ETA diagram



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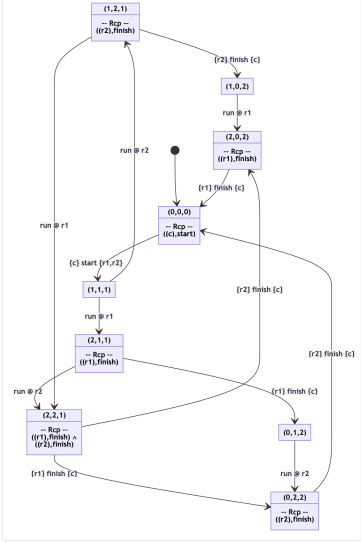
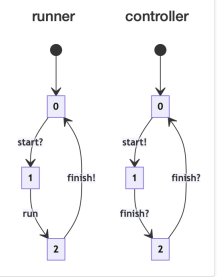


CA



Online Prototype: `https://github.com/arcalab/team-a`

Communication Properties' Characterisation in mCRL2

Receptiveness:

```
[ (r1_finish|c_finish + r2_run + c_start|r1_start|r2_start + r2_finish|c_finish + r1_run)* ](
  ((<c_start> true)  =>  (<c_start|r1_start|r2_start> true)) &&
  ((<r1_finish> true)  =>  (<r1_finish|c_finish> true)) &&
  ((<r2_finish> true)  =>  (<r2_finish|c_finish> true))
)
```

Responsiveness:

```
[ (r1_finish|c_finish + r2_run + c_start|r1_start|r2_start + r2_finish|c_finish + r1_run)* ](
   (<c_finish +
     r1_start|r2_start> true)
   =>
   (<r1_finish|c_finish +
     c_start|r1_start|r2_start +
     r2_finish|c_finish> true)
)
```

Weak Receptiveness:

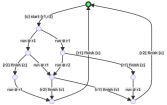
```
[ (r1_finish|c_finish + r2_run + c_start|r1_start|r2_start + r2_finish|c_finish + r1_run)* ](
  ((<r1_finish> true)  =>  (<(r2_run+r2_finish|c_finish)* . r1_finish|c_finish> true)) &&
  ((<r2_finish> true)  =>  (<(r1_finish|c_finish+r1_run)* . r2_finish|c_finish> true)) &&
  ((<c_start> true)  =>  (<(r2_run+r1_run)* . c_start|r1_start|r2_start> true))
)
```

Weak Responsiveness:

```
[ (r1_finish|c_finish + r2_run + c_start|r1_start|r2_start + r2_finish|c_finish + r1_run)* ](
   (<c_finish +
     r1_start|r2_start> true)
   =>
   (<(r2_run+r1_run)* . r1_finish|c_finish +
     c_start|r1_start|r2_start +
     (r2_run+r1_run)* . r2_finish|c_finish> true)
)
```

