Surviving in a world of change

Towards evolvable and self-adaptive service-oriented systems

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Talk's roadmap

- Understanding change
- Understanding evolution and adaptation
- How can we detect change?
- How can we detect the need to evolve/adapt?
- How can we react to support evolution/adaptation?
- Lessons learned beyond SASs

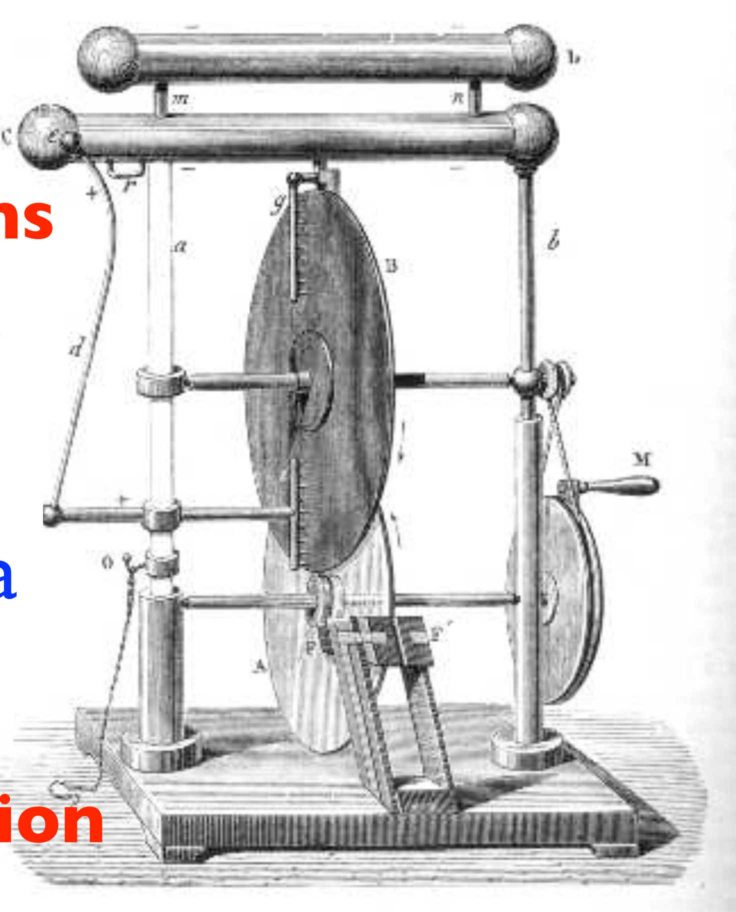
The root of the problems: endemic change

The global picture: the *machine* and the *world* (*Jackson/Zave*)

World (the environment)

Machine

Domain properties, assumptions



Shared phenomena

Goals Requirement

Specification

Domain properties and assumptions

- Both refer to problem world phenomena
- ***Properties*** hold regardless of any software-to-be
  - *if a positive net force is applied in one direction then the body accelerates in that direction*
  - *(if plane has touched down then wheels turn)*
- ***Assumptions*** may be violated
  - *submission rate of user requests does not exceed XXX/sec*
  - *temperature is in the range -40 +40 Celsius*
  - *librarians register return of books when users bring borrowed books back*

Domain assumptions

May concern

- usage profiles
- users' responsiveness
- remote servers response time
- network latency
- sensors/actuators behaviors
- …

"Domain assumptions bridge the gap between requirements and specifications"
(M. Jackson & P. Zave)

Dependability arguments

- Assume you have a formal representation for
  - R = requirements
  - S = specification
  - D = $D_p + D_a$ domain properties and assumptions

if S and D are both satisfied and consistent, it is necessary to prove

- S, D |= R

Change

- Requirements change
- Environment changes

- Change is often a manifestation of uncertainty
- Change asks for evolution (of the machine)

Changes may cause evolution

- Changes are exogenous phenomena that may concern
  - R
  - D (actually, D_a)
- Changes likely break the dependability argument
- **Evolution** (of the machine) is a consequence of change
  - we need to change S (and hence the implementation) to continue to satisfy the dependability argument

$$S, D \models R$$

Evolution and adaptation

Adaptation is a special case of evolution due to changes in domain assumptions, D_a

- an increasingly relevant phenomenon, often due to uncertainty
  - cyber-physical systems
    - interaction with the physical environment
  - user-intensive systems
    - changes in usage profile
  - cloud/service infrastructure
    - platform volatility

Our focus here

On-line vs off-line evolution (type vs instance) vs self-adaptive systems

- Traditionally, response to change is performed off-line by engineers (aka software maintenance)
- More and more often systems are required to be continuously running
- This asks for on-line evolution, i.e. applying changes to the machine as the system is running and providing service
- The special case of **self-adaptive systems**
  - (instance-level) self-managed on-line adaptation

