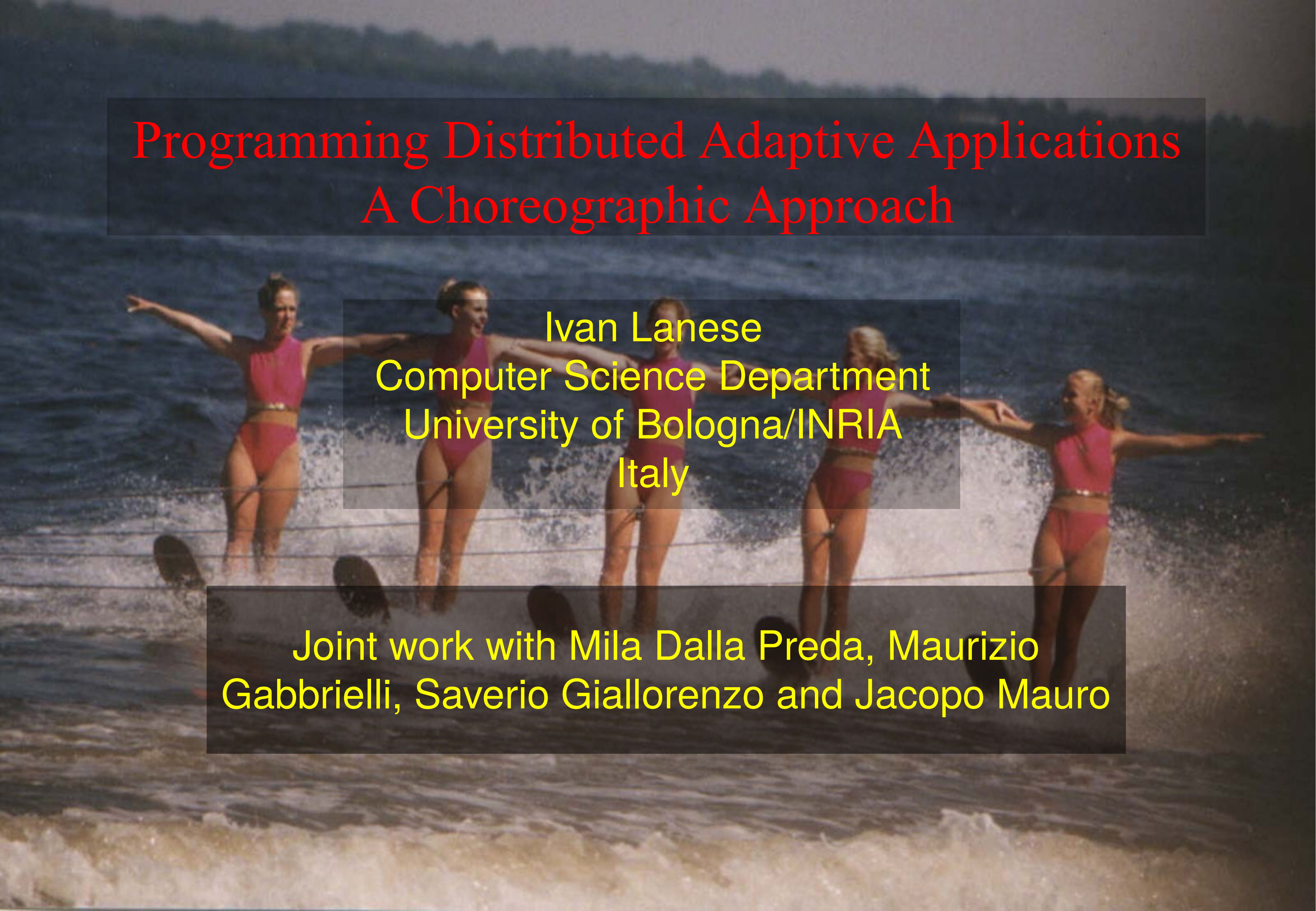


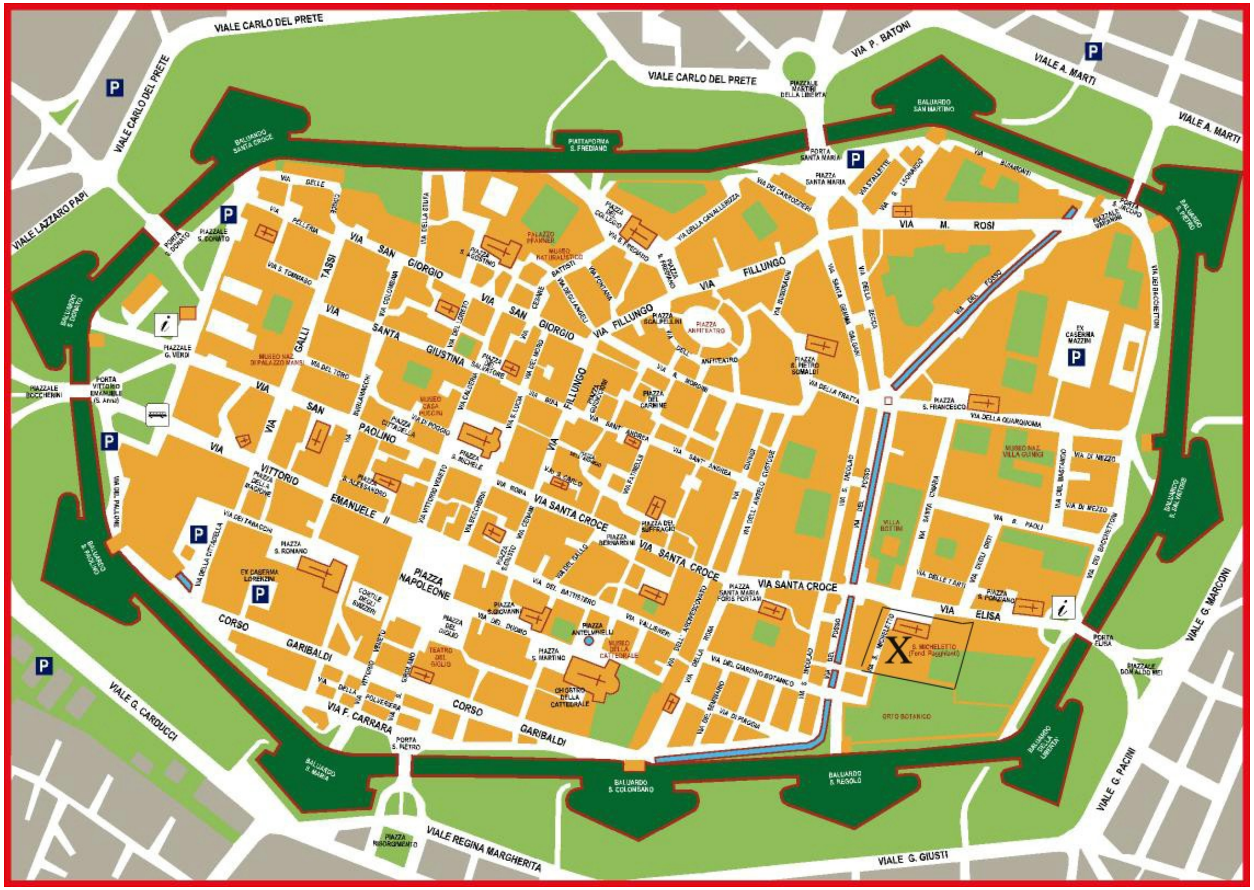
Programming Distributed Adaptive Applications
A Choreographic Approach

Ivan Lanese
Computer Science Department
University of Bologna/INRIA
Italy

Joint work with Mila Dalla Preda, Maurizio Gabbrielli, Saverio Giallorenzo and Jacopo Mauro

