Model-Based Testing Real-Time and Interactive Music Systems

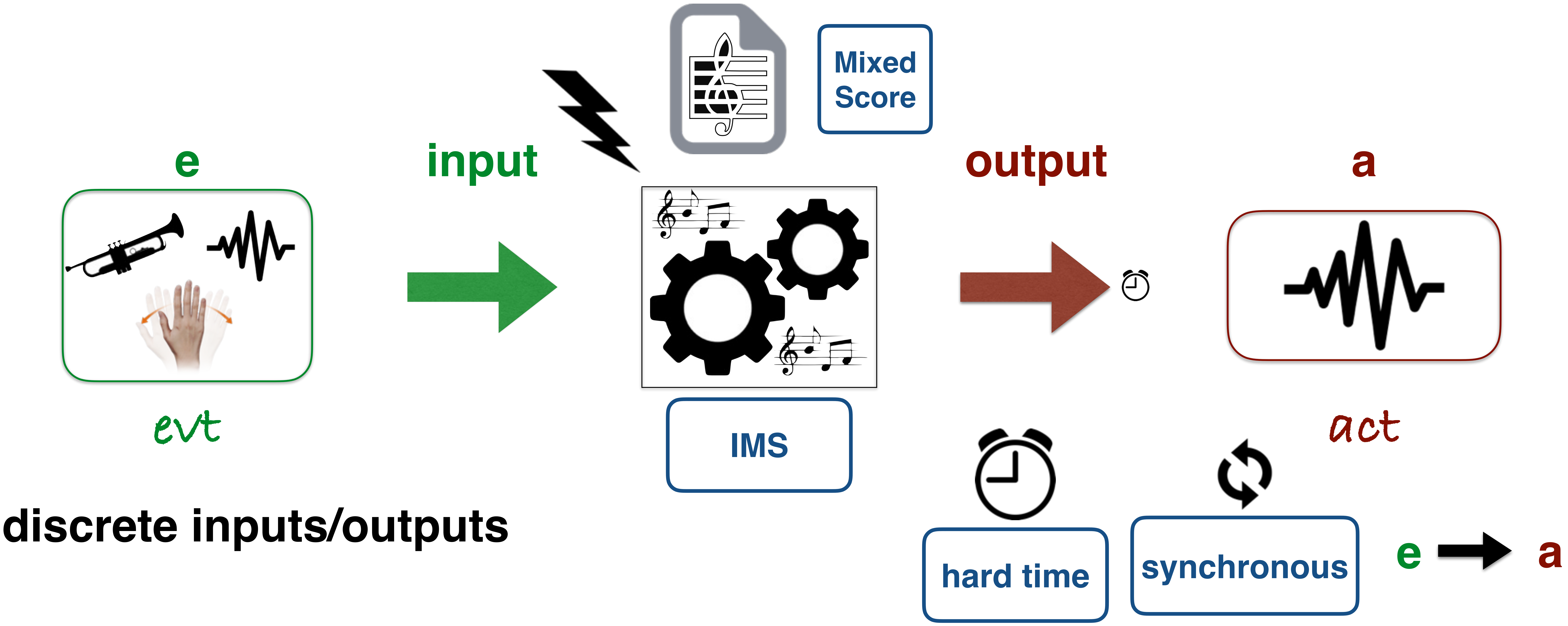
Thesis defended on 11/10/16

Poncelet Sanchez Clement,
Florent Jacquemard

SYNCHRON 2016

Team: RepMus

Score-Based Interactive Music Systems



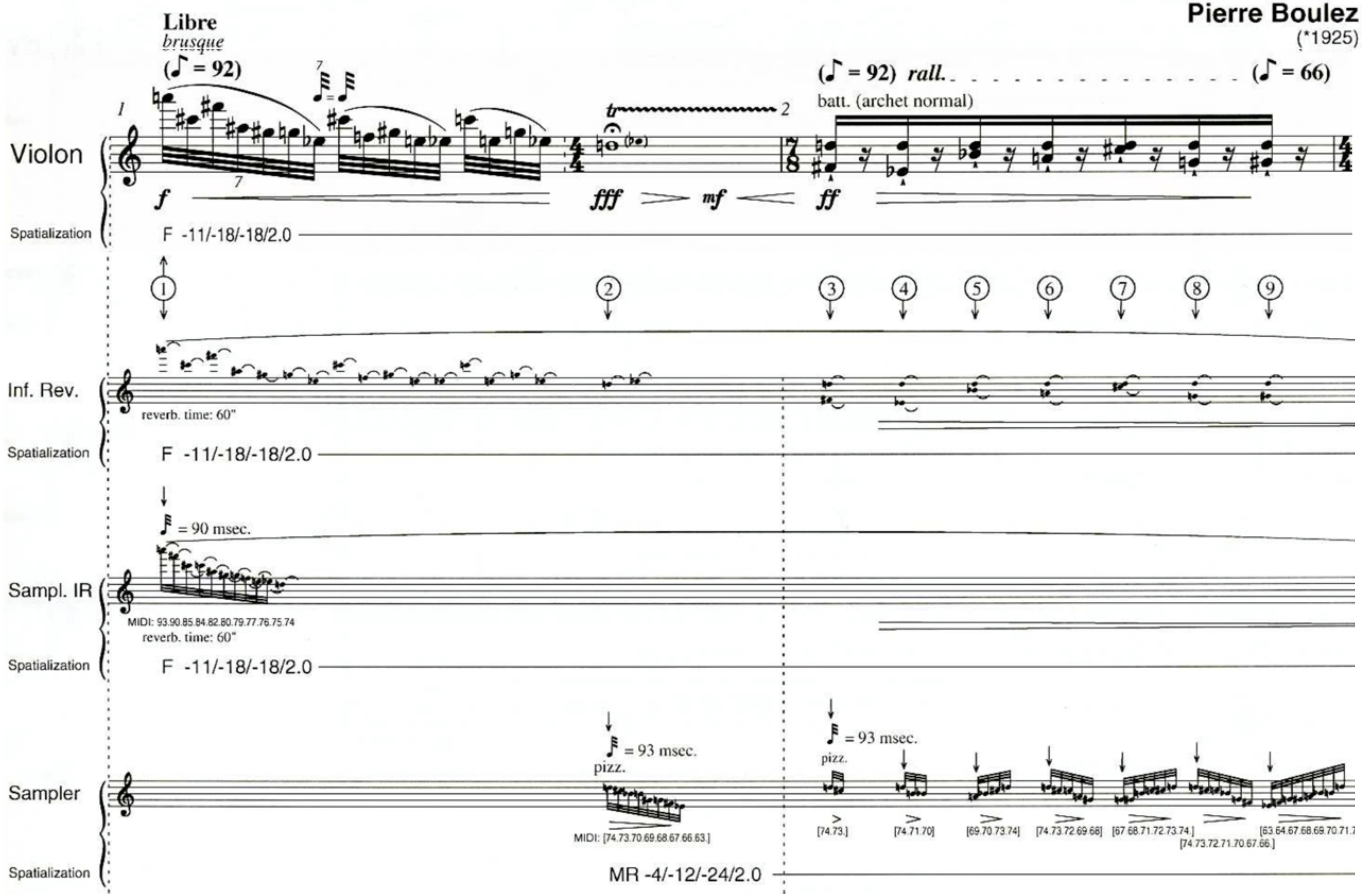
Régie informatique

Anthèmes 2

pour violon et dispositif électronique (1997)

Pierre Boulez
(*1925)

Mixed Score



Régie informatique

Anthèmes 2

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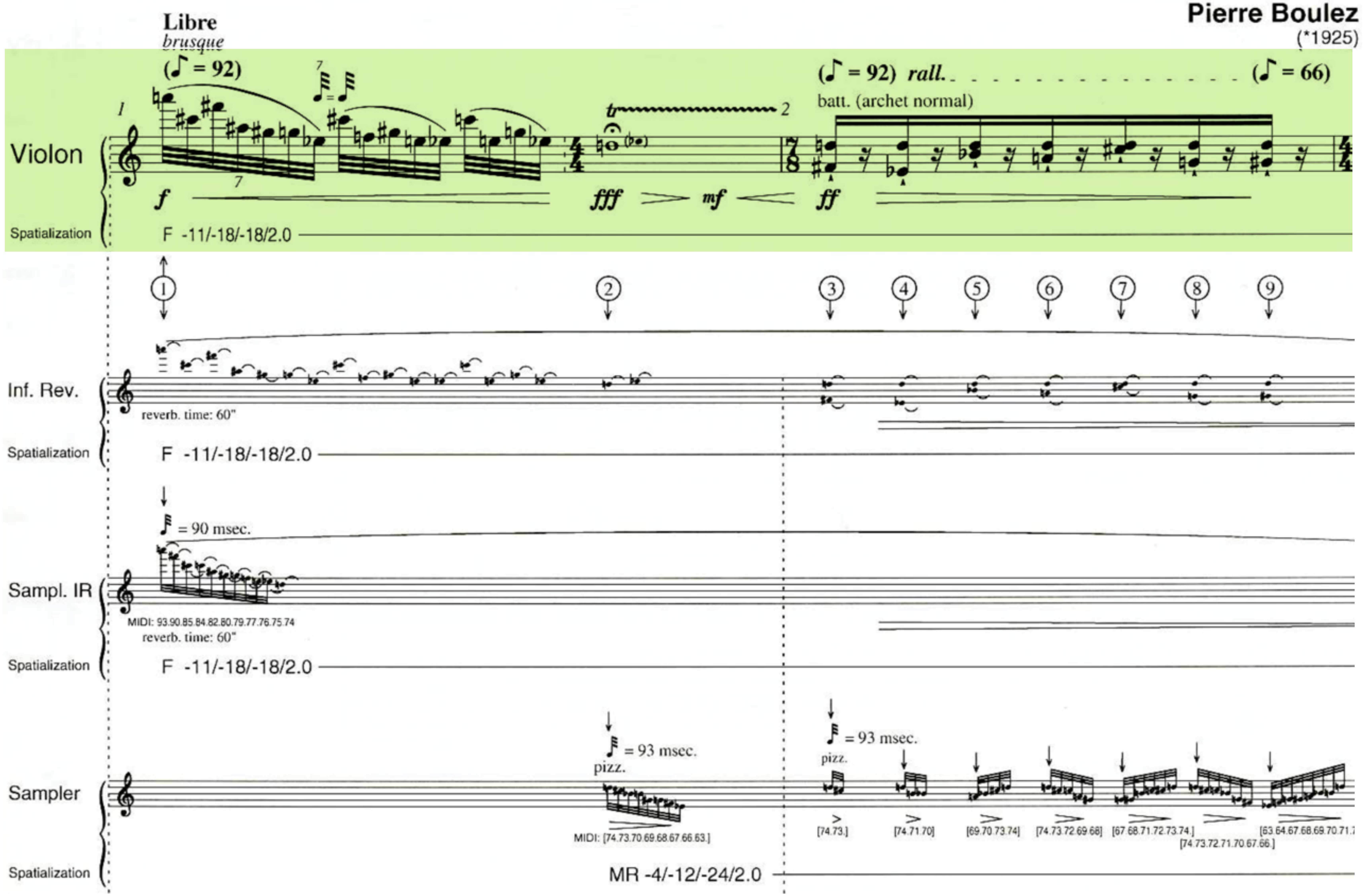
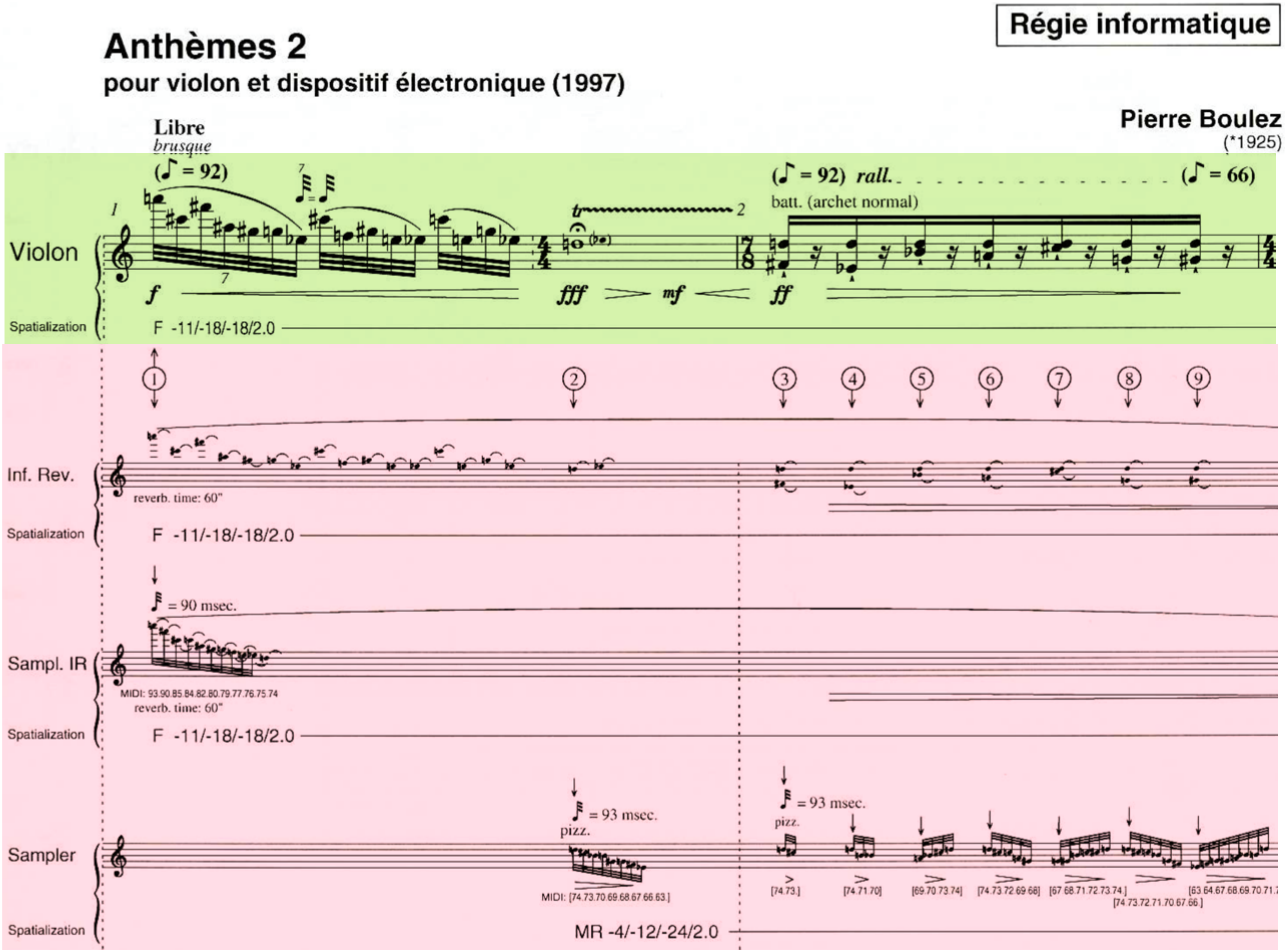