Self-adaptive system (SaS)

- D decomposed into D_f and D_c
  - D_f is the fixed/stable part
  - D_c is the changeable part

S, D |= R

- A SaS should
  - **detect changes to D_c**
  - **modify itself** (the *machine* --- S, and the implementation) to keep satisfying the dependability argument, if necessary

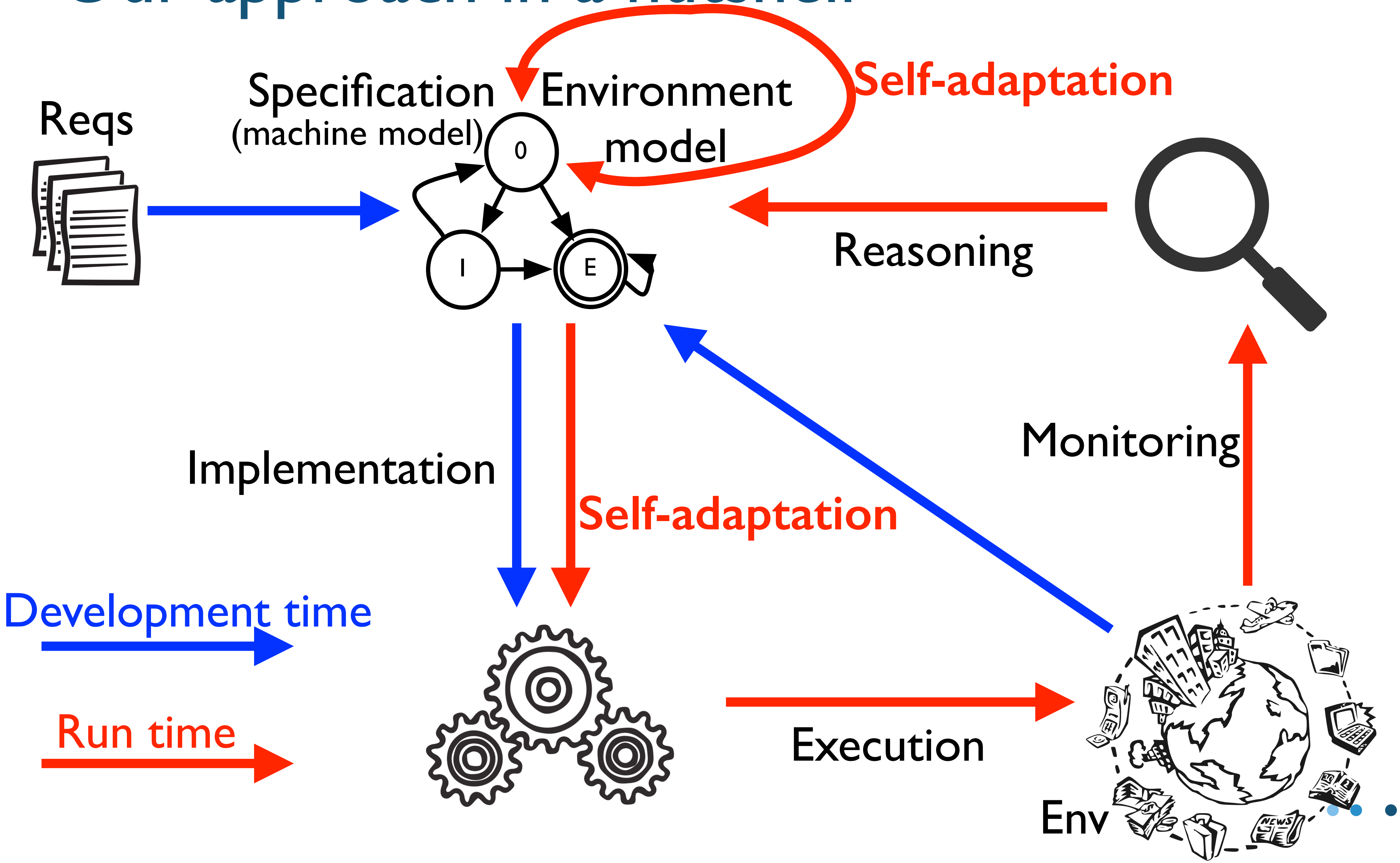
Paradigm shift

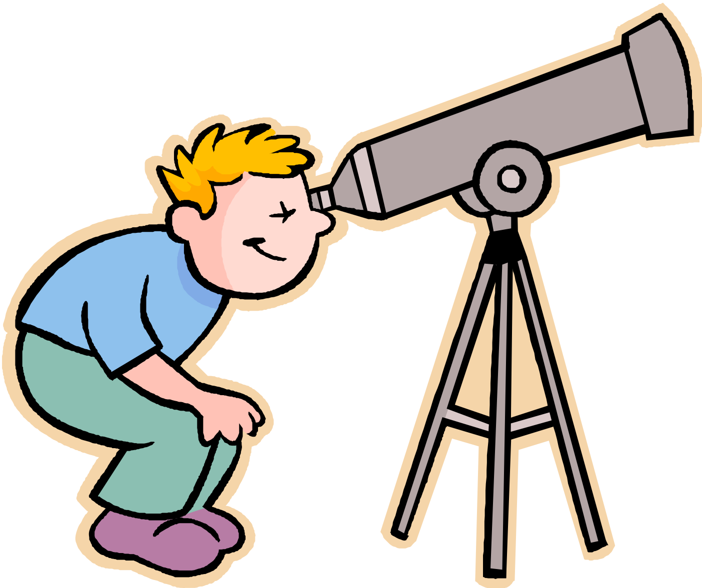
- SaSs ask for a paradigm shift, which involves both development time (DT) and run time (RT)
- The boundary between DT and RT fades
- Reasoning and reacting capabilities must enrich the RT environment
  - **detect** change
  - **reason** about themselves and the possible consequences of change
  - **react** to change

Models+verification@runtime

- To detect change, we need to **monitor** the environment