Map of the talk

- Choreographic programming
- Dynamic updates
- Conclusion



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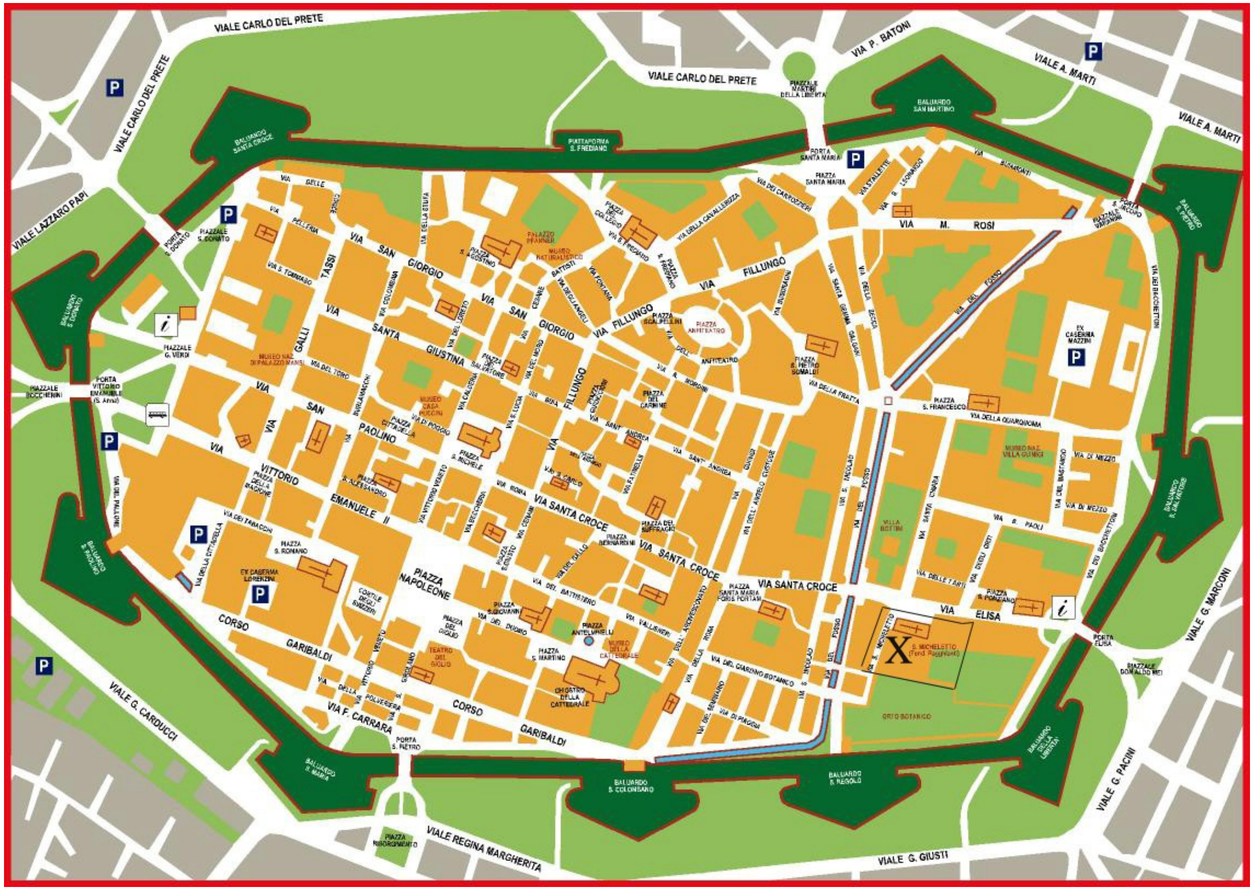

Programming distributed applications

- Distributed applications are composed by many nodes
- Each node executes a program, possibly different from the ones executing on the other nodes
- The nodes interact by exchanging messages
  - Main primitives: send and receive of a message
- Distributed applications are everywhere
  - Facebook, google, expedia, …
  - Banking applications, online shops, ...

Distributed programming: pitfalls

- Programming distributed applications is difficult and error-prone
- Deadlocks: a process waits for a message that will never arrive
- Orphan messages: a message is sent to a target not expecting it
- Races: two messages are expected in a given order, but may arrive in a different one
- (Same problems also in message-based concurrent programming)

Choreographic programming: aim

- Choreographic programming aims at avoiding these pitfalls
- Pitfalls due to a mismatch between send and receive
- Solution: send and receive cannot be written in isolation, but only composed inside an interaction
- An interaction is a communication between two participants:

$$\mathrm{op}\!: \mathrm{alice}(z+5) \rightarrow \mathrm{bob}(x)$$

Choreographic programming: basics

- A single interaction needs to be executed by two participants
  - Not just one as for standard programming language constructs
- A single choreographic program describes the behavior of a whole distributed application
- It is built by composing interactions using standard constructs: sequences, conditionals, cycles,...
- Each construct may describe the behavior of one, two, or more participants

Choreographic syntax

- C ::= o: s(e) → r(x)
  | x@r = e
  | skip
  | C ; C’
  | C | C’
  | if b@r {C} else {C’}
  | while b@r {C}

- For multiparty session types addicts
  choreographic programs ≈ global types + data + conditions

A sample choreographic program

```
product_name@client = getInput( "Insert product name" );
quote: client( product_name ) → seller( sel_product );
price@seller = getInput( "Quote " + sel_product )
```

Choreographic programming: advantages

- Unique description of the whole distributed system ⇒
  Clear view of the global behavior
- Sends and receives are paired into interactions ⇒
  No deadlocks, orphan messages nor races by construction

How to execute choreographic programs?