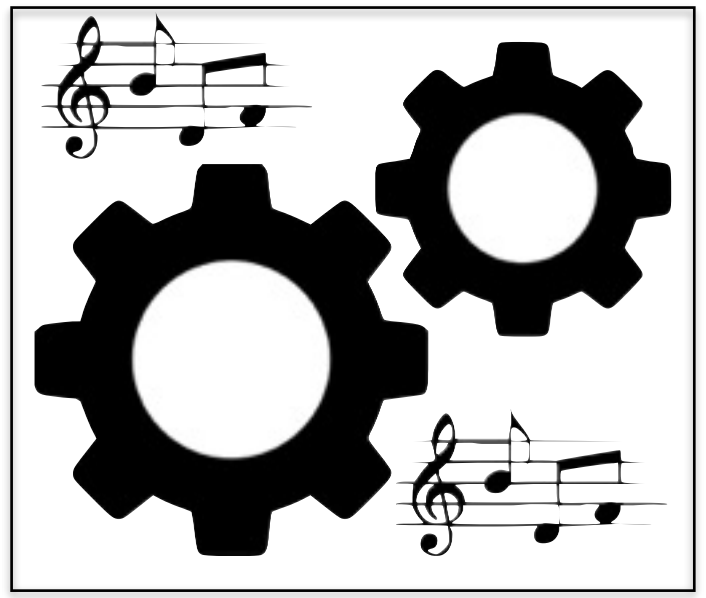
Interpretation

Mixed Score

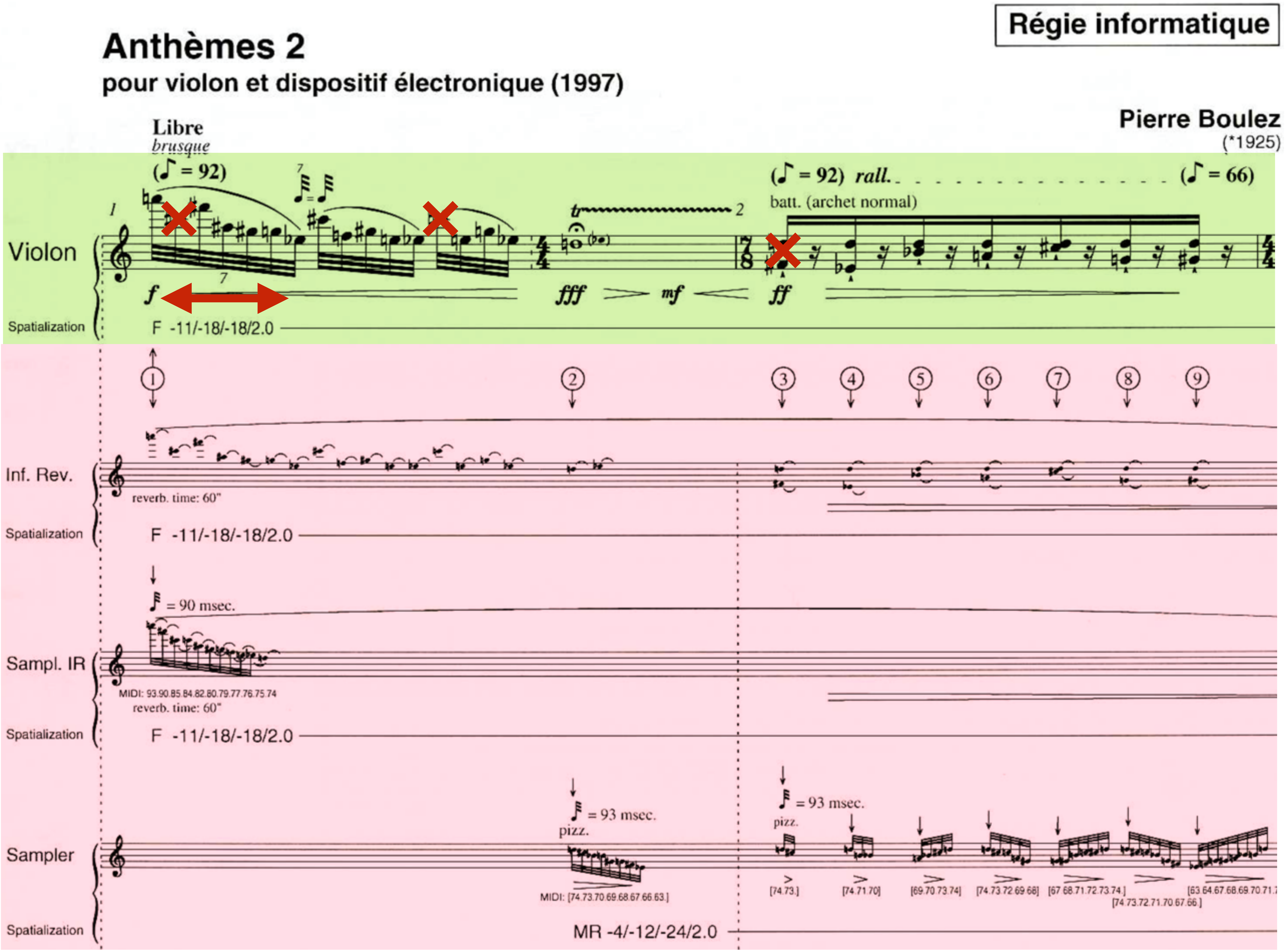
Mixed Score



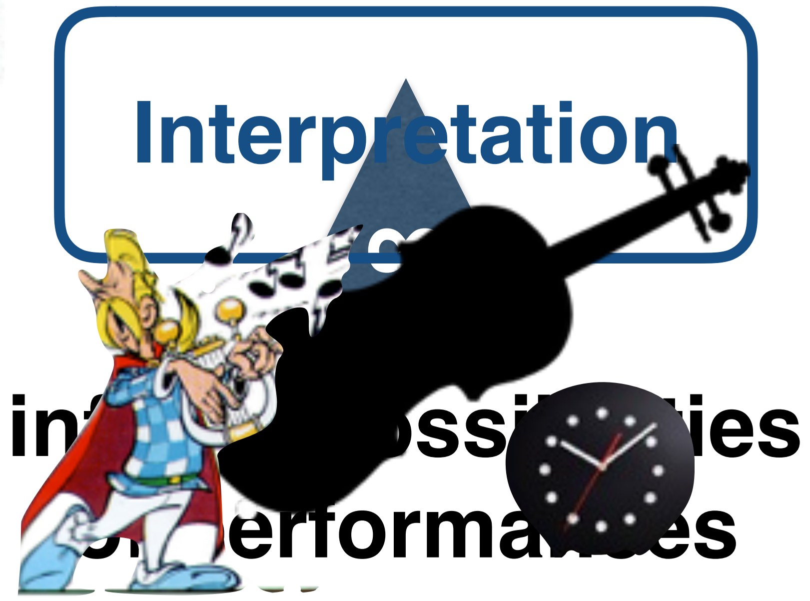
Interpretation



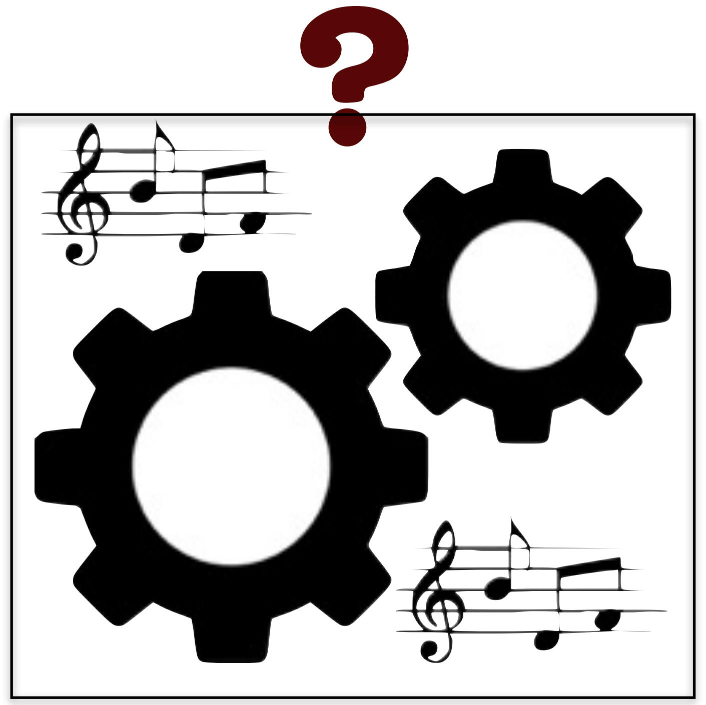
Mixed Score



Régie informatique
Anthèmes 2
pour violon et dispositif électronique (1997)
Pierre Boulez
(*1925)
Libre
brusque
(♩ = 92)
(♩ = 92) rall.
(♩ = 66)
batt. (archet normal)
Violon
Spatialization
F -11/-18/-18/2.0
Inf. Rev.
reverb. time: 60"
Spatialization
F -11/-18/-18/2.0
= 90 msec.
Sampl. IR
MIDI: 93.90.85.84.82.80.79.77.76.75.74
reverb. time: 60"
Spatialization
F -11/-18/-18/2.0
= 93 msec.
pizz.
= 93 msec.
pizz.
Sampler
MIDI: [74.73.70.69.68.67.66.63.]
[74.73]
[74.71.70]
[69.70.73.74]
[74.73.72.69.66]
[67.68.71.72.73.74.]
[74.73.72.71.70.67.66.]
Spatialization
MR -4/-12/-24/2.0

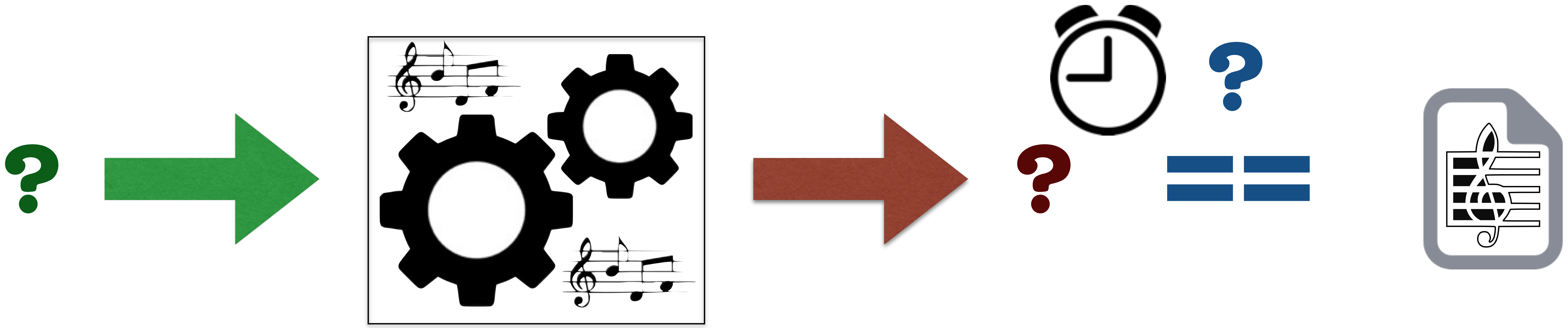


Interpretation



Timed Conformance Testing

Timed conformance



Set of relevant inputs

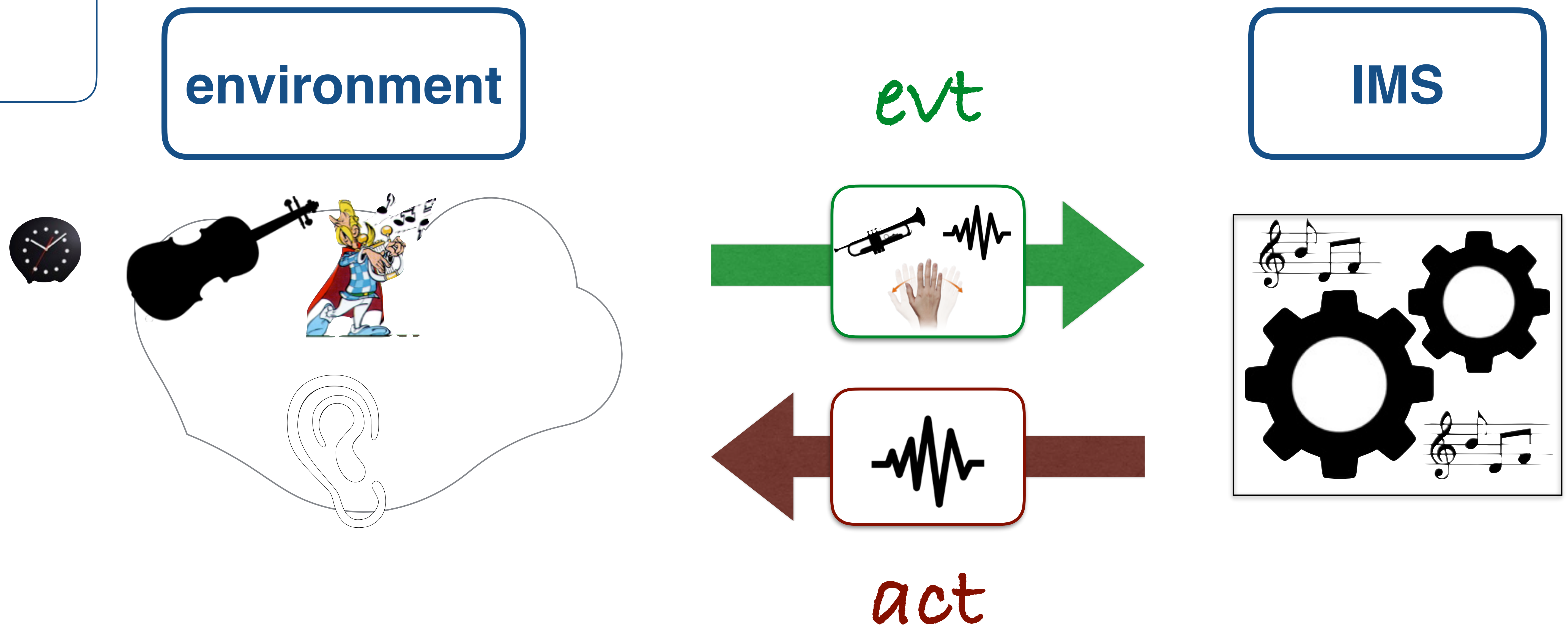
Set of corresponding implementation outputs