- The changes must be retrofitted to models of the machine+environment that support reasoning about the dependability argument (a **learning** step)
- The updated models must be **verified** to check for violations to the dependability argument
- In case of a violation, a **self-adaptation** must be triggered

Our approach in a nutshell



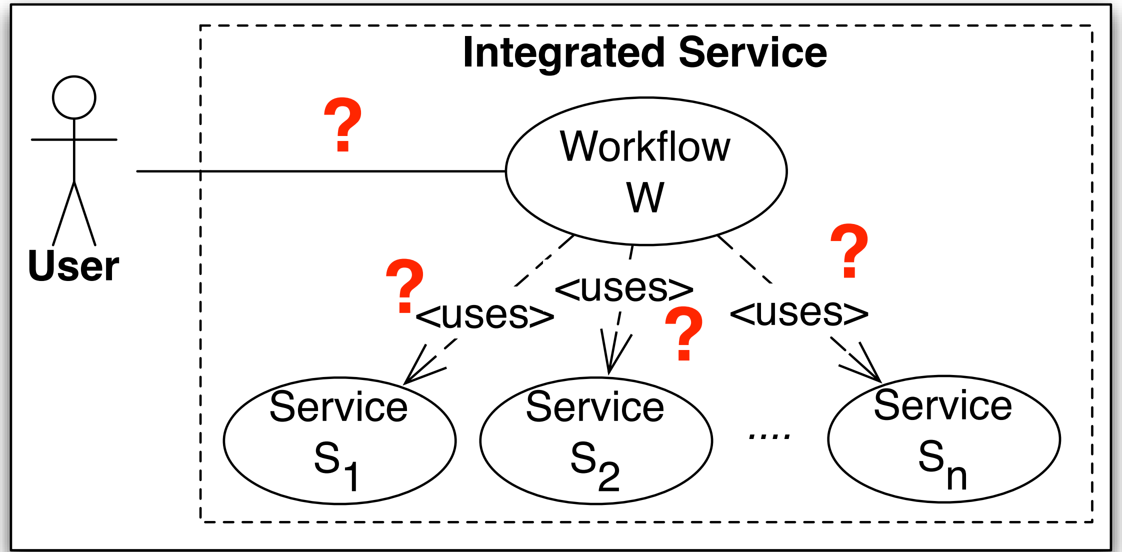


Zooming in

- I. Epifani, C. Ghezzi, R. Mirandola, G. Tamburrelli, "Model Evolution by Run-Time Parameter Adaptation", ICSE 2009
- C. Ghezzi, G. Tamburrelli, "Reasoning on Non Functional Requirements for Integrated Services", RE 2009
- I. Epifani, C. Ghezzi, G. Tamburrelli, "Change-Point Detection for Black-Box Services", FSE 2010
- A. Filieri, C. Ghezzi, G. Tamburrelli, " A formal approach to adaptive software: continuous assurance of non-functional requirements", Formal Aspects of Computing, 24, 2, March 2012.