- A choreographic program describes the behavior of many participants
- We want to compile the choreographic program generating a local code for each participant
- When executed, the derived local codes should interact as specified in the choreographic program
  - Correctness of the compilation
  - No deadlocks, orphan messages nor races
- We specify compilation as a projection function

The target language

- P ::= o: send e to r
  | o: receive x from r
  | x = e
  | skip
  | P ; P’
  | P | P’
  | if b {P} else {P’}
  | while b {P}

- A distributed program is composed by multiple named participants each executing its own P

Projection: basic idea

- An interaction o: s(e) → r(x) is projected as
  - o: send e to r on s
  - o: receive x from s on r
  - skip on all the other participants
- Assignments x@r = e are executed by the role r
- Other constructs are projected homomorphically

- Very simple…
- …but it does not work

Projection: problems

- Actions of different participants are independent
  $o_1: s_1(5) \rightarrow r_1(x) \; ; \; o_2: s_2(7) \rightarrow r_2(y)$
- Interaction on o_2 should happen after interaction on o_1
  - No participant can force this
- The behavior of a participant may depend on the decision of another participant
  if $b@s_1$ $\{o: s_2(5) \rightarrow r(x)\}$ else $\{o: s_2(7) \rightarrow r(x)\}$
- Participant s_2 should send 5 or 7 according to a local decision of s_1

Projection: solutions

- These problems are solved by introducing auxiliary communications
- Automatically generated by the projection
- In a sequence C;C’, the participants in C notify the participants in C’ when C is finished and C’ can start
- In a conditional if b@r {C} else {C’} participant r notifies participants in C and C’ of the outcome of the choice

From abstract theory to the real world

- We implemented AIOCJ as an instance of this theory
- Choreographic programs can be written in Eclipse
- Projection generates code in the Jolie language
  - Jolie is a language for programming distributed systems
  - Follows the microservice paradigm
  - Microservices are independent entities communicating via message passing over well-defined interfaces
- The microservices can be executed, obtaining the desired behavior

Integration with Legacy Software

- In the real world applications are not built from scratch
- One uses external libraries, services (e.g., google maps), existing applications…
- We want to integrate them into our framework
- We allow invocations to external software inside expressions
- We allow the use of various technologies (sockets, bluetooth,...) and protocols (SOAP, HTML,…)
- We declare at the beginning which functions we need, where they are, and how to interact with them

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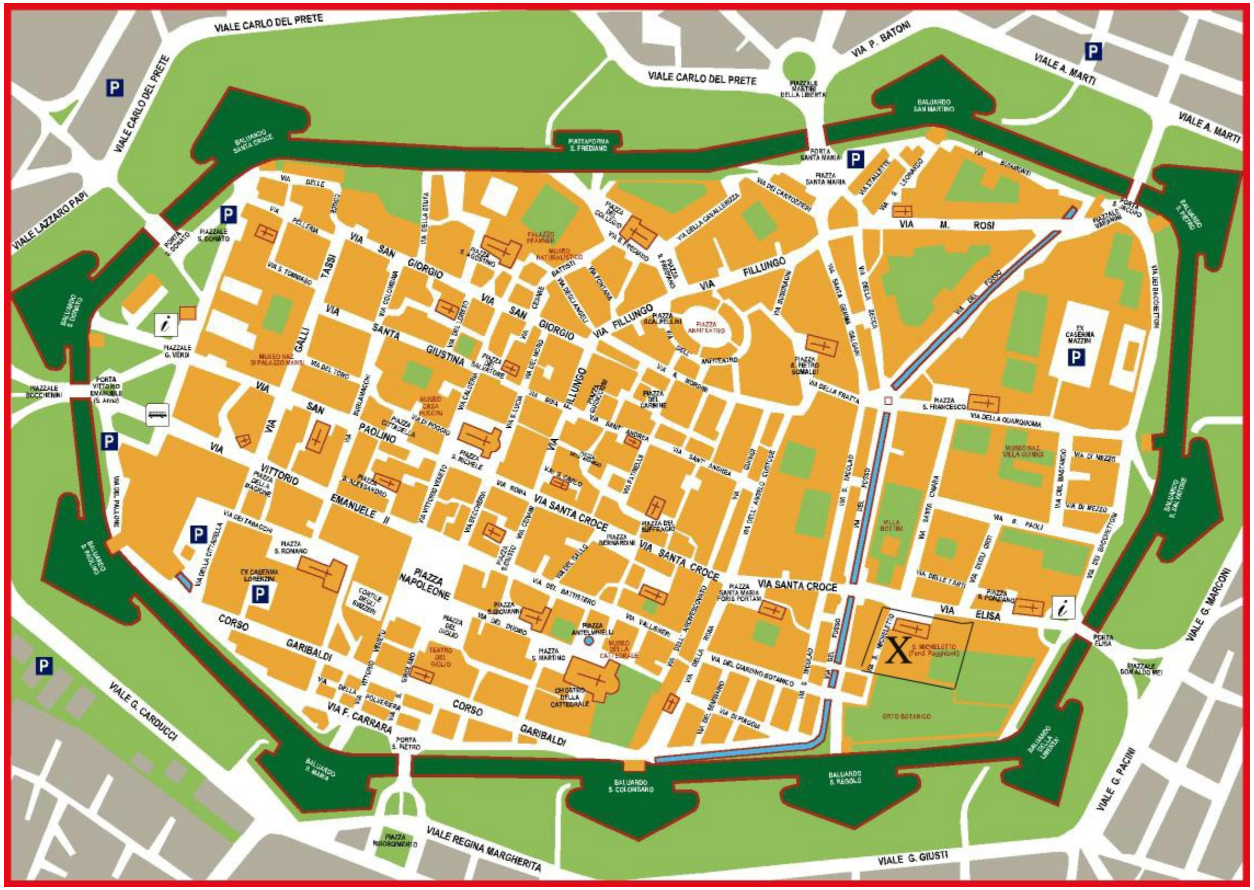