Computation of expected outputs

Manual Testing IMS

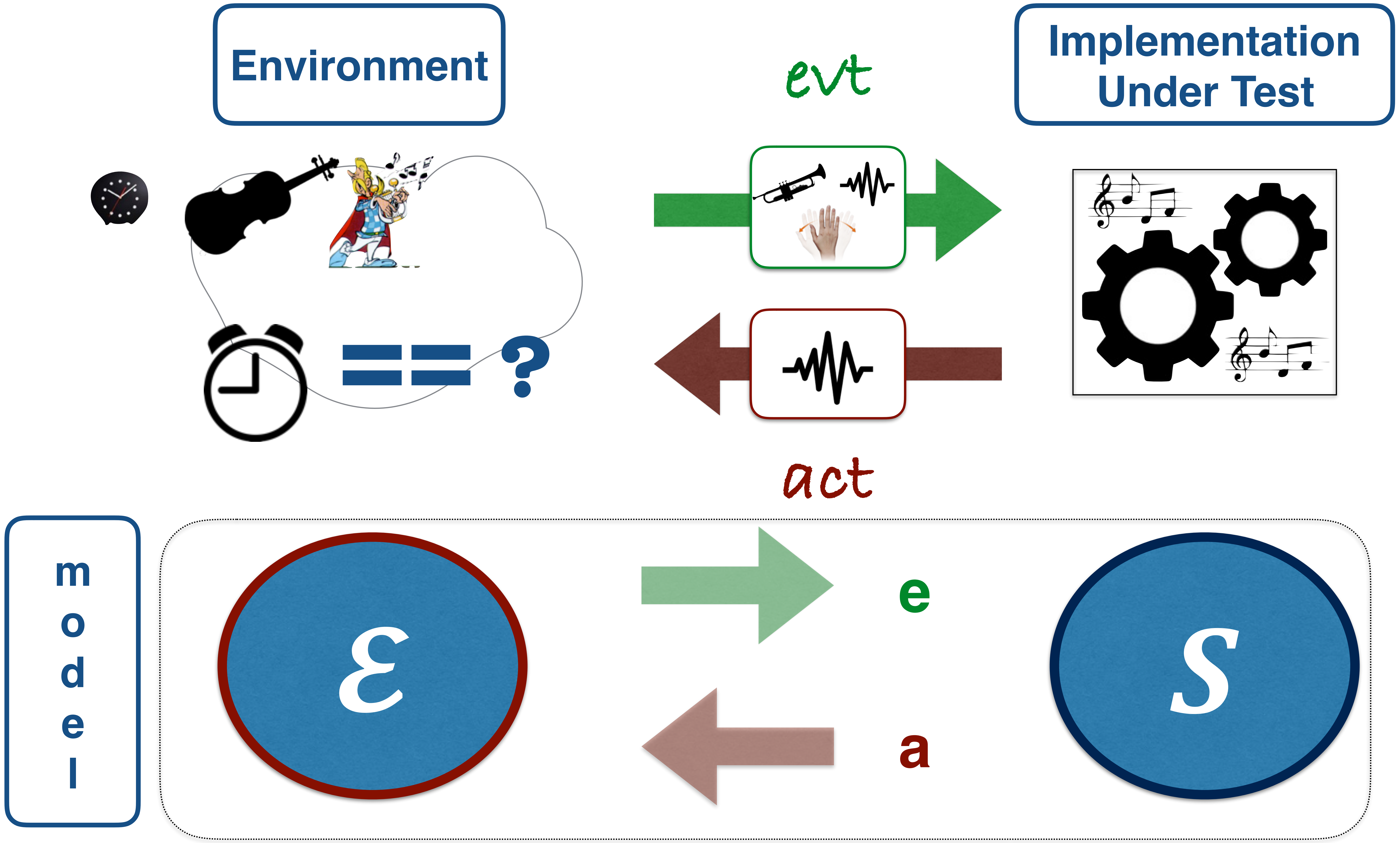
Manual Methods
Rehearsals

- **Test for one performance**
- **Time costly**
- **Not precise**

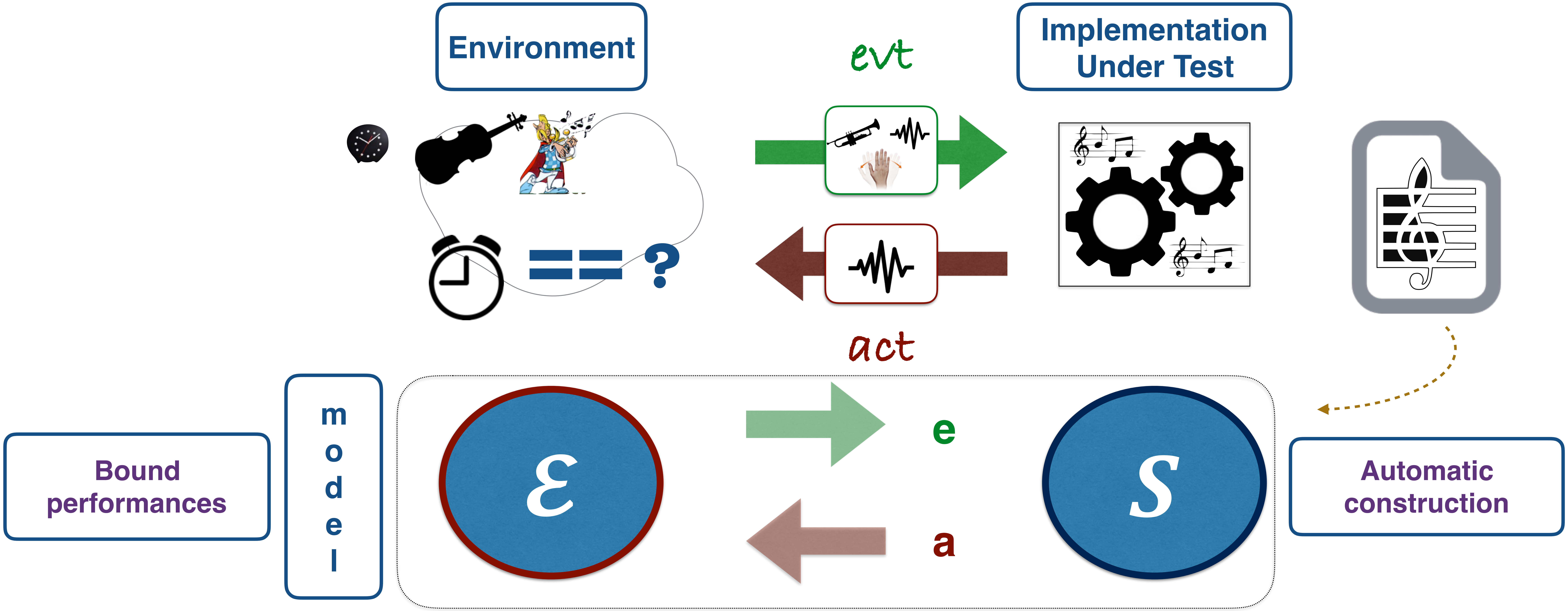


Model-Based Testing IMS

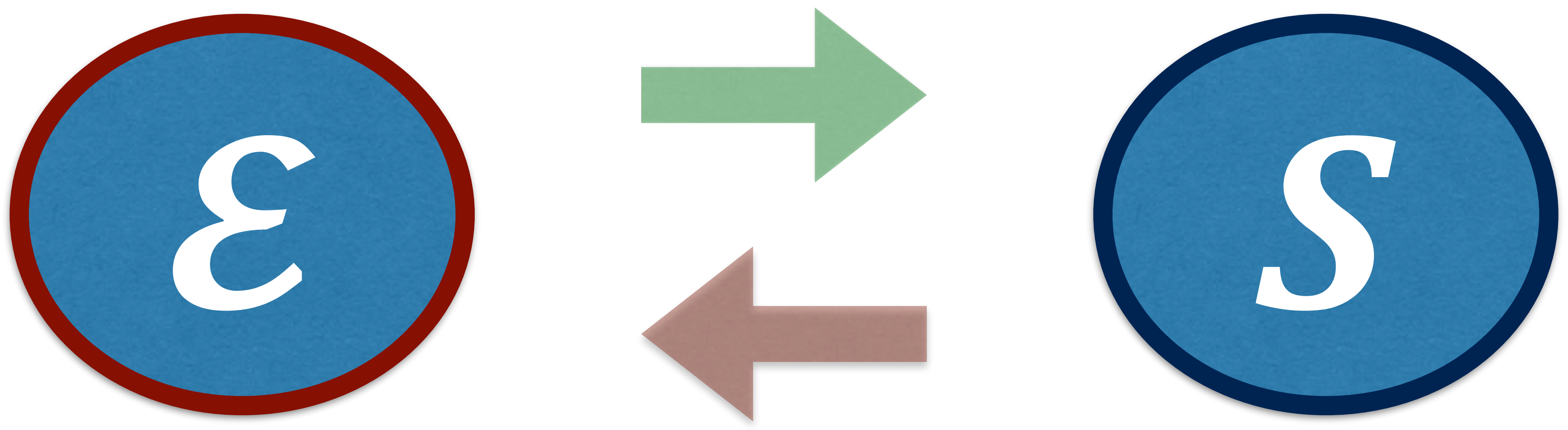
- ‘Exhaustive’ generation
- Fast forward execution (virtual clocks)
- Precise:
  - Automated comparison
  - Formal conformance criteria
  - informative feedbacks