Zooming in

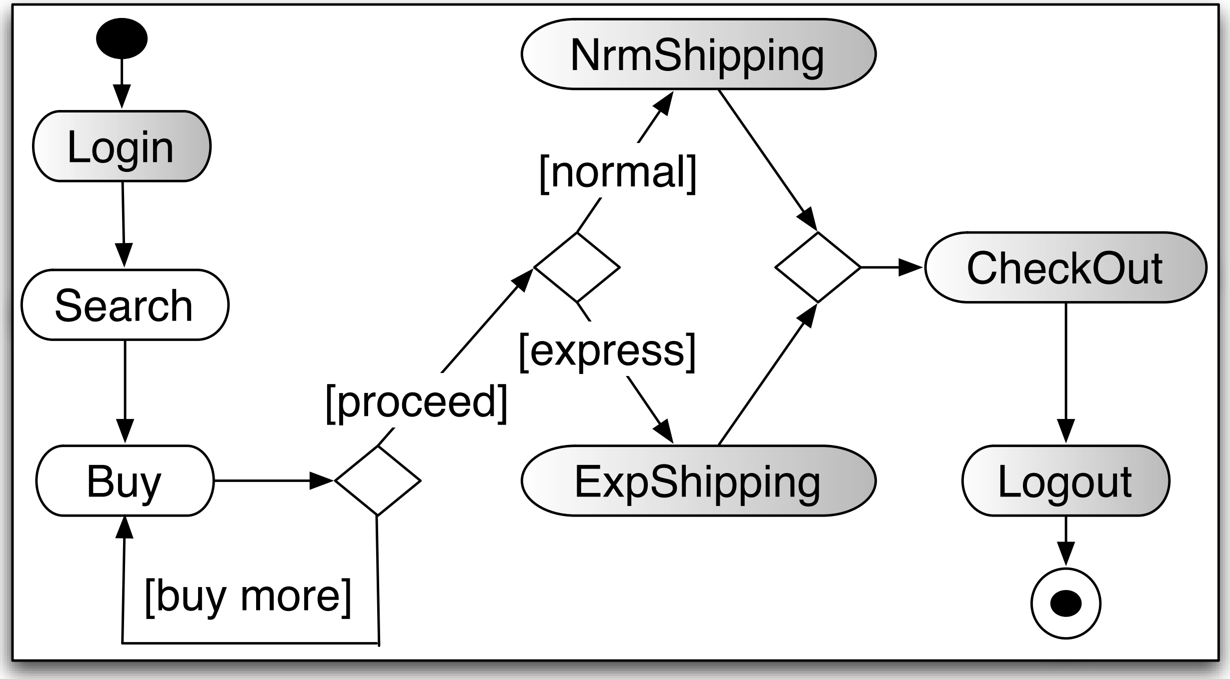
- Focus on **non-functional** requirements
  - reliability, performance, energy consumption, cost, …
- Quantitatively stated in **probabilistic** terms
- D_c decomposed into D_u , D_s
  - D_u = usage profile
  - $D_s = S_1 \wedge .... \wedge S_n$ S_i assumption on i-th service



Models

- Different models provide different **viewpoints** from which a system can be analyzed
- Focus on **non-functional** properties and quantitative ways to deal with uncertainty
- Use of **Markov models**
  - DTMCs for reliability
  - Reward DTMCs for energy/cost/performance..
- Use of probabilistic model checking for verification that a model satisfies a given property
  - Properties written in PCTL

An example



Returning customers
vs
new customers

3 probabilistic requirements:
R1: "Probability of success is > 0.8"
R2:"Probability of a ExpShipping failure for a user recognized as ReturningCustomer < 0.035"
R3:"Probability of an authentication failure is less then < 0.06"