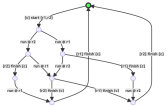
View mCRL2 evidence

Receptiveness: true

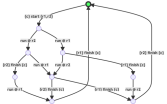


Responsiveness: false

Weak Receptiveness: true



Weak Responsiveness: true



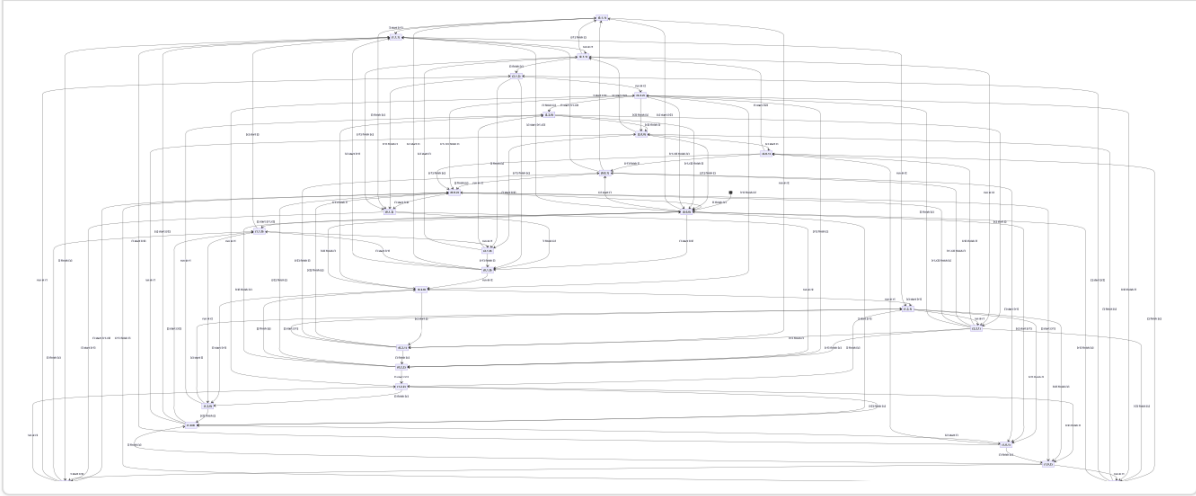
Online Prototype: https://github.com/arcalab/team-a

mCRL2 full system:

```
act
   r1_start,c_finish,r2_run,c_start,r2_finish,r2_start,r1_finish,r1_run;
proc
   r1(s:Int) =
     (s == 2) -> ( r1_finish.r1(0) ) +
     (s == 1) -> ( r1_run.r1(2) ) +
     (s == 0) -> ( r1_start.r1(1) );
   r2(s:Int) =
     (s == 2) -> ( r2_finish.r2(0) ) +
     (s == 1) -> ( r2_run.r2(2) ) +
     (s == 0) -> ( r2_start.r2(1) );
   c(s:Int) =
     (s == 2) -> ( c_finish.c(0) ) +
     (s == 1) -> ( c_finish.c(2) ) +
     (s == 0) -> ( c_start.c(1) );
init
   allow({
     r1_start,
     c_finish,
     c_start|r2_start,
     c_start,
     c_start|r2_start|r1_start,
     r2_finish|r1_finish,
     c_finish|r2_finish,
     r2_finish,
     r2_start,
     r1_finish,
     c_start|r1_start,
     r1_run,
     c_finish|r2_finish|r1_finish,
     r2_run,
     r2_start|r1_start,
     c_finish|r1_finish},
   r1(0) || r2(0) || c(0));
```

Online Prototype: https://github.com/arcalab/team-a

System diagram



Realisable Team Automata

Challenge

How to check if a global model is realisable and, if it is, how to synthesise a realisation?

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$$\mathcal{M} \textit{ realised by } \mathcal{S} = (\mathcal{M}_i)_{i \in \mathcal{I}} ?$$

Solutions typically impose syntactic restrictions on global types, using projections to obtain local models:

F. Barbanera, I. Lanese, and E. Tuosto, Formal Choreographic Languages @ COORDINATION'22

M. Hüttel et al., Foundations of Session Types and Behavioural Contracts. *ACM Comput. Surv.* 49 (2016)

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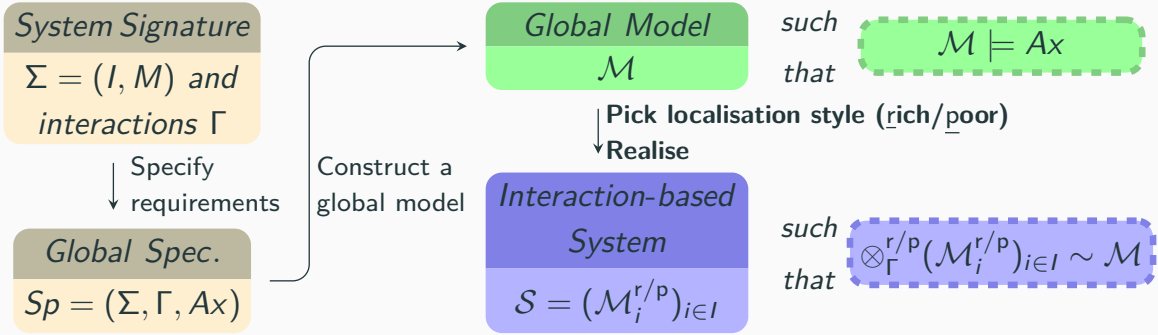
$$\otimes(\mathcal{M}_i)_{i \in \mathcal{I}} \models Sp \, ?$$