Model-Based Testing IMS



Outline

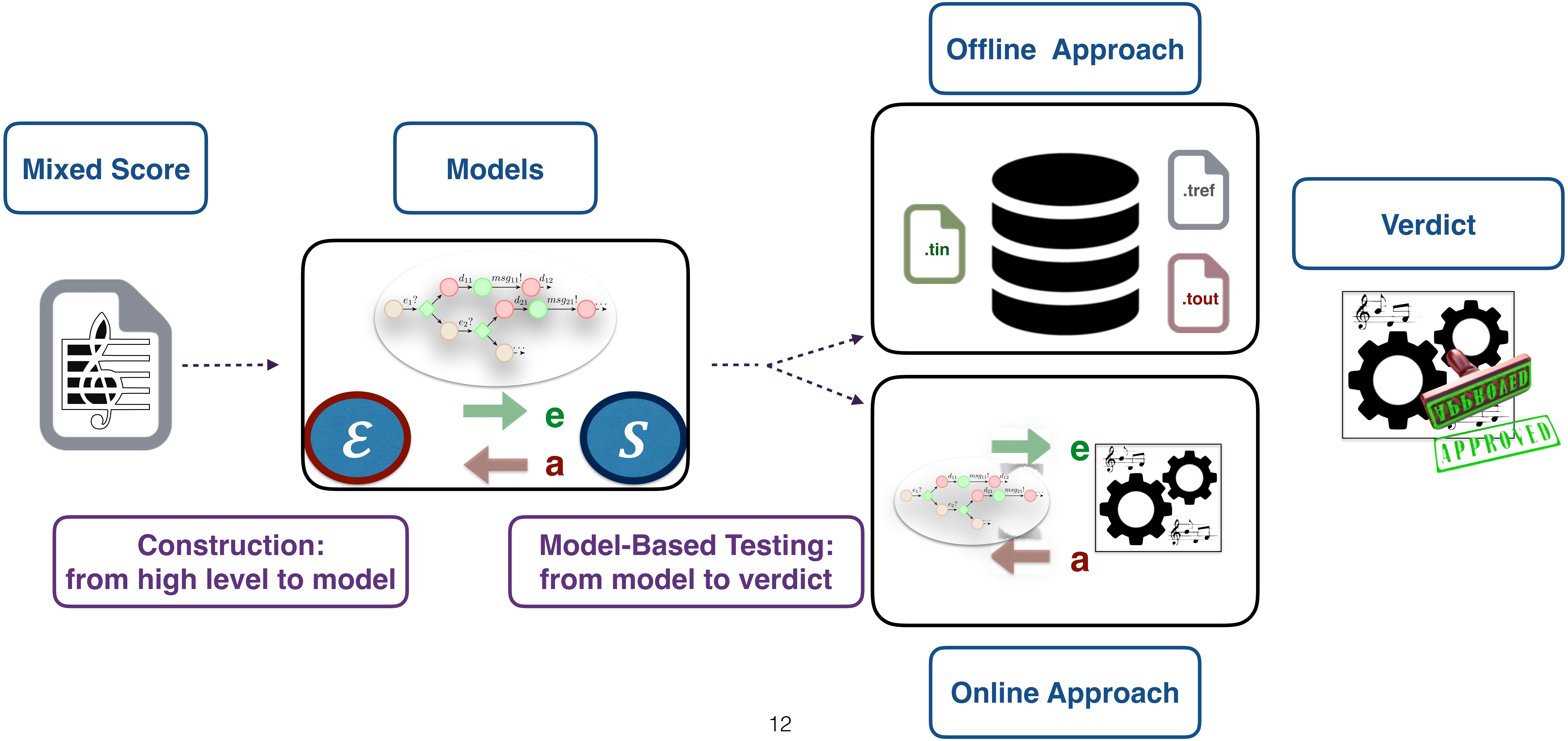


1. Objectives

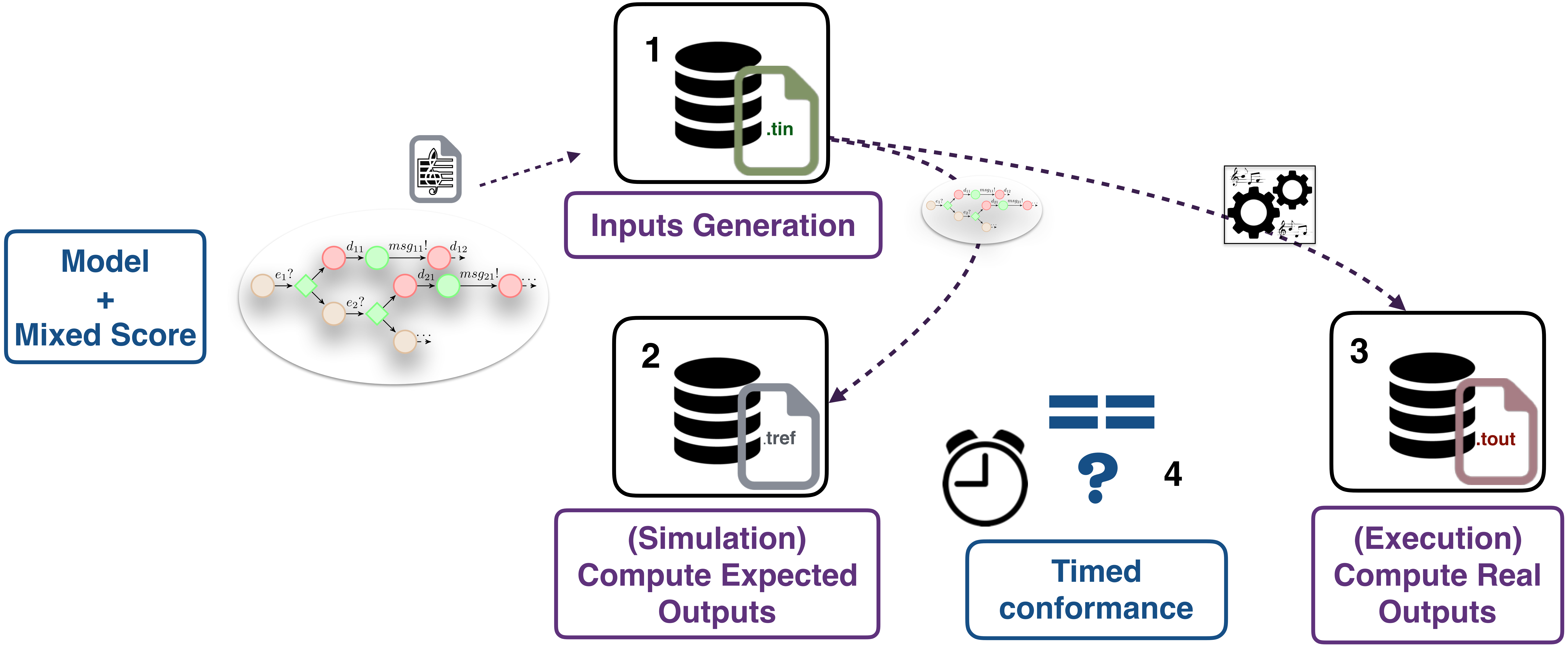
2. **Testing Framework**

3. Interactive Real-Time Model

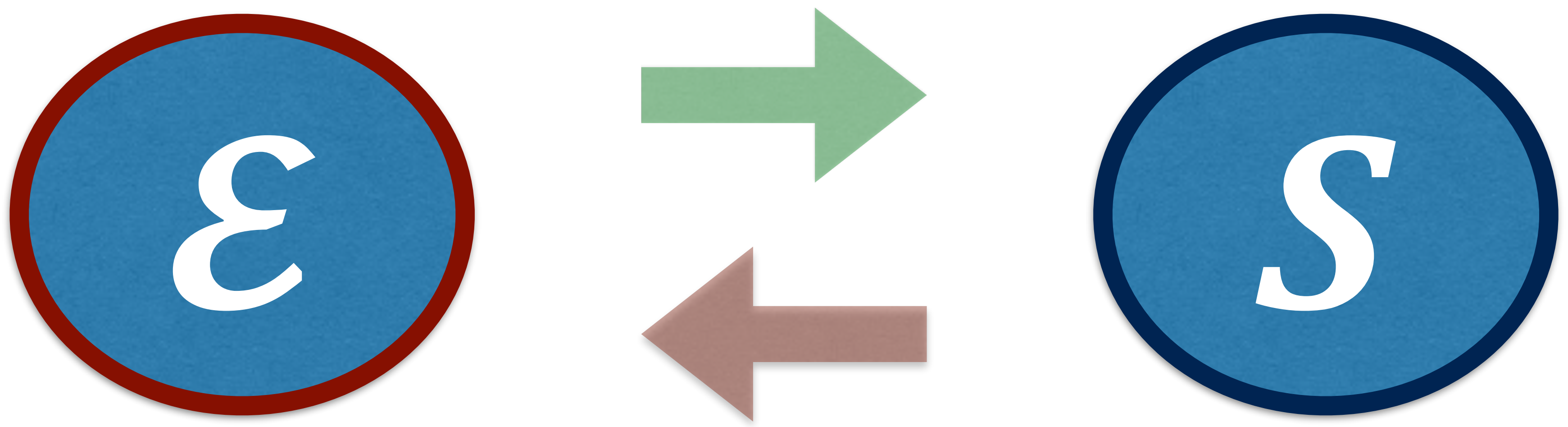
Testing Framework Overview



Testing Approaches



Outline

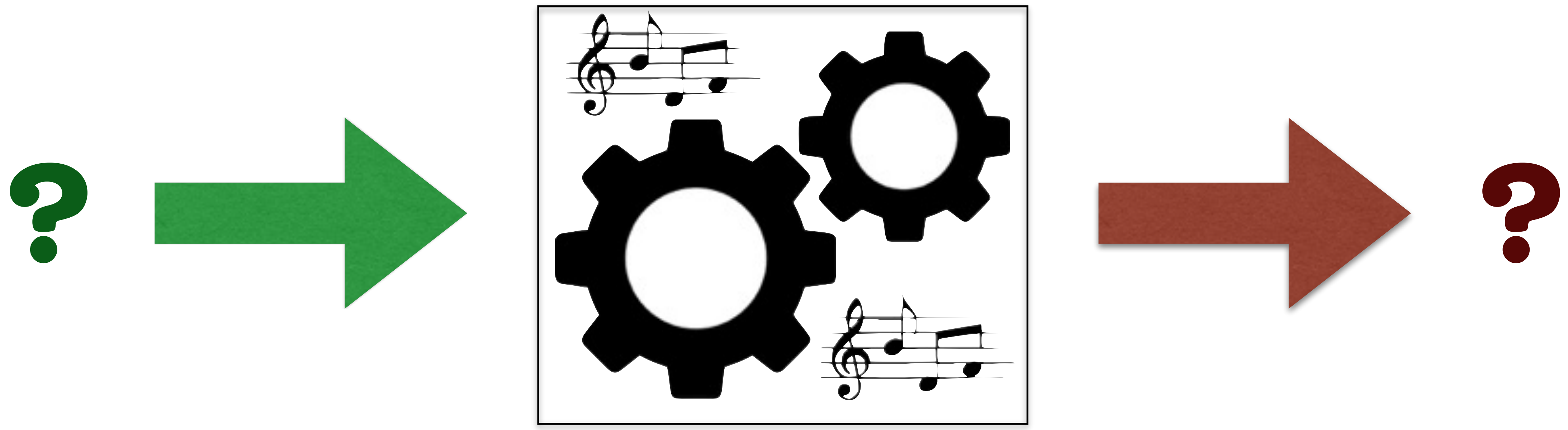


1. Objectives

2. Testing Framework

3. <u>Interactive Real-Time Model</u>

Input / Output formalisation

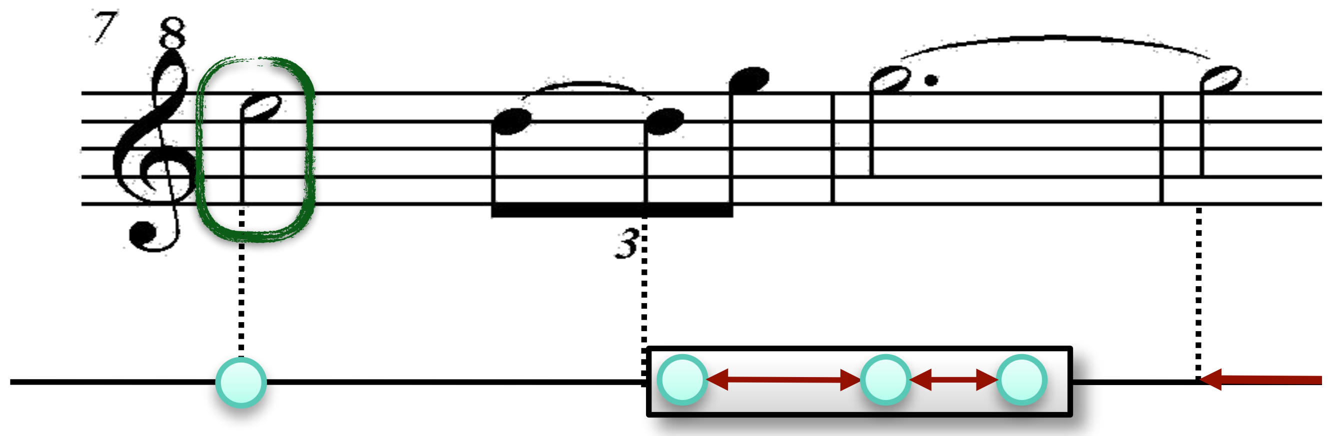


Timed Traces

Timed Input Trace

e

tempo: 120bpm



Specified inputs

$\langle e_1, 0, 120 \rangle$

Definition:

A timed trace is a tuple <s, t, p>:

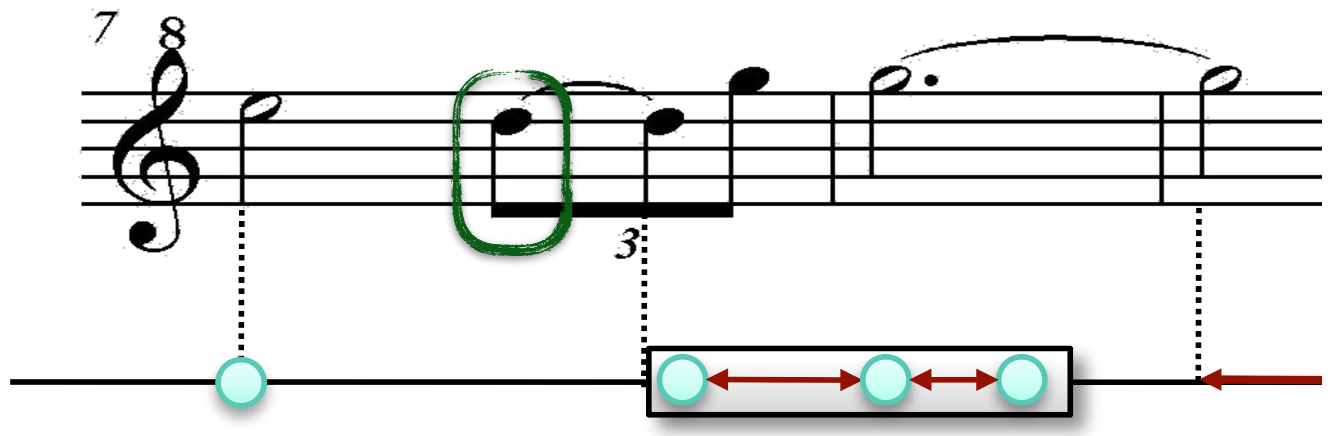
s: symbol
t: timestamp in time unit
p: pace in time unit per minute

Timed Traces

Timed Input Trace

e

tempo:
120bpm



Definition:

A timed trace is a tuple <s, t, p>:

s: symbol
t: timestamp in time unit
p: pace in time unit per minute

Specified inputs

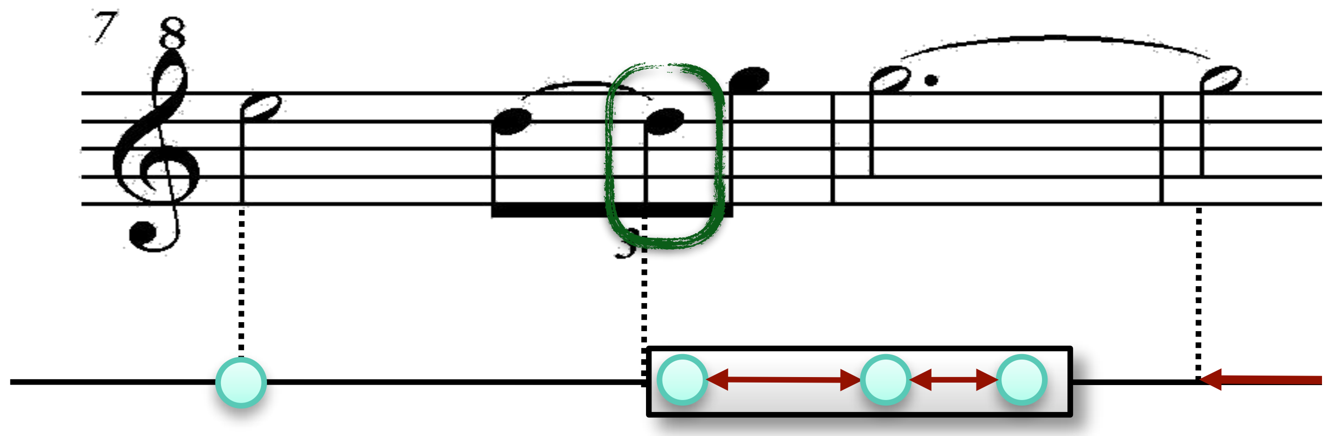
$\langle e_1, 0, 120 \rangle \langle e_2, 2, 120 \rangle$

Timed Traces

Timed Input Trace

e

tempo: 120bpm



Definition:

A timed trace is a tuple <s, t, p>:

s: symbol
t: timestamp in time unit
p: pace in time unit per minute

Specified inputs

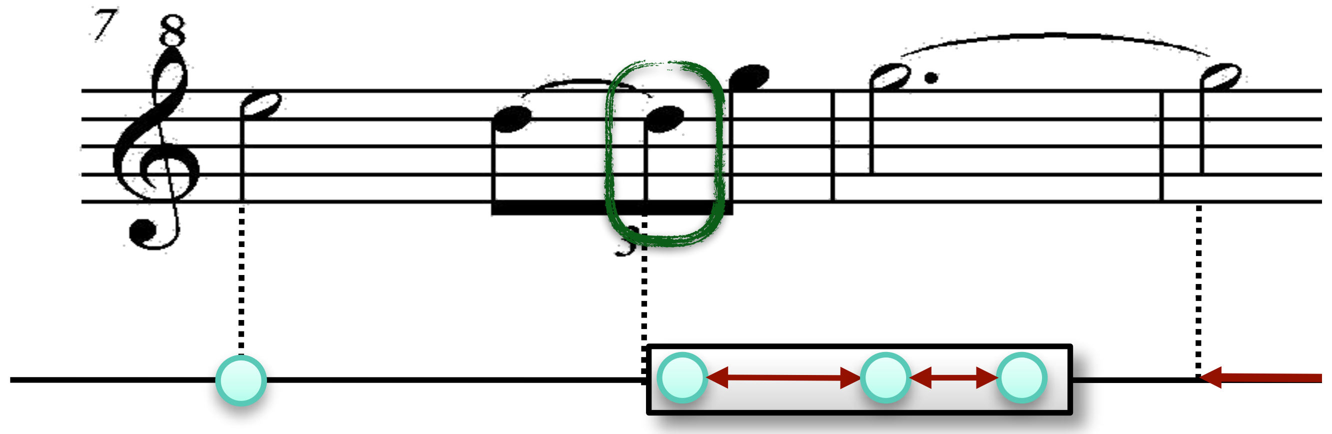
$\langle e_1, 0, 120 \rangle \langle e_2, 2, 120 \rangle \langle e_3, 2.33, 120 \rangle$

Timed Traces

Timed Input Trace

e

tempo: 120bpm



Definition:

A timed trace is a tuple <s, t, p>:

s: symbol
t: timestamp in time unit
p: pace in time unit per minute

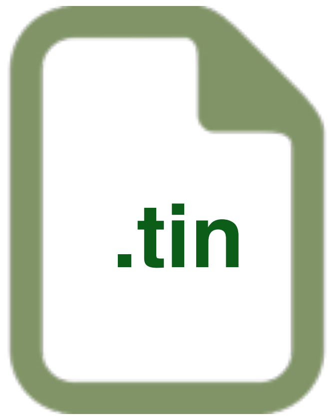
Specified inputs

$\langle e_1, 0, 120 \rangle \langle e_2, 2, 120 \rangle \langle e_3, 2.33, 120 \rangle \langle e_4, 2.66, 120 \rangle \langle e_5, 3, 120 \rangle \langle e_6, 6, 120 \rangle$

$\langle e_1, 0, 120 \rangle \langle e_2, 2, 120 \rangle$! $\langle e_4, 2.66, 120 \rangle \langle e_5, 3, 120 \rangle \langle e_6, 6, 120 \rangle$

$\langle e_1, 0, 120 \rangle \langle e_2, 1.9, 120 \rangle$ $\langle e_4, 2.76, 120 \rangle \langle e_5, 3.2, 120 \rangle \langle e_6, 5.9, 120 \rangle$

$\langle e_1, 0, 119 \rangle \langle e_2, 1.9, 80.9 \rangle$ $\langle e_4, 2.76, 114 \rangle \langle e_5, 3.2, 115.3 \rangle \langle e_6, 5.9, 119 \rangle$



errors

Interpretation

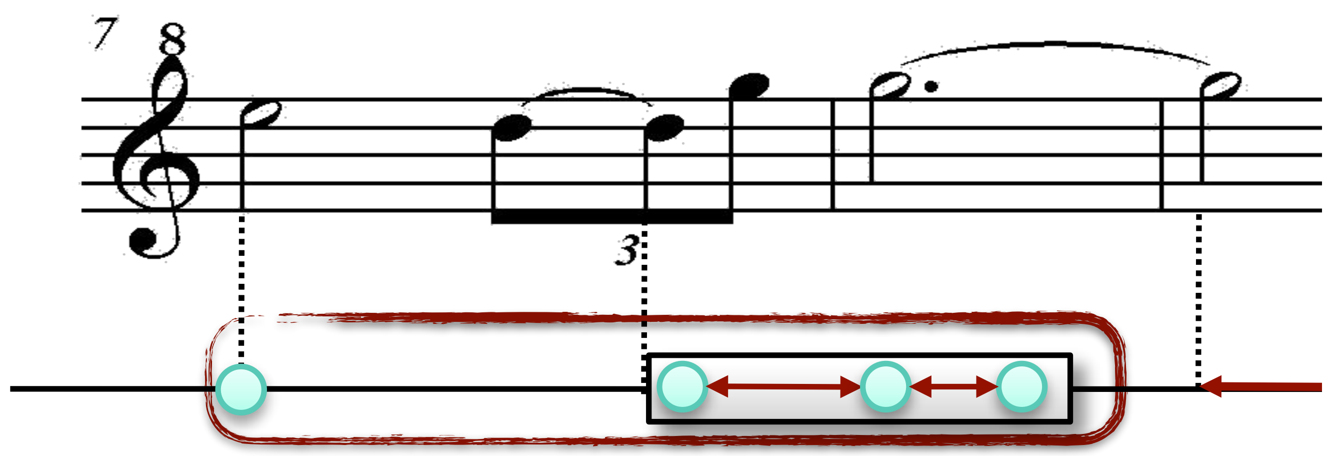
variations

Timed Traces

Timed Input Trace

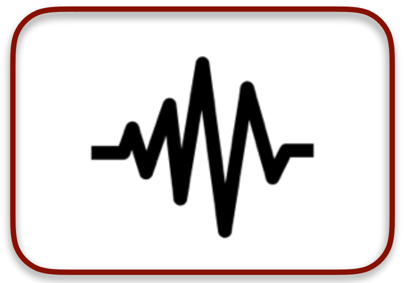
e

tempo: 120bpm



Timed Output Trace

a



Specified inputs

.tref

Expected trace

$\langle e_1, 0, 120\rangle\langle e_2, 2, 120\rangle\langle e_3, 2.33, 120\rangle\langle e_4, 2.66, 120\rangle\langle e_5, 3, 120\rangle\langle e_6, 6, 120\rangle$

$\langle a_1, 0, 60\rangle\langle a_2, 2.66, 60\rangle\langle a_3, 3, 60\rangle$

$\langle e_1, 0, 120\rangle\langle e_2, 2, 120\rangle$ **!** $\langle e_4, 2.66, 120\rangle\langle e_5, 3, 120\rangle\langle e_6, 6, 120\rangle$

$\langle e_1, 0, 120\rangle\langle e_2, 1.9, 120\rangle$ $\langle e_4, 2.76, 120\rangle\langle e_5, 3.2, 120\rangle\langle e_6, 5.9, 120\rangle$

$\langle e_1, 0, 119\rangle\langle e_2, 1.9, 80.9\rangle$ $\langle e_4, 2.76, 114\rangle\langle e_5, 3.2, 115.3\rangle\langle e_6, 5.9, 119\rangle$

.tin

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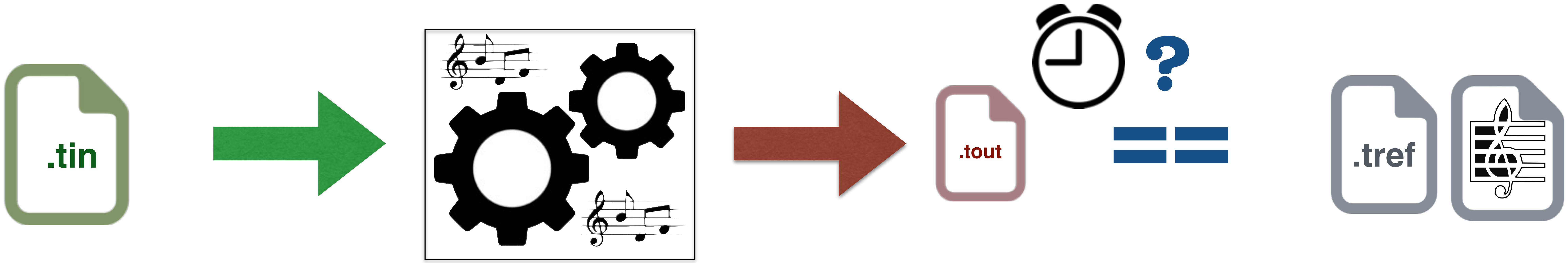
Timed Conformance Testing