Assumptions

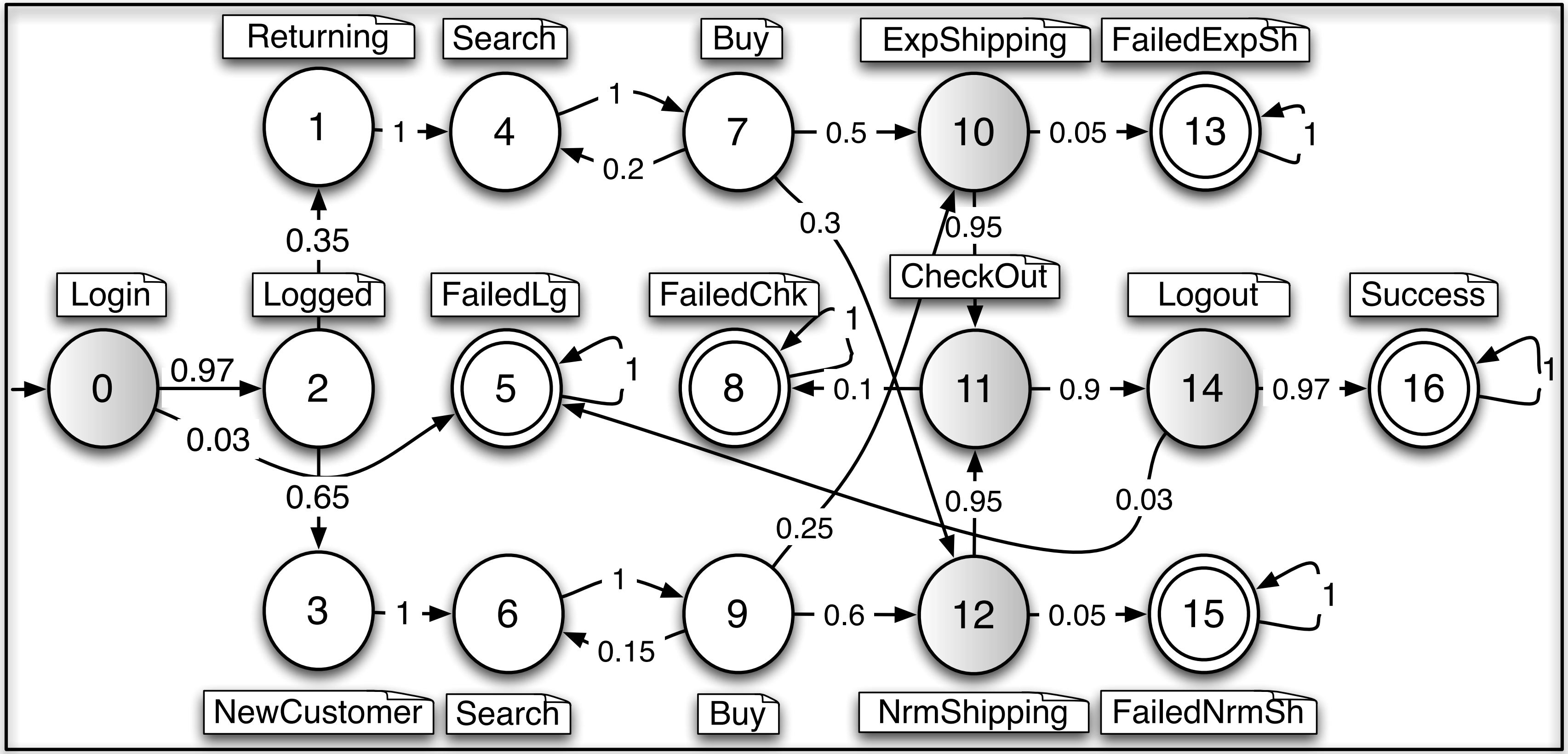
User profile domain knowledge

$D_{u,n}$	Description	Value
$D_{u,1}$	*P(User is a RC)*	0.35
$D_{u,2}$	*P(RC chooses express shipping)*	0.5
$D_{u,3}$	*P(NC chooses express shipping)*	0.25
$D_{u,4}$	*P(RC searches again after a buy operation)*	0.2
$D_{u,5}$	*P(NC searches again after a buy operation)*	0.15

External service assumptions (reliability)

$D_{s,n}$	Description	Value
$D_{s,1}$	*P(Login)*	0.03
$D_{s,2}$	*P(Logout)*	0.03
$D_{s,3}$	*P(NrmShipping)*	0.05
$D_{s,4}$	*P(ExpShipping)*	0.05
$D_{s,5}$	*P(CheckOut)*	0.1

DTMC model



R1: "Probability of success is > 0.8" 0.84

R2:"Probability of a ExpShipping failure for a user recognized as ReturningCustomer < 0.035" 0.031

R3:"Probability of an authentication failure is less then < 0.06" 0.056

What happens at run time?

- Actual environment behavior is monitored
- Model updated by using a Bayesian approach to estimate DTMC matrix (posterior) given run time traces and prior transitions
- Boils down to the following updating rule

$$m_{i,j}^{(N_i)} = \frac{c_i^{(0)}}{c_i^{(0)} + N_i} \times m_{i,j}^{(0)} + \frac{N_i}{c_i^{(0)} + N_i} \times \frac{\sum_{h=1}^{d} N_{i,j}^{(h)}}{N_i}$$