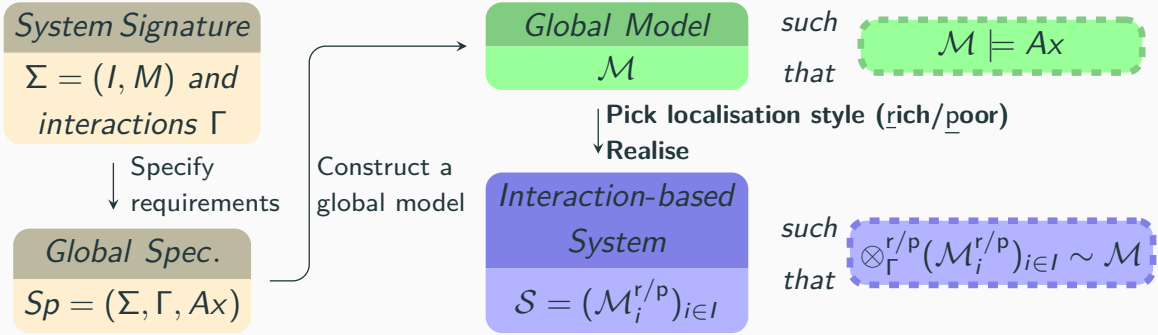
Alternatively, provide a specification in some logical formalism, and construct local models from scratch:

R. Hennicker, Role-Based Development of Dynamically Evolving Esembles @ WADT'18

Contributions ICTAC'23



Contributions ICTAC'23



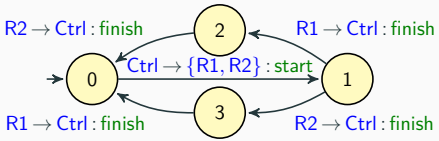
Multi-interactions

rich (à la multi-party session types, choreography languages) $i \to j : m \Rightarrow$ local output action $ij!m$ for i and local input action $ij?m$ for j

poor (à la component-based I/O development, loose coupling) $i \to j : m \Rightarrow$ local output action $!m$ for i and local input action $?m$ for j

Example

$$\Gamma_{\text{Race}} = \left\{ \begin{array}{l} \text{Ctrl} \to \{\text{R1}, \text{R2}\} : \text{start}\,, \\ \text{R1} \to \text{Ctrl} : \text{finish}\,, \\ \text{R2} \to \text{Ctrl} : \text{finish} \end{array} \right\}$$



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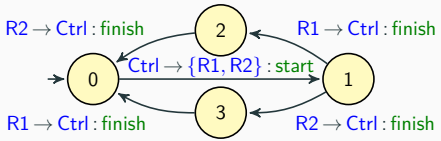
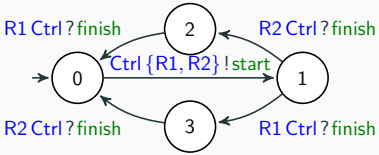
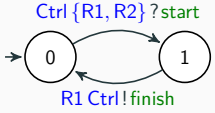
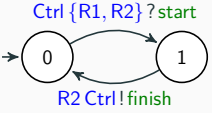
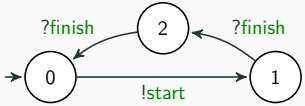
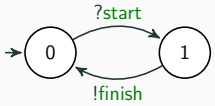
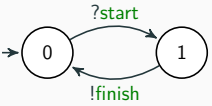
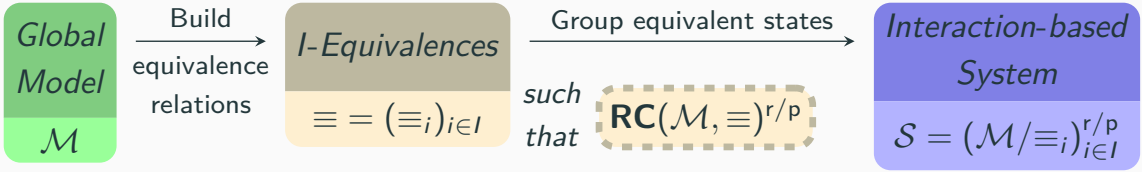