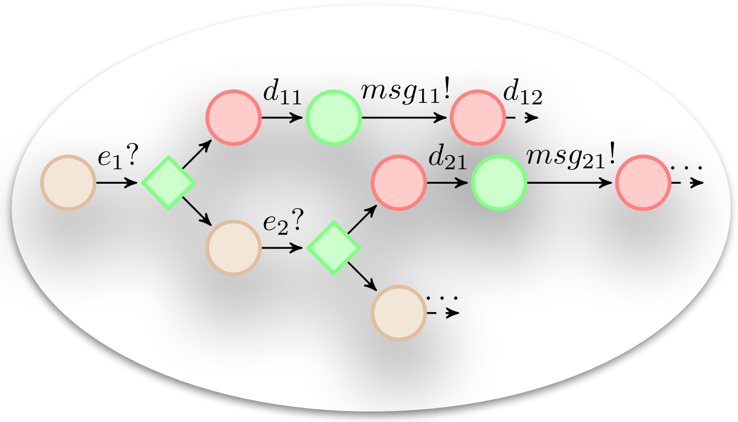
Timed conformance



Set of relevant inputs

Set of corresponding implementation outputs

Computation of expected outputs



Models

Environment Model

$\mathcal{E}$

e

a

$\mathcal{S}$

System Model

Model = E + S

Bound performances

Compute expected output

Interactive Real-Time Model

Timed Automata with Input-Output

TA aspects

Synchronous aspects

IRTM

TAIO

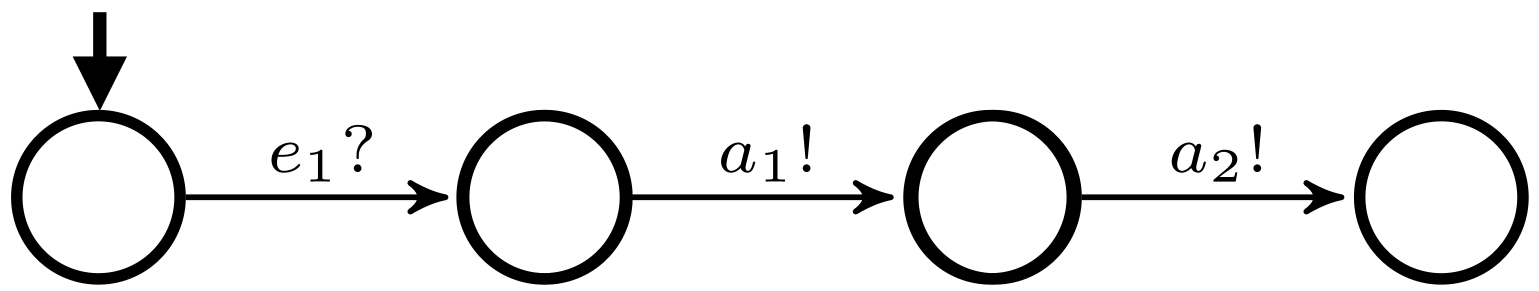
model-checking / decidability

Labelled Transition System

System Specification

Input/Output

e **a**

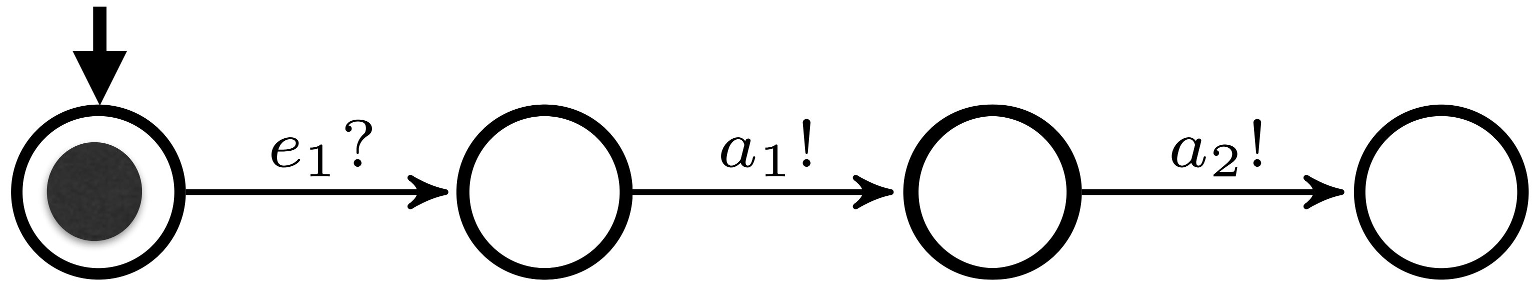


Jan Tretmans.
Model Based Testing with Labelled Transition Systems.
Formal Methods and Testing, an outcome of the FORTEST.

M. Timmer, E. Brinsksma and M. Stoelinga.
Model Based Testing.
Software and Systems Safety - Specification and Verification.

Labelled Transition System

Simulation



.tin

.tref

Jan Tretmans.
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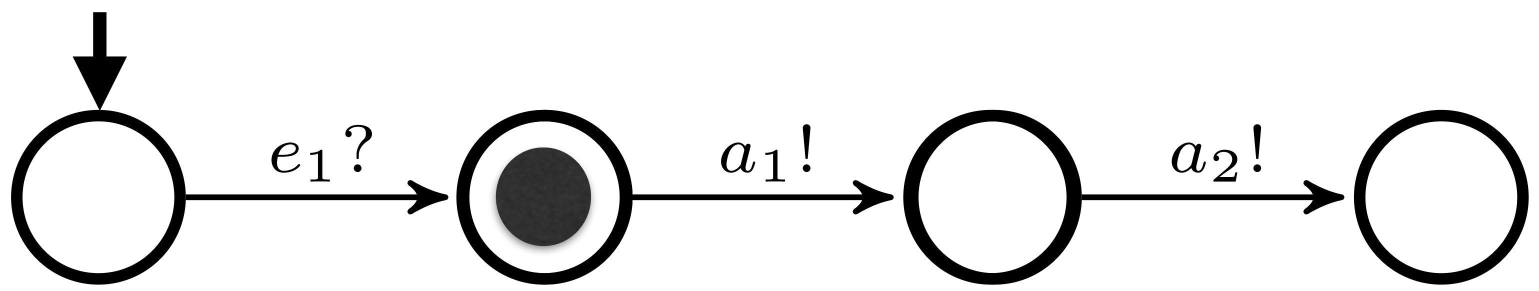

Receive e_1

.tin

e_1

.tref

Jan Tretmans.
Model Based Testing with Labelled Transition Systems.
Formal Methods and Testing, an outcome of the FORTEST.

M. Timmer, E. Brinksma and M. Stoelinga.
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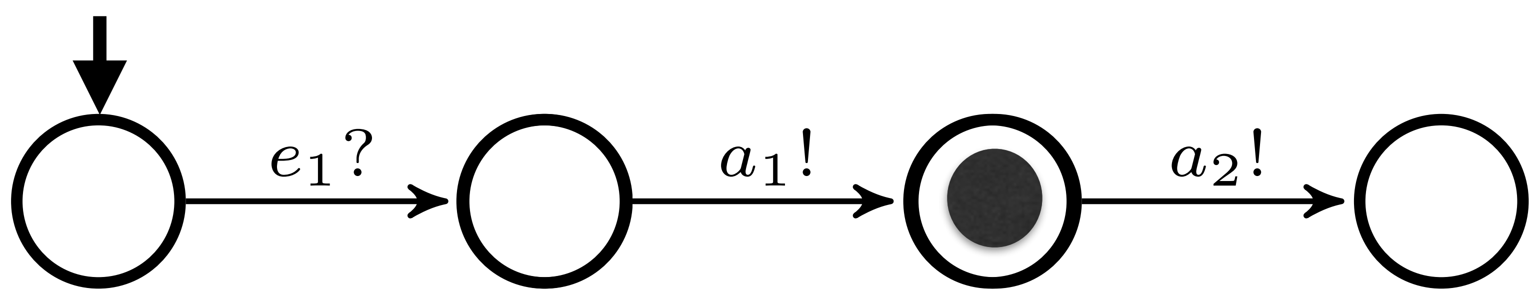
Labelled Transition System

Simulation



Send a_1

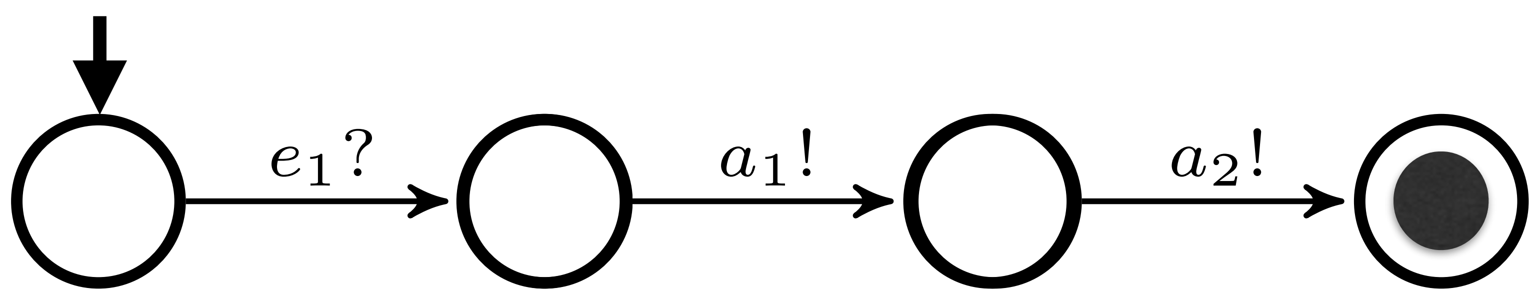
a_1

Jan Tretmans.
Model Based Testing with Labelled Transition Systems.
Formal Methods and Testing, an outcome of the FORTEST.

M. Timmer, E. Brinksma and M. Stoelinga.
Model Based Testing.
Software and Systems Safety - Specification and Verification.

Labelled Transition System

Simulation



Send a_2

a_1 a_2

Jan Tretmans.
Model Based Testing with Labelled Transition Systems.
Formal Methods and Testing, an outcome of the FORTEST.

M. Timmer, E. Brinksma and M. Stoelinga.
Model Based Testing.
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Timed Automata with Input-Output

System Specification

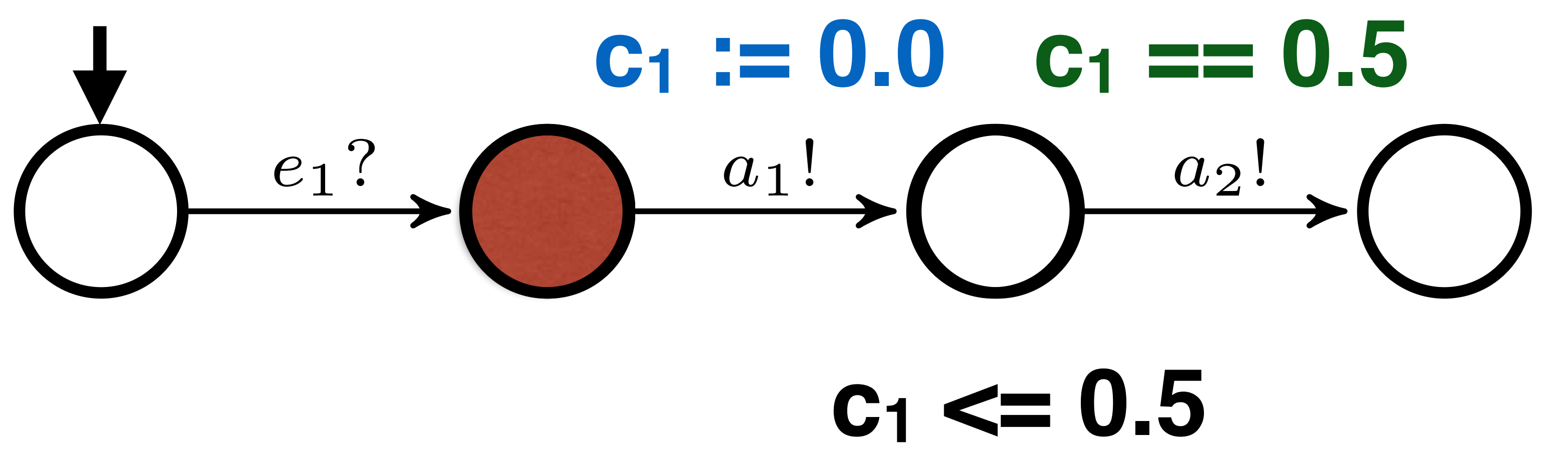
Time

clock value: $c_i = \mathbb{R}_+.$

Finite set of clocks valued on <u>reels</u>

Abstract Time

Same rate



Urgent locations

Restricted with **guards** and **invariants**

Reset with **affectations**

R. Alur and D. Dill.
A theory of timed automata.
Theoretical Computer Science.

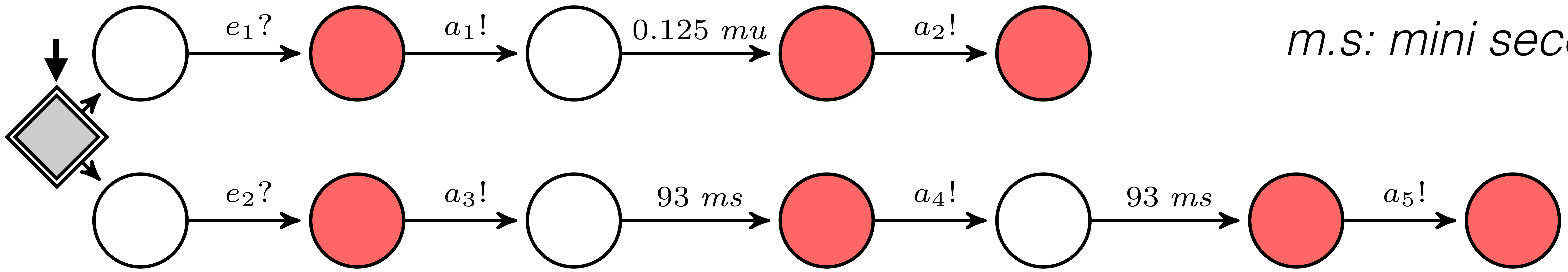
A. David, K.G. Larsen, S. Li, M. Mikucionis, B. Nielsen.
Testing real-time systems under uncertainty. FMCO'10.