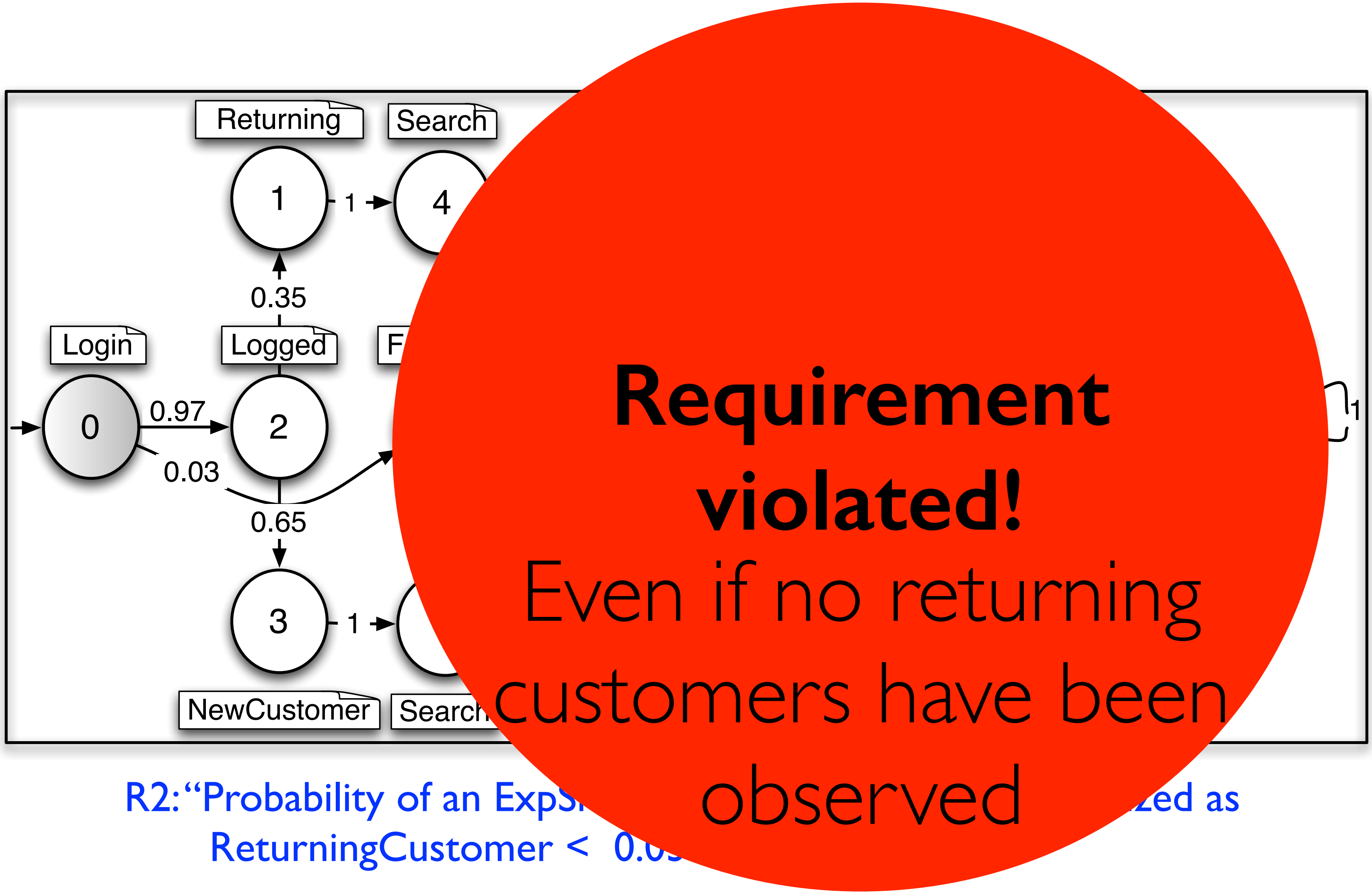
A-priori Knowledge

A-posteriori Knowledge

Model update and failure prediction

- Model checking applied to after each update
- Model checking may *predict* requirements violations
- ... and trigger self-adaptations before violations manifest themselves

In our example



R2:"Probability of an ExpS... ...zed as ReturningCustomer < 0.0...

The problem

- Verification subject to (application-dependent) hard real-time requirements
- Running conventional model checking tools after any change impractical in most realistic cases
- But changes are often local, they do not disrupt the entire specification
- Can they be handled in an **incremental** fashion?
- This requires revisiting model checking algorithms!

Incrementality by parameterization

- Requires anticipation of changing parameters
- The model is partly numeric and partly symbolic
- Evaluation of the verification condition requires *partial evaluation* (mixed numerical/symbolic processing)
- Result is a formula (polynomial for reachability on DTMCs)
- Evaluation at run time substitutes actual values to symbolic parameters and is very efficient

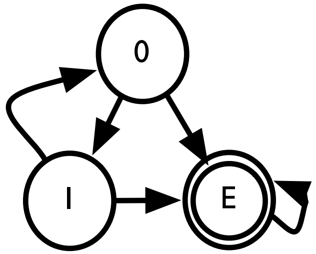
Working mom paradigm

Cook first

Warm-up later

Working mom paradigm

Design-Time (offline)