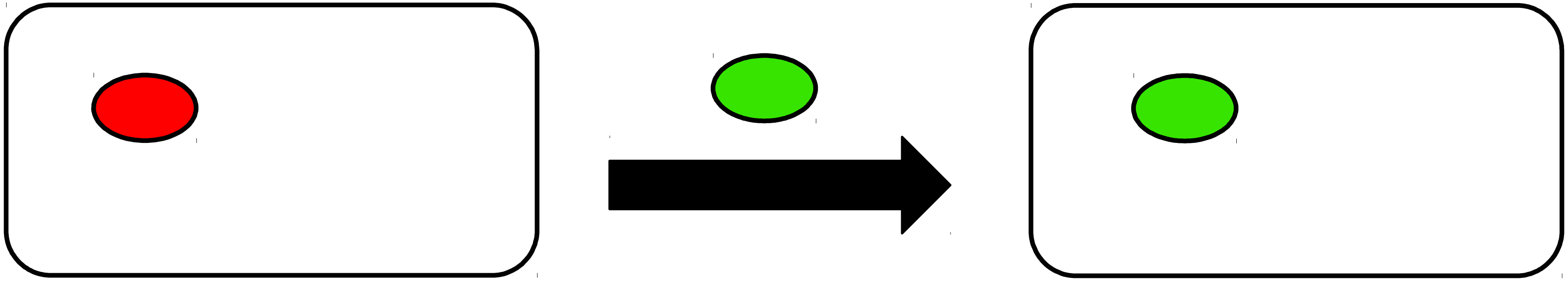
Dynamic updates

- We want to change the code of running applications, by integrating new pieces of code coming from outside
- Many possible uses
  - Deal with emergency behavior
  - Deal with changing business rules or environment conditions
  - Specialise the application to user preferences
- The external pieces of code are called updates
- External updates may arrive at any time, and disappear at any time
- Only currently available updates may be applied