Interactive Real-Time Model (IRTM)

System Specification

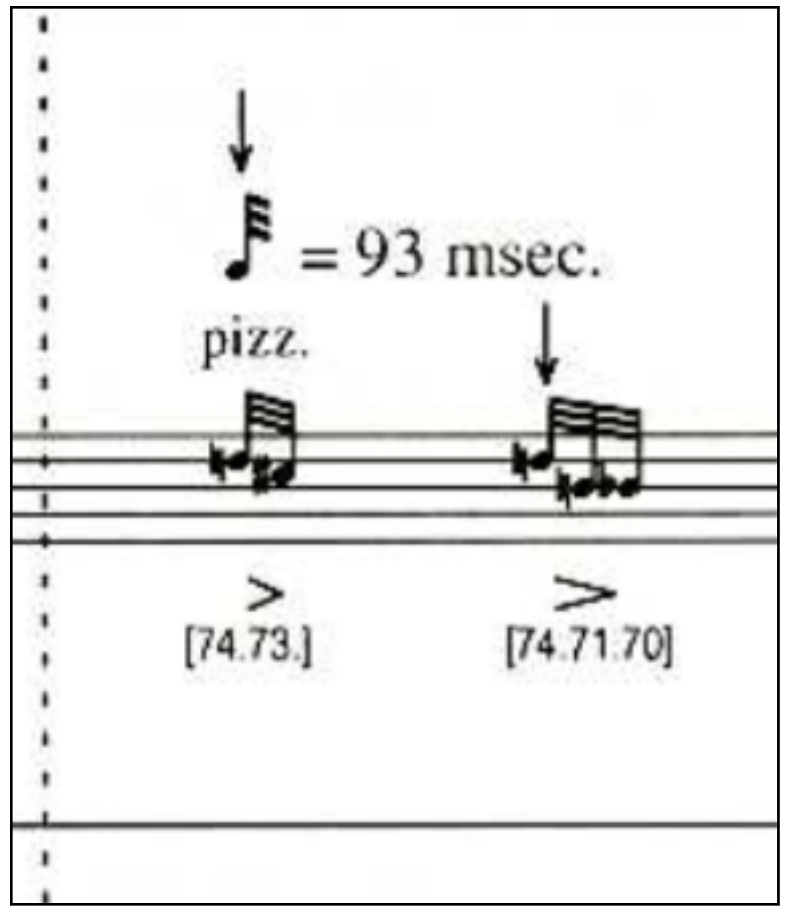
m.u: musical time unit

m.s: mini seconds



Extended aspects

TA aspects



Multiple time units

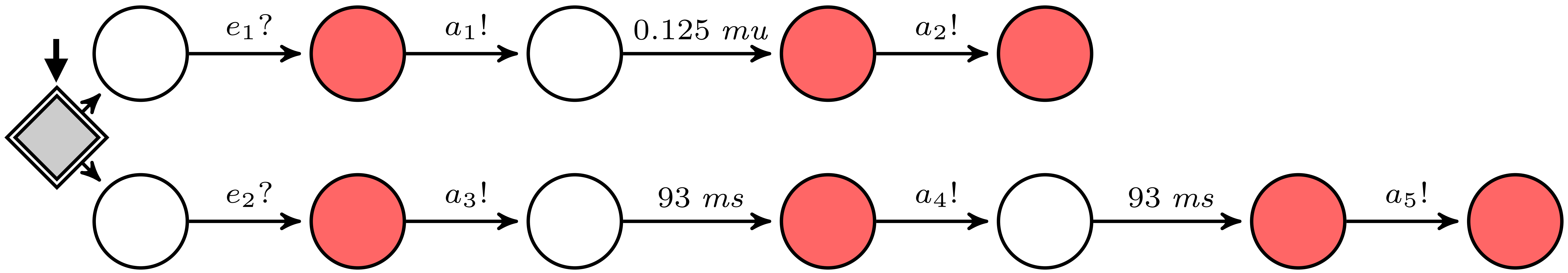
Alternation

Clock constraints

Transition Discrete/Temporal

IRTM: System Model

Synchronous aspects



Dense time

State: $\langle$ t, n $\rangle$ [controls] { symbols }

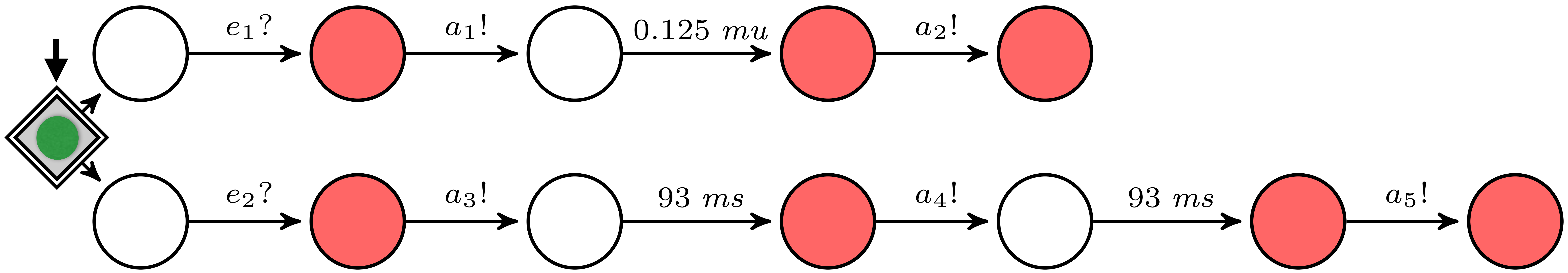
control: $C_i = \mathbb{R}_+$

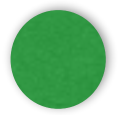
Poncelet, Jacquemard.
Model Based Testing of an Interactive Music System. 30th ACM/SIGAPP Symposium Computing (ACM SAC, 2015).

Poncelet, Jacquemard.
Model-Based Testing for Building Reliable Realtime Interactive Music Systems. Science of Computer Programming (SCP, 2016).

IRTM: System Model

Simulation





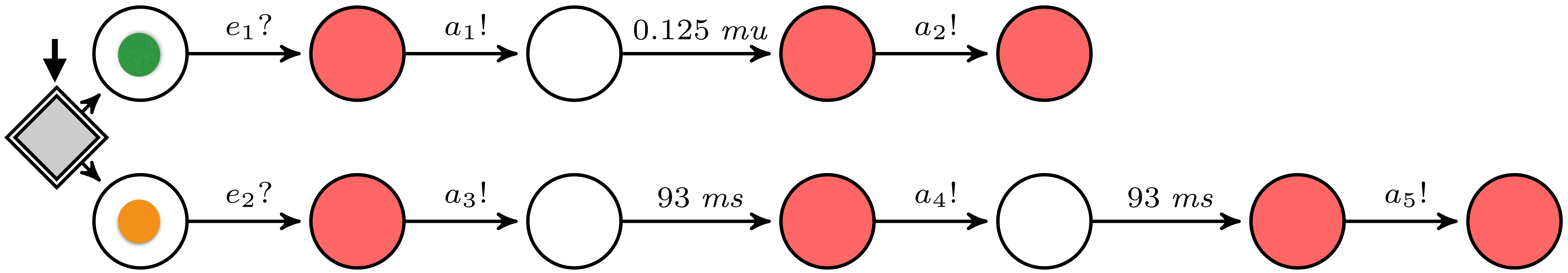
lead

State: $\langle 0, 0 \rangle$ $[$ C1:0 $]$ $\{\,\}$

IRTM: System Model

Simulation

Alternation



lead

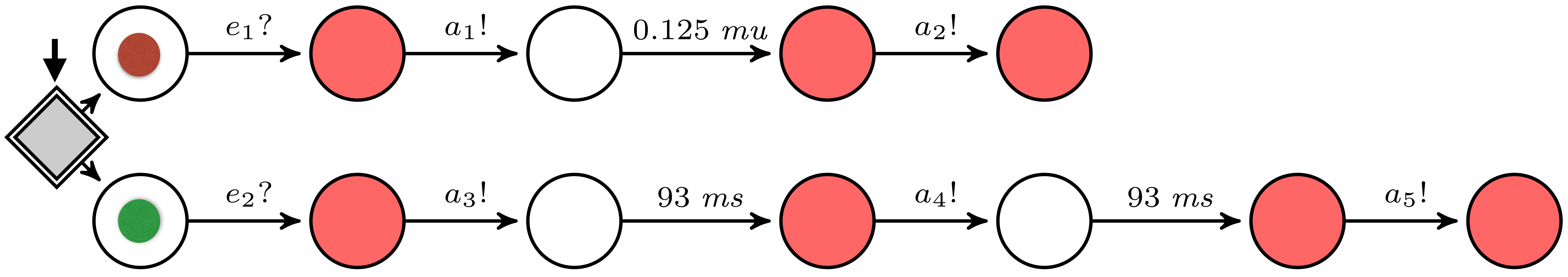
wait

State: $\langle 0, 1 \rangle \left[\underline{C_1{=}0} :: C_2{=}0 \right] \{\,\}$

IRTM: System Model

Simulation

Cooperative Scheduling



lead

wait

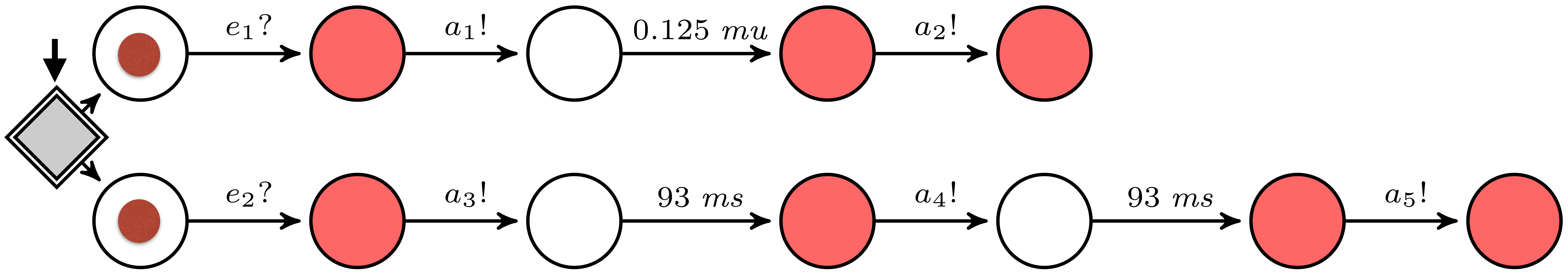
suspended

State: $\langle 0, 1 \rangle \ [\ C_1{=}0 :: \underline{C_2{=}0}\ ]\ \{\ \}$

IRTM: System Model

Simulation

End of logical instant



Synchronous aspect

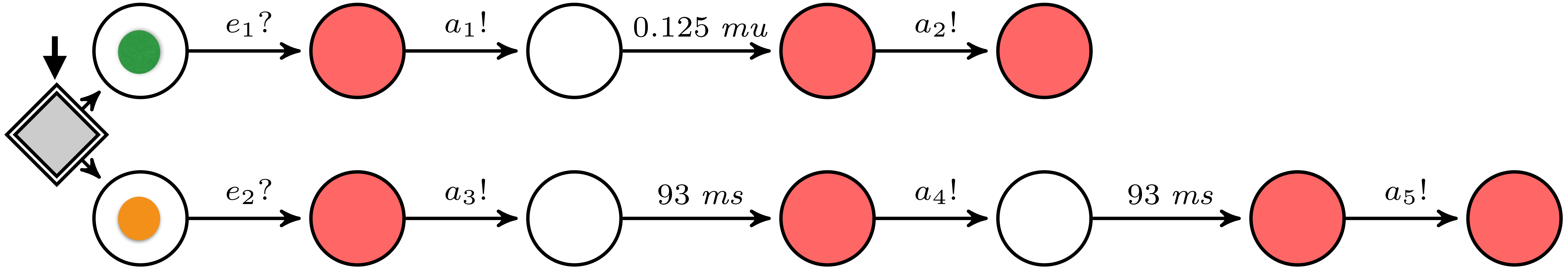
TA aspects

Transition Discrete/Temporal

State: $\langle 0, 1 \rangle \left[C_1{=}0 :: C_2{=}0 \right] \{\ \}$

IRTM: System Model

Simulation

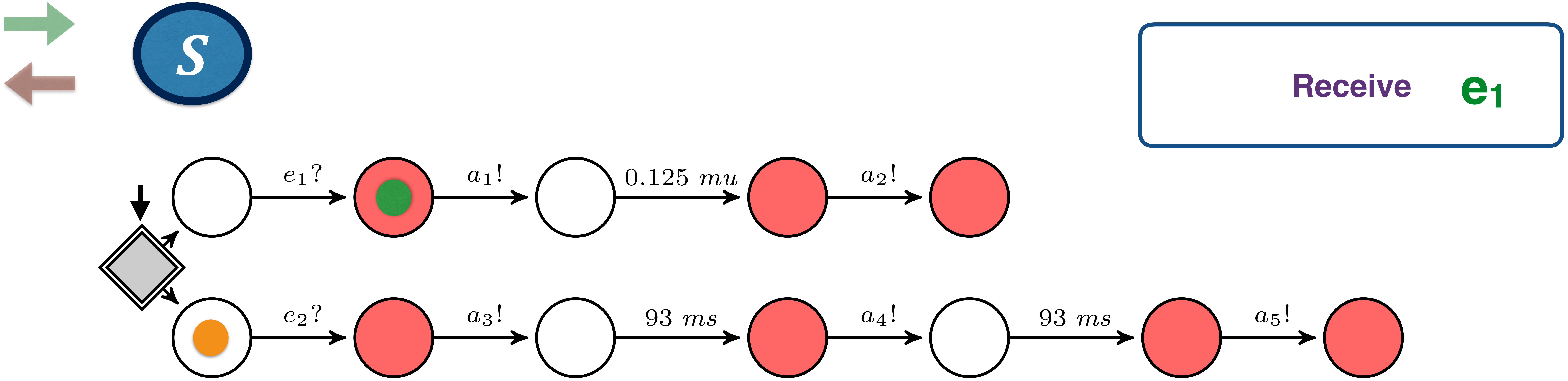


.tin → $\langle e_1, 0, 184 \rangle$

State: $\langle 0, 1 \rangle$ $[\ \underline{C_1=0} :: C_2=0\ ]$ $\{ e_1 \}$

IRTM: System Model

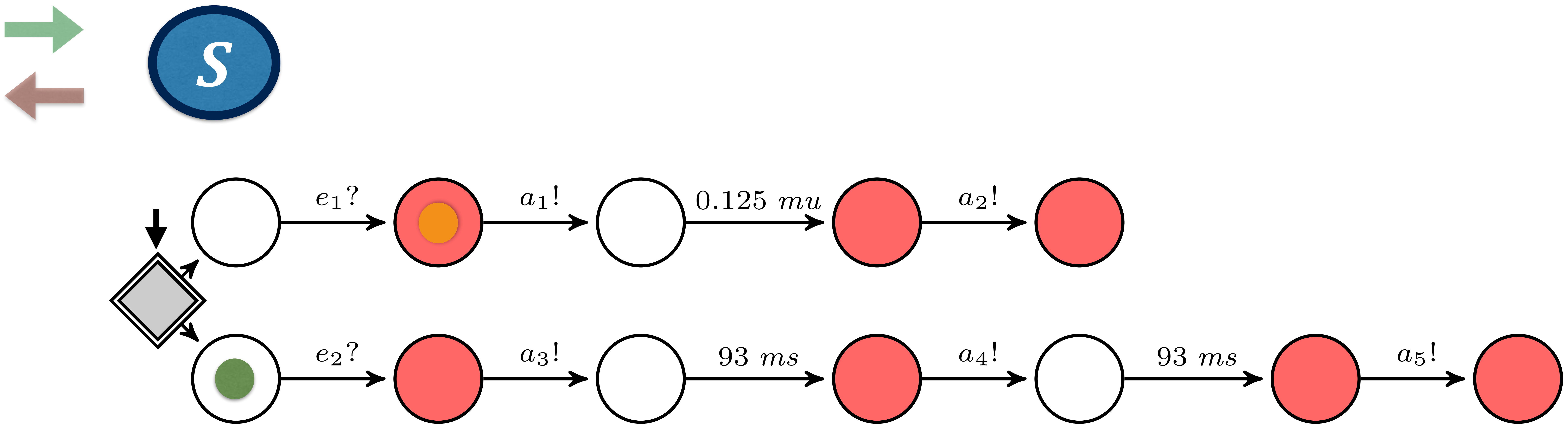
Simulation



State: $\langle 0, 2 \rangle \left[\underline{C_1{=}0} :: C_2{=}0 \right] \{ e_1 \}$

IRTM: System Model

Simulation



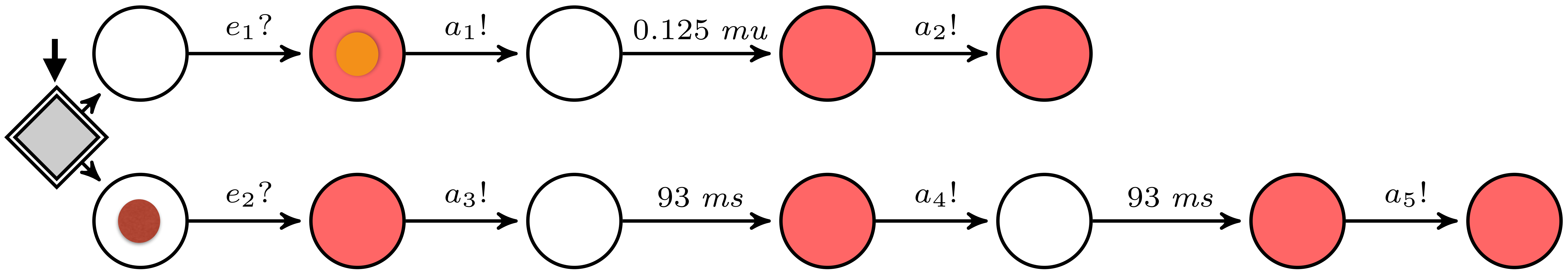
extended aspects

Priorities

State: $\langle 0, 2 \rangle \left[\underline{C_1{=}0} :: C_2{=}0 \right] \{ e_1 \}$