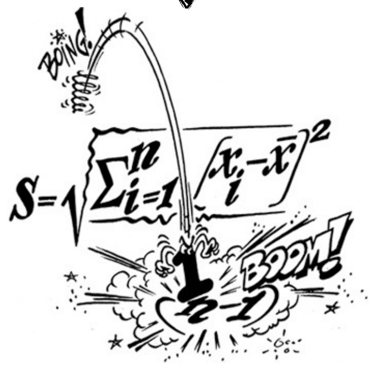


Partial evaluation

Run-Time (online)

Trace	
p11	0.34
p12	0.21
p31	0.12
p43	0.71
p31	0.23
p32	0.54

Parameter values

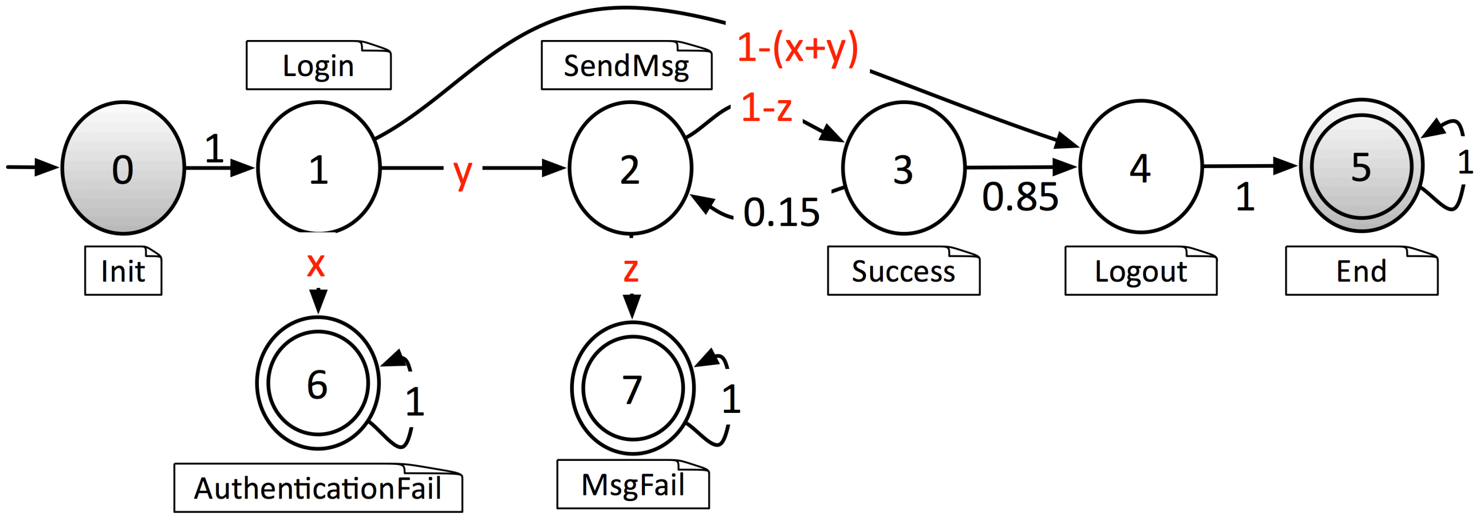


Analyzable properties: reliability, costs (e.g., energy consumption)

[ICSE 2011] A. Filieri, C. Ghezzi, G. Tamburrelli " Run-time efficient probabilistic model checking"
[FormSERA 2012] A. Filieri, C. Ghezzi, "Further steps towards efficient runtime verification: Handling probabilistic cost models"