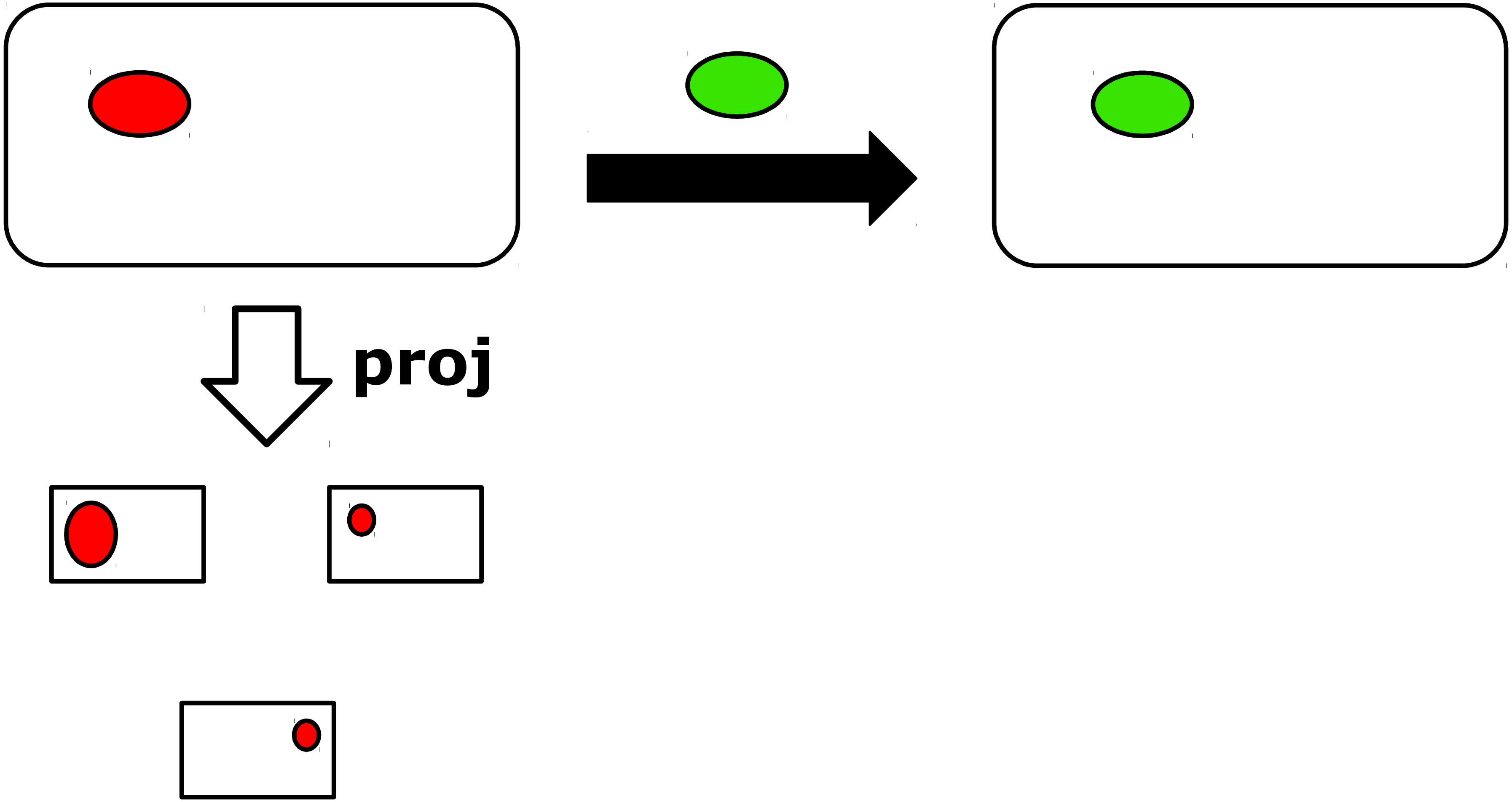
Our approach, syntactically

- Pair a running application with a set of updates
  - Each update is a choreographic program
  - The set of updates may change at any time
- At the choreographic level, the update may replace a part of the application
  - Which part?
- Extend choreographic programs with scopes
  - scope @r {C}
  - Normally executes C, but executes an update instead if a suitable one is available
  - Participant r is in charge of managing the update procedure