IRTM: System Model

Simulation



extended aspects

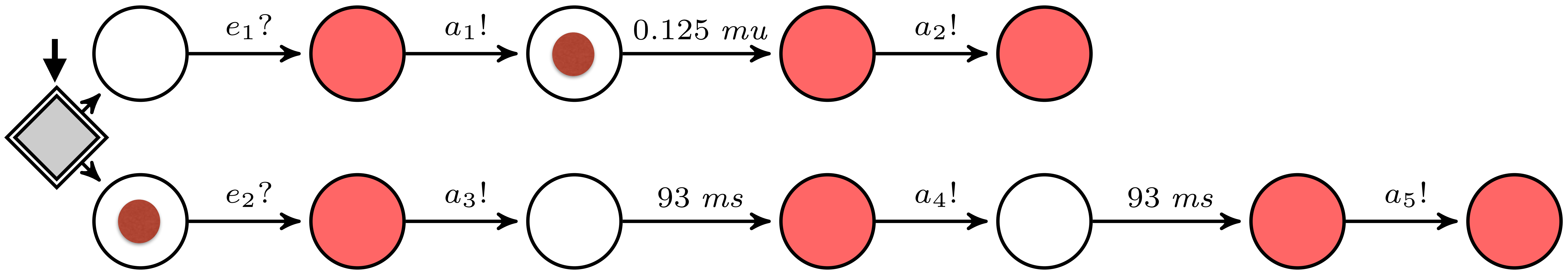
Priorities

State: $\langle 0, 2 \rangle \left[\underline{C_1{=}0} :: C_2{=}0 \right] \{ e_1 \}$

IRTM: System Model

Simulation

Send a_1



State: $\langle 0, 3 \rangle \left[\underline{C_1{=}0} :: C_2{=}0 \right] \{ e_1 \}$

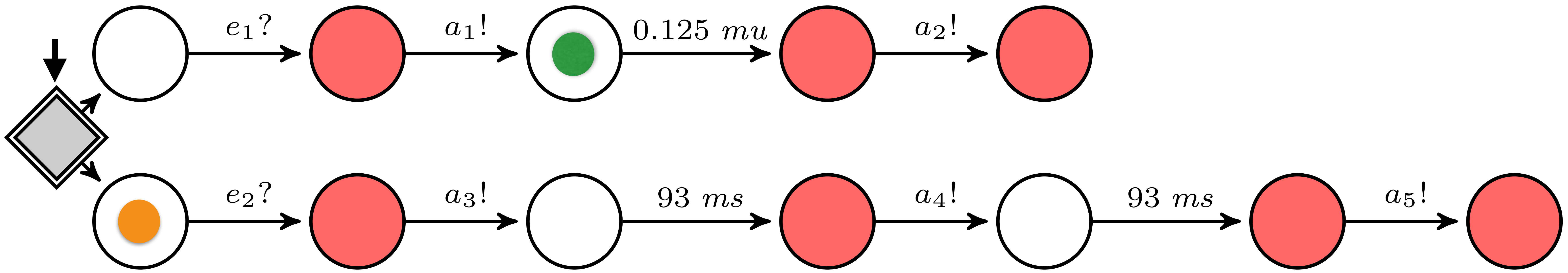
.tref

$\langle a_1, 0 \rangle$

IRTM: System Model

Simulation

Delay **0.040**

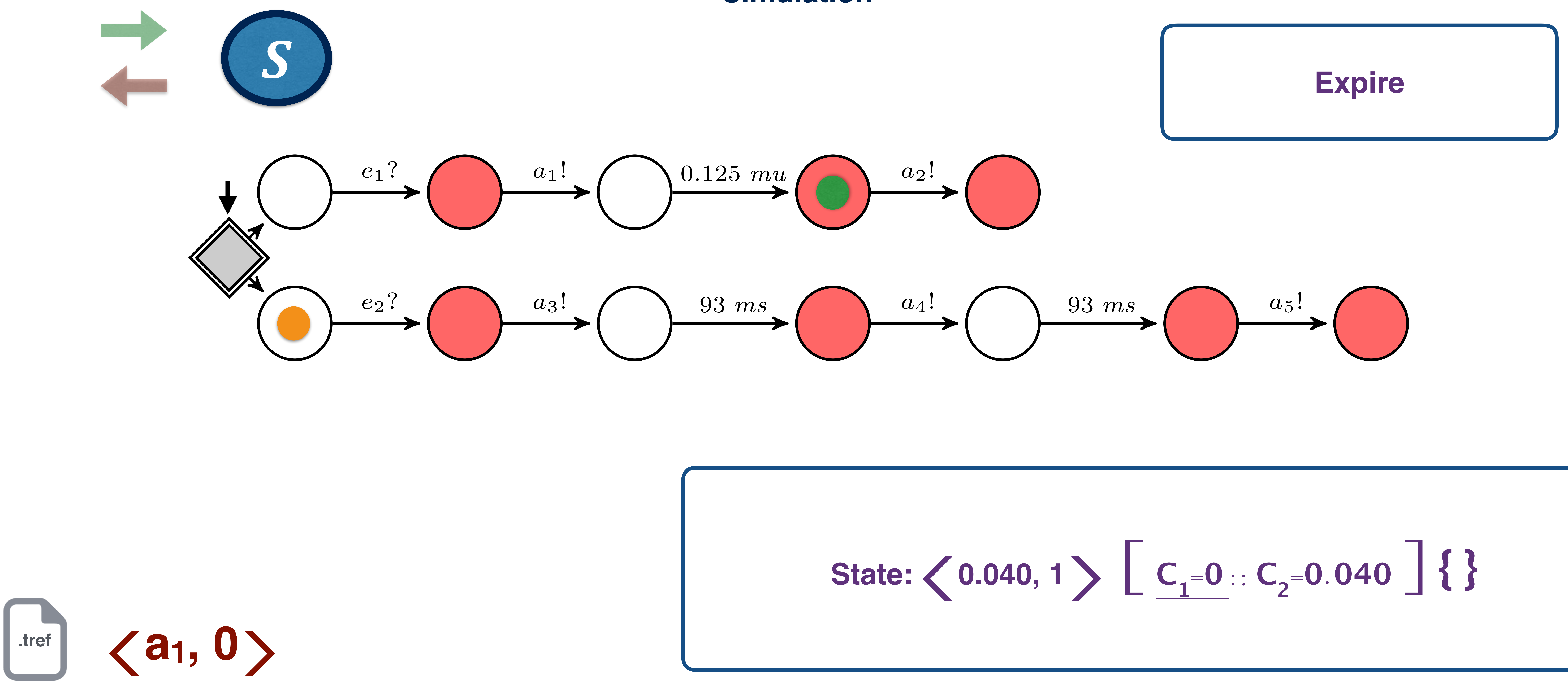


State: $\langle 0.040, 0 \rangle$ $[\ C_1{=}0.040 :: C_2{=}0.040\ ]$ $\{\ \}$

.tref $\langle a_1, 0 \rangle$

IRTM: System Model

Simulation

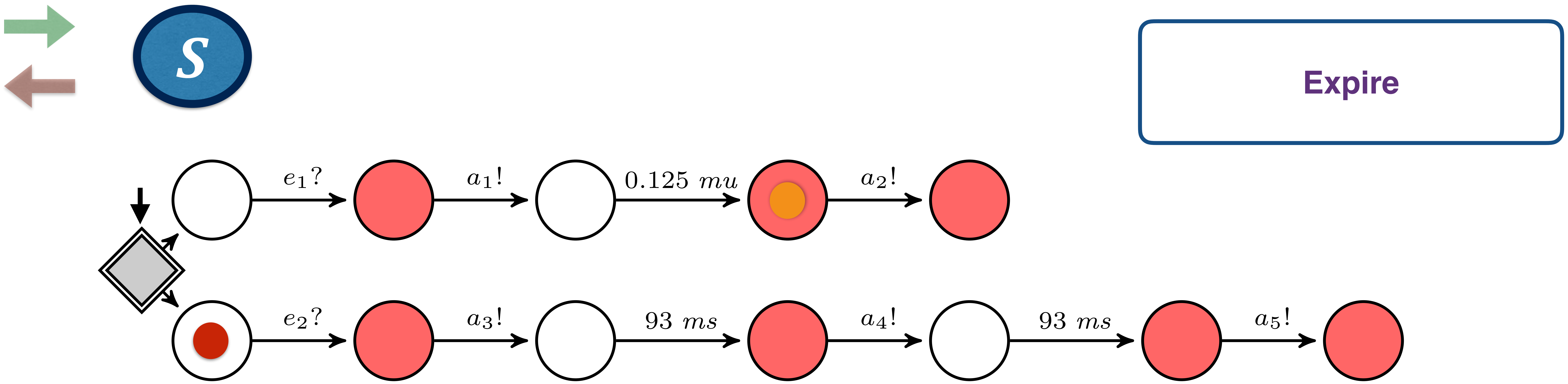


$\langle a_1, 0 \rangle$

State: $\langle 0.040, 1 \rangle \left[\underline{C_1{=}0} :: C_2{=}0.040 \right] \{\}$

IRTM: System Model

Simulation



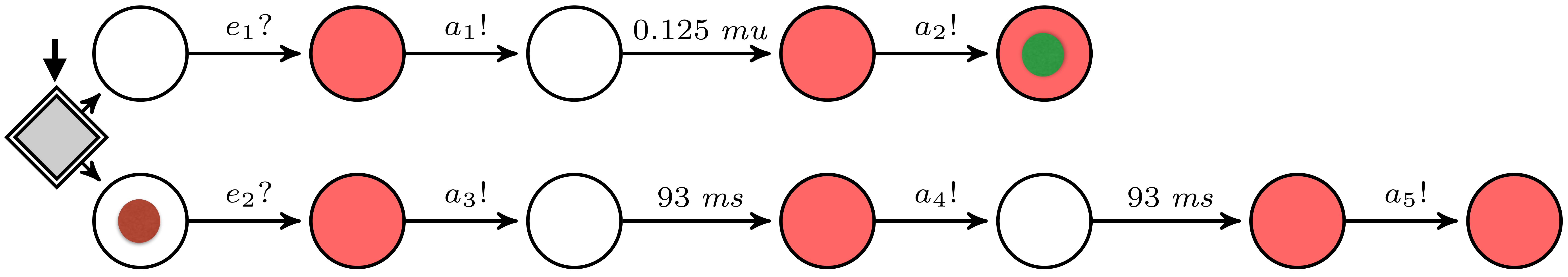
State: $\langle 0.040, 1 \rangle$ $[\, \underline{C_1=0} :: C_2=0.040 \,]$ { }

$\langle a_1, 0 \rangle$

IRTM: System Model

Simulation

Send a_2



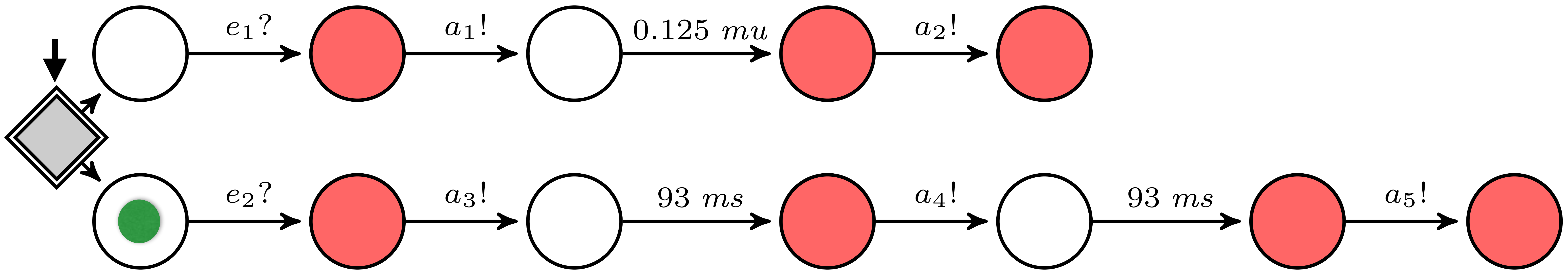
State: $\langle 0.040, 2 \rangle \left[\underline{C_1{=}0} :: C_2{=}0.040 \right] \{\}$

.tref $\langle a_1, 0 \rangle \langle a_2, 0.040 \rangle$

IRTM: System Model

Simulation

Remove Control Point

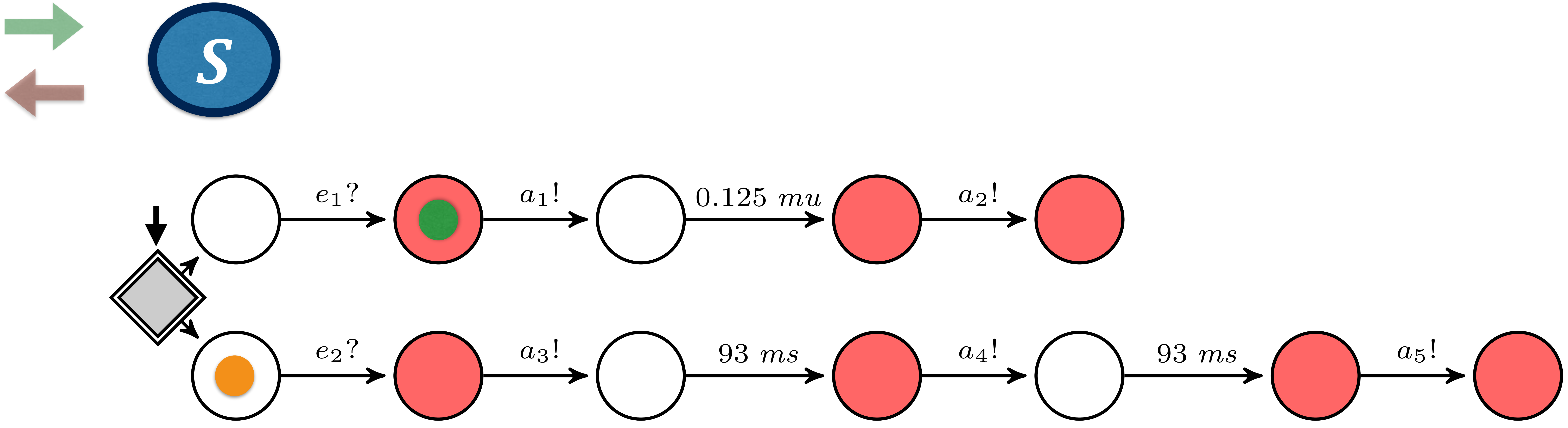


State: $\langle$ **0.040, 3** $\rangle$ $[\ \underline{C_2 = 0.040}\ ]$ { }

.tref $\langle$ **a_1, 0** $\rangle\langle$ **a_2, 0.040** $\rangle$

IRTM: System Model

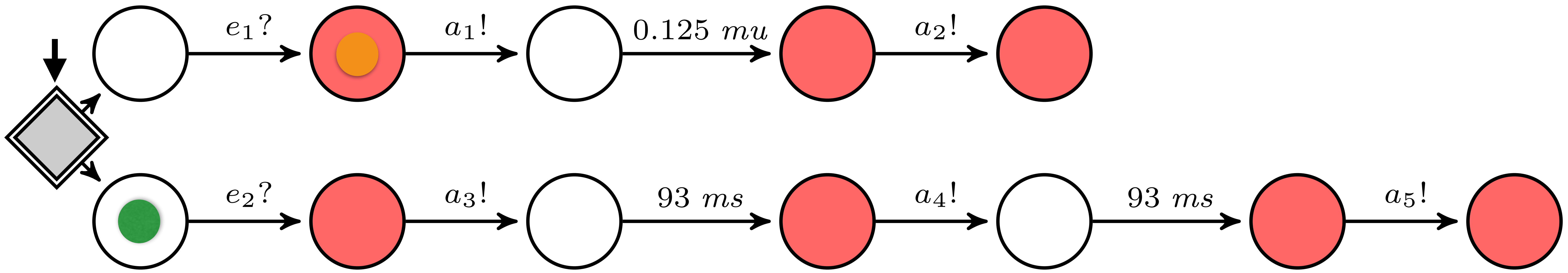
Simulation



State: $\langle 0, 2 \rangle\ [\ C_1{=}0 :: C_2{=}0\ ]\ \{ e_1, e_2 \}$

IRTM: System Model

Simulation

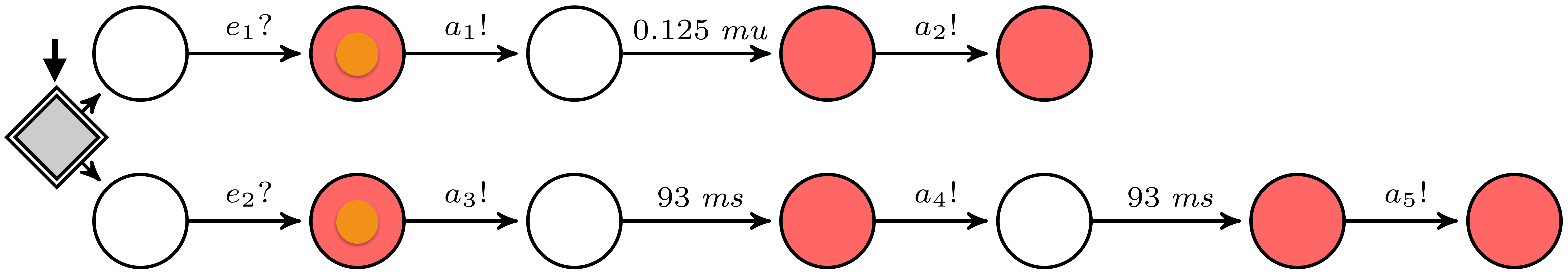


State: $\langle 0, 2 \rangle \left[C_1{=}0 :: \underline{C_2{=}0} \right] \{ e_1, e_2 \}$