Localisation	Local Ctrl	Local R1	Local R2
Rich			
Poor			

Check Realisability and System Synthesis



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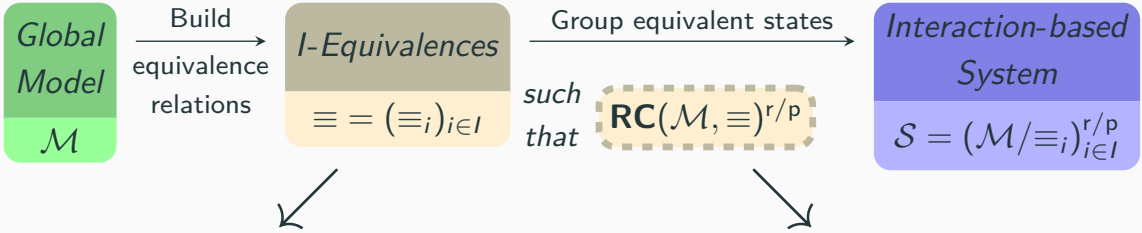

I. Castellani, M. Mukund, and P.S. Thiagarajan,
Synthesizing Distributed Transition Systems
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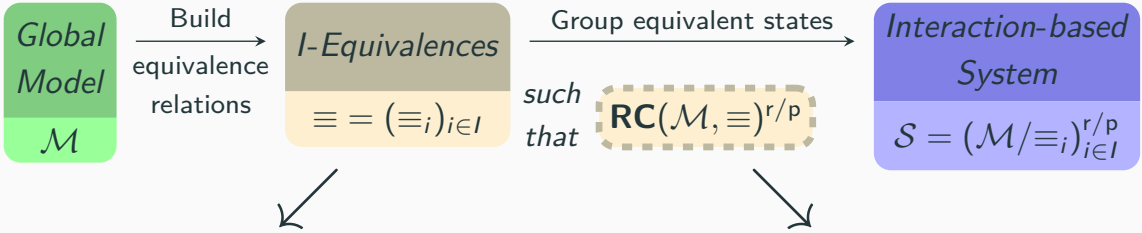

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Theorems 2/3

If $RC(\mathcal{M}, \equiv)^{r/p}$ holds, then $\mathcal{M} \sim \otimes^{r/p}_{\Gamma}((\mathcal{M}/\equiv_i)^{r/p})_{i \in I}$

Novelty

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3. To construct realisations we consider, and analyse, two different localisation styles: rich and poor local actions
4. A prototypical tool Ceta checks the realisability conditions and, if they are satisfied, generates local quotients and hence realisations

`https://github.com/arcalab/choreo/tree/ceta`

`https://lmf.di.uminho.pt/ceta`

Online Prototype: `https://lmf.di.uminho.pt/ceta`

Choreographic Extended Team Automata

Choreography

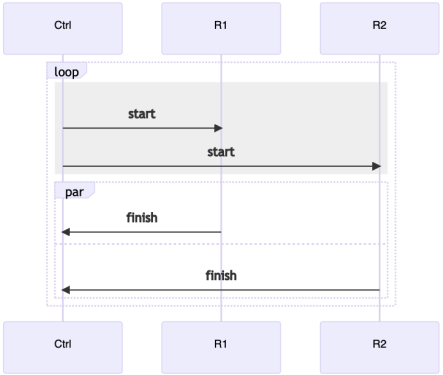
```
1 // Race example
2 (
3  (Ctrl->R1,R2: start);
4  (R1->Ctrl:finish ||
5   R2->Ctrl:finish)
6 )*
```

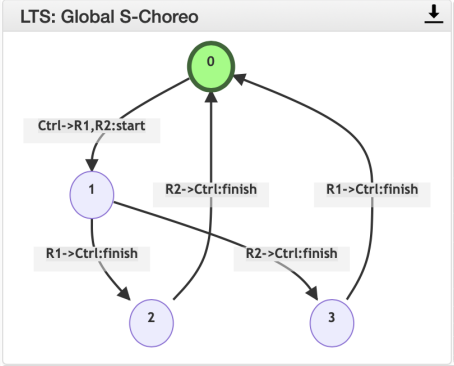
A controller starts 2 runners at the same time, and receives a finish message from each runner at a time.