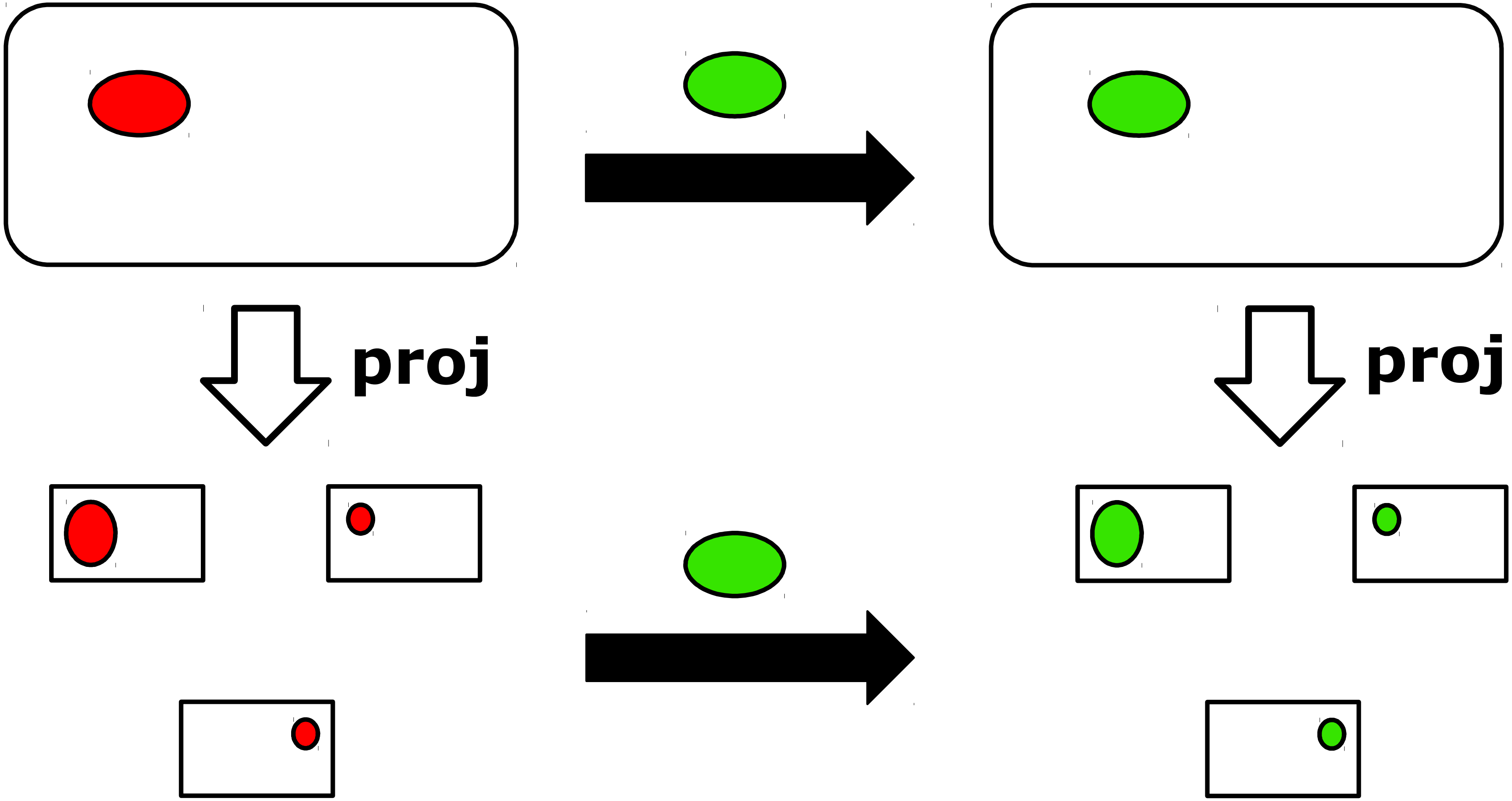
Our approach, graphically



Our approach, graphically



Our approach, graphically



Dynamic updates: challenges

- All the participants should agree on
  - whether to update a scope or not
  - in case, which update to apply
- All the participants need to retrieve (their part of) the update
  - Not easy, since updates may disappear
- No participant should start executing the code inside a scope that needs to be updated

Dynamic updates: our approach

- For each scope a single participant coordinates its execution
  - Decides whether to update it or not, and which update to apply
  - Gets the update, and sends to the other participants their part
- The other participants wait for the decision before executing the scope
- This behavior can be formalized by extending our target language, and actually programmed in practice

Results

- A choreographic program and its projection behave the same
  - They have the same set of traces (up to auxiliary actions)
  - Under all possible, dynamically changing, sets of updates
- The projected application is deadlock free, orphan message free and race free by construction

- These results are strong given that we are considering an application which is
  - distributed
  - updatable

From updates to adaptation rules

- Nondeterminstic application of updates is not practical
- We use adaptation rules composed by an update and its applicability condition
  - May refer to environment variables, scope properties, and local variables of the coordinator of the update
- A rule can be applied only if its applicability condition is satisfied
- We add properties to scopes

Back to the real world

- Adaptation managed by a dedicated middleware composed of microservices
- Rules are managed by dedicated microservices called adaptation servers
- A microservice called adaptation manager coordinates the adaptation procedure
- A microservice stores environment information