An example

$$r = \Pr(\Diamond s = 5) > \bar{r}$$

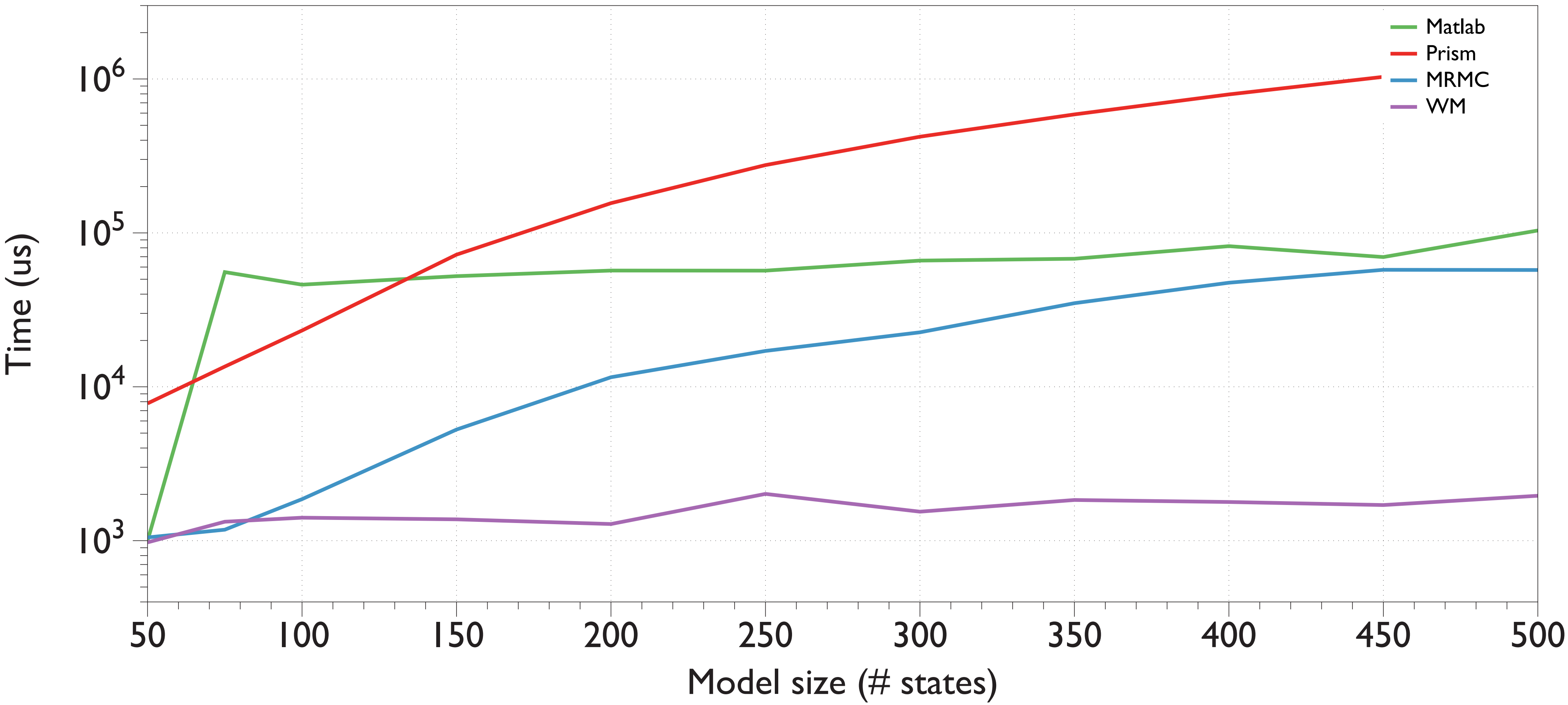


$$r = \frac{0.85 - 0.85 \cdot x + 0.15 \cdot z - 0.15 \cdot x \cdot z - y \cdot x}{0.85 + 0.15 \cdot z}$$

The WM approach

- Assumes that the Markov model contains absorbing states, and that they are reachable
- Works by symbolic/numeric matrix manipulation
- All of (R) PCTL covered
- Expensive design-time partial evaluation, fast run-time verification
  - symbolic matrix multiplications, but very sparse and normally only few variables

Run-time verification



Further advantage of WM

- Because reachability properties can be expressed via polynomial functions, it is also possible to compute their (partial) derivative and perform sensitivity analysis
  - Which parameters affect most the global quality in the current operation point?
- Similar approach can deal also with rewards
  - Energy consumption, Average Execution time, Outsourcing cost, CPU time, Bandwidth

The rest of the story

- After you detect the need for an adaptation, how do you react?
- You need to perform a dynamic update
- This means disconnecting components and ensuring a correct + safe update
- … but this is subject for another talk

What did we learn?

How/where do we proceed from here?

Run-time management

- The run-time environment for self-adaptive software should not *just run* applications
  - it should support *introspection* and *reaction*
    - on the application's requirements
    - its behaviour
    - the environment's behavior
- ***Models*** and ***continuous verification*** are essential for introspection and reaction
- But because models change, verification must be efficient
  - ✓ constrained by real-time requirements
- This is agility taken to extremes

Beyond self-adaptation

- Lessons learned are far reaching
  - Agile (explorative, incremental) development may become verification-driven by supporting incremental modelling and verification
  - Agility and formal methods may be reconciled rather than being antagonistic
- Vision
  - Towards verification-driven development as complementary to today's test-driven development

Key feature: incrementality

Incremental verification

Given a system (model) S, and a set of properties P met by S

Change = new pair S', P' where S'= S + ΔS and P'= P + ΔP

Let ∏ be the proof of S against P

The proof ∏' of P' against S' can be done by just performing a proof increment Δ∏ such that ∏' = ∏ + Δ∏

Expectations:

- Δ∏ easy and efficient to perform
- Δ∏ helps designers reason about change

A long way to go, but possible

- Revisit development models and verification procedures to make them incremental
- Make model-driven development practical
- Package above in IDEs

Acknowledgements

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- **...and thanks to**

Thanks for your attention

Questions?