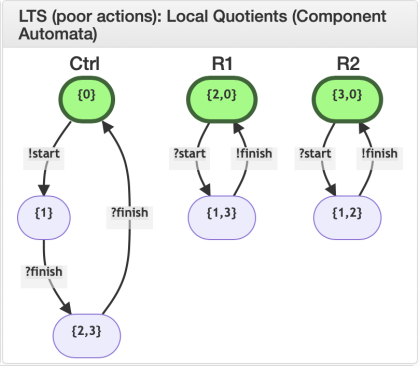
Examples

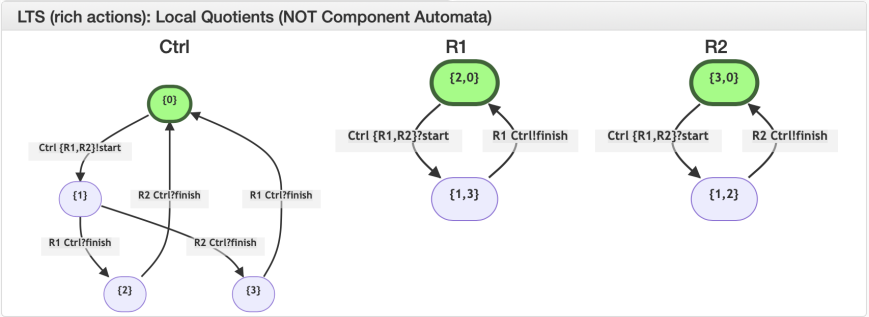
Race (simple) | Race (R1-first) | Race (once, simple) | Toss | Gossip (bad) | Gossip (good) | Cast-v1 | Cast-v2 | ab+cb+ca | ab;ac | ab|ac | ab;cd | ab|cd

Sequence Diagram




LTS: Global S-Choreo
0
Ctrl->R1,R2:start
1
R2->Ctrl:finish
R1->Ctrl:finish
R1->Ctrl:finish
R2->Ctrl:finish
2
3


LTS (poor actions): Local Quotients (Component Automata)
Ctrl
{0}
!start
{1}
?finish
?finish
{2,3}
R1
{2,0}
?start
!finish
{1,3}
R2
{3,0}
?start
!finish
{1,2}


LTS (rich actions): Local Quotients (NOT Component Automata)
Ctrl
{0}
Ctrl {R1,R2}!start
{1}
R2 Ctrl?finish
R1 Ctrl?finish
R1 Ctrl?finish
R2 Ctrl?finish
{2}
{3}
R1
{2,0}
Ctrl {R1,R2}?start
R1 Ctrl!finish
{1,3}
R2
{3,0}
Ctrl {R1,R2}?start
R2 Ctrl!finish
{1,2}

Future Work

Communication properties:

1. Consider final states to distinguish *possible* from *required* communication in case of (local) enabledness of actions (where execution can stop but may also continue, in addition to states where progress *is* required)

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Team automata with asynchronous communication?

Thanks for your attention!

Global model $\mathcal{M}$ does not satisfy $\mathbf{RC}(\mathcal{M}, \equiv)$, but $\mathcal{S} = \{\mathcal{M}_p, \mathcal{M}_q, \mathcal{M}_r\}$ does realise $\mathcal{M}$:

global $\mathcal{M}$	local $\mathcal{M}_p$	local $\mathcal{M}_q$	Local $\mathcal{M}_r$	$\mathbf{ta}(\mathcal{S}, \mathbf{st})$