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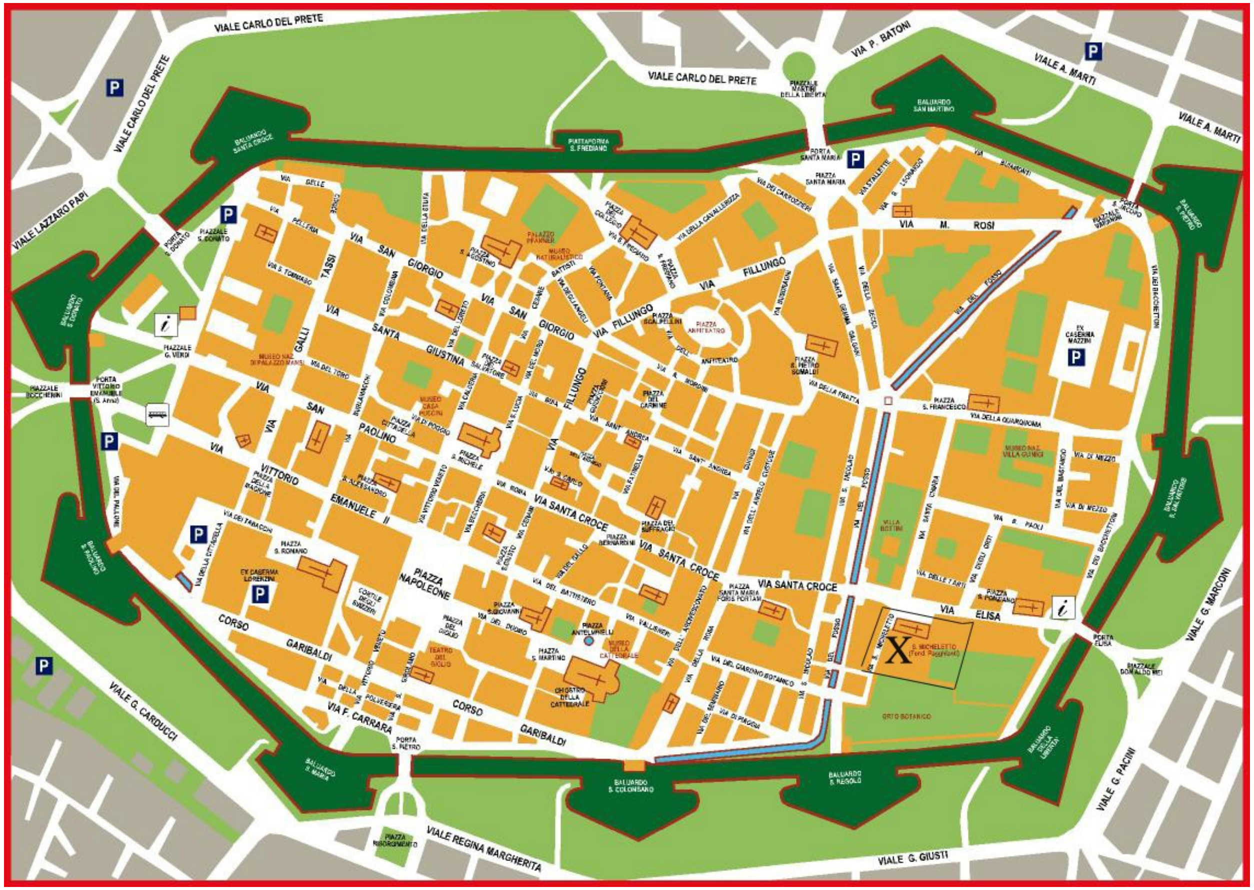

Conclusion

- A choreographic approach to program distributed applications
- The derived distributed application follows the behavior defined by the choreographic program
- We ensure deadlock freedom, orphan message freedom and race freedom in a challenging setting
- We allow integration of external functionalities
- We allow dynamic update, preserving the correctness guarantees
- We instantiated the theoretical framework into a real programming language

Future work

- Is choreographic programming practical?
  - We need to allow asynchronous communication
  - We need to improve performance
    - Drop redundant communications
  - We need error handling
- Only a serious case study can tell
  - Not so easy to find a suitable case study for adaptation

(Partial) Bibliography

- For a general introduction to choreographies and related topics: Hans Hüttel et al.: Foundations of Session Types and Behavioural Contracts. ACM Comput. Surv. 49(1): 3:1-3:36 (2016)
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- AIOCJ website: http://www.cs.unibo.it/projects/jolie/aiocj.html
- Jolie website: http://www.jolie-lang.org/

End of talk

Thanks!

Questions?