IRTM: System Model

Simulation

Receive e_2

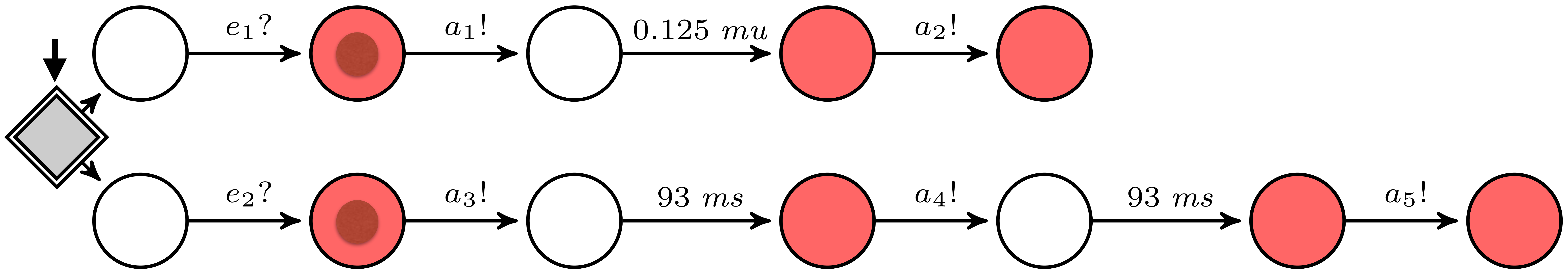


State: $\langle 0, 3 \rangle \; [\, C_1{=}0 :: C_2{=}0 \,] \; \{ e_1, e_2 \}$

IRTM: System Model

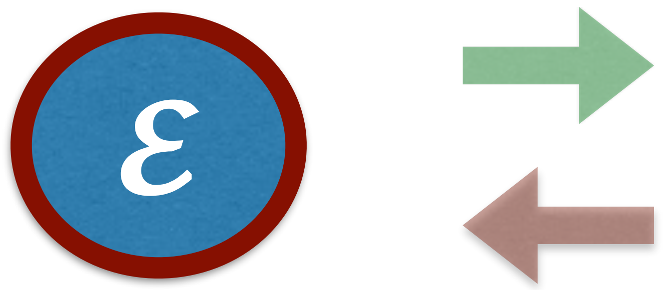
Simulation

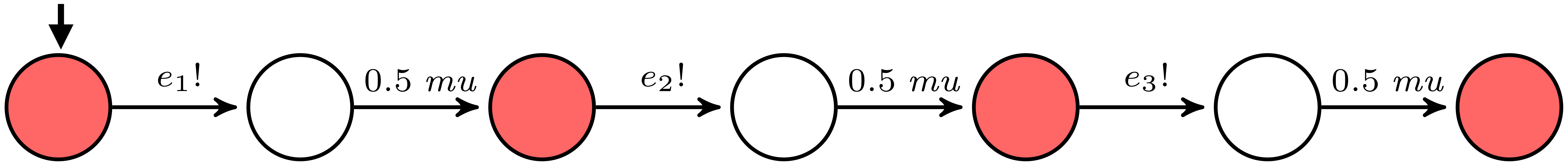
Send $\min(a_1, a_3)$

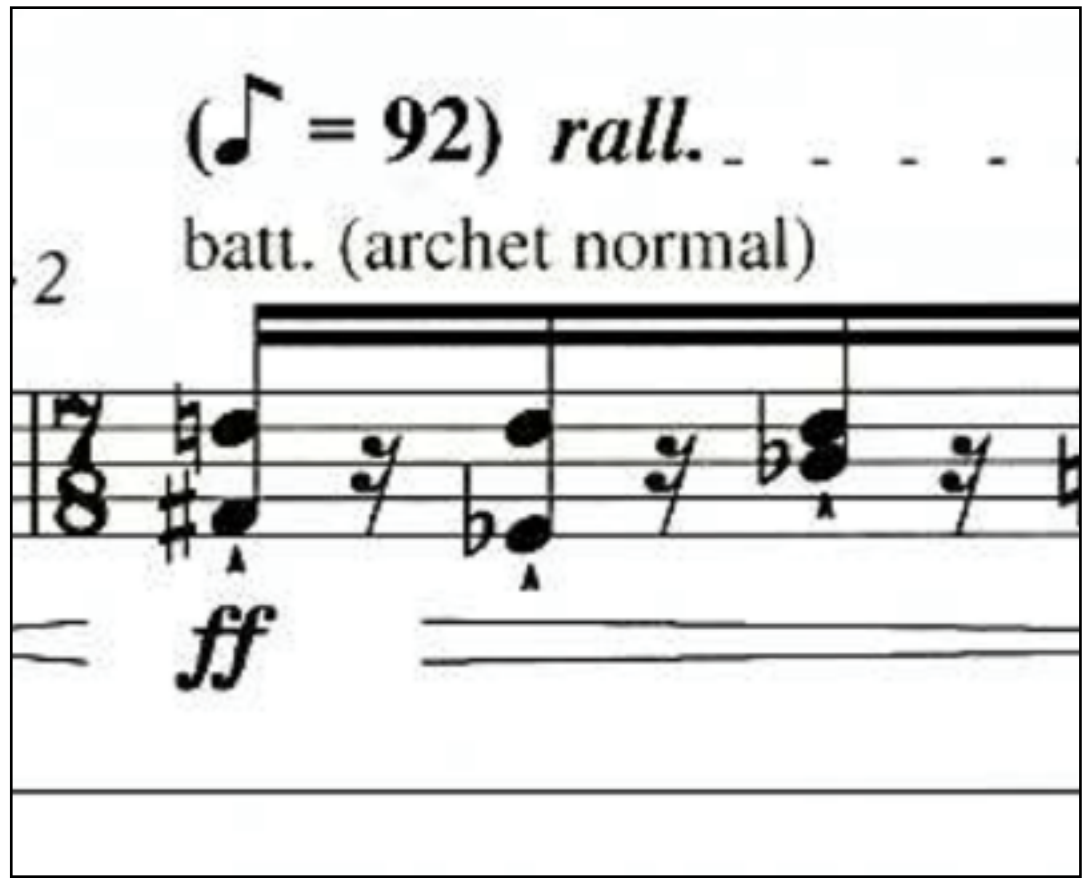


State: $\langle 0, 3 \rangle \left[C_1{=}0 :: C_2{=}0 \right] \{ e_1, e_2 \}$

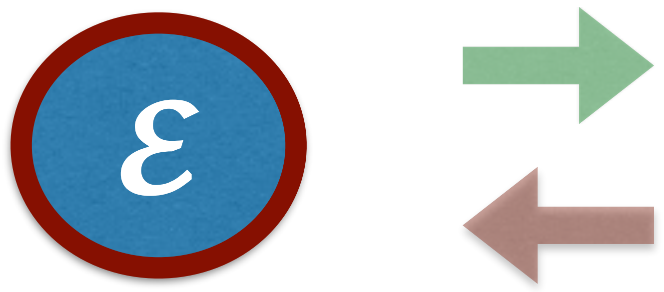
IRTM: Environment Model

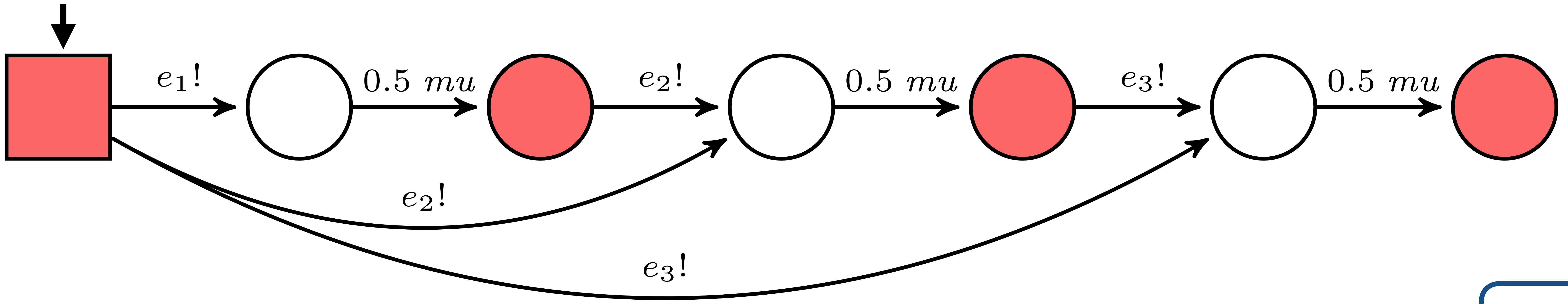






Non-Determinism: missed events





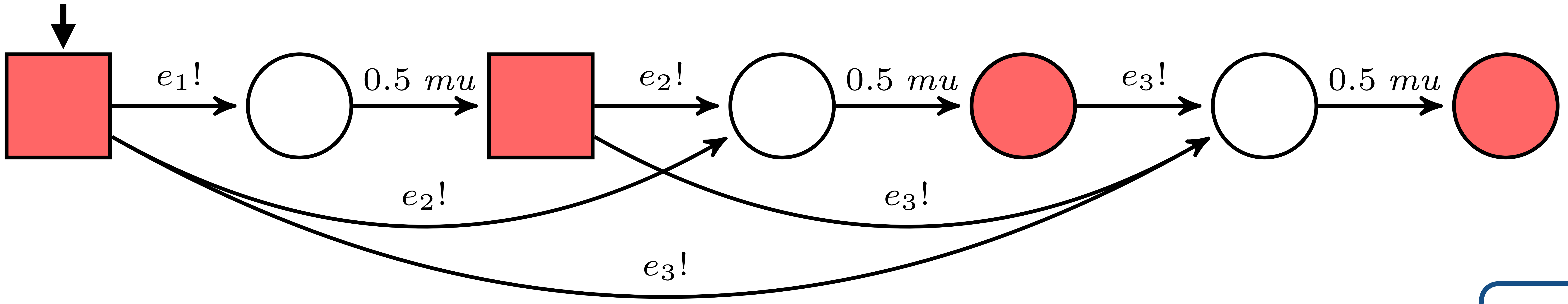
TA aspects

missed events

Non-determinism

Interpretation

Non-Determinism: missed events



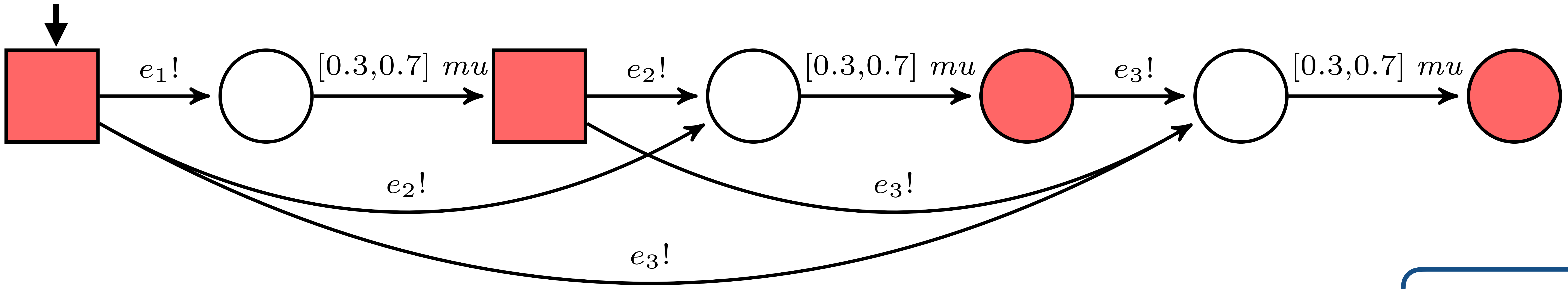
TA aspects

missed events

Non-determinism

Interpretation

Non-Determinism: duration variation



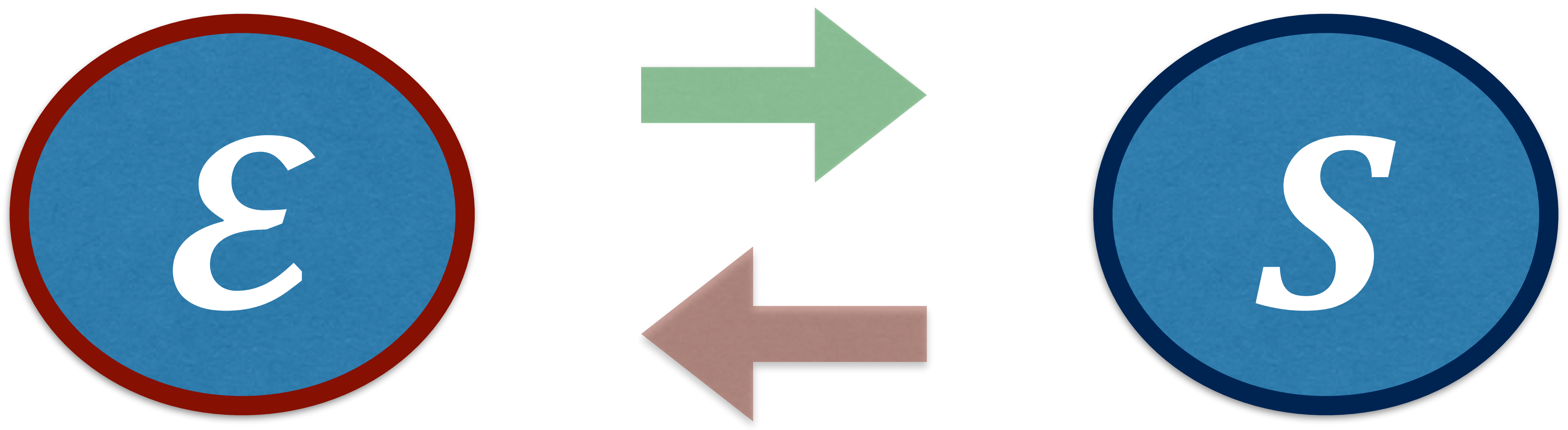
TA aspects

duration bounds

Interpretation

Non-determinism

Outline



1. Objectives

2. Interactive Real-Time Model

3. **Testing Framework**

Contribution

Publications

journals

Poncelet, Jacquemard.
Model-Based Testing for Building Reliable Realtime Interactive Music Systems. Science of Computer Programming (SCP, 2016).

Burloiu, Cont, *Poncelet.* A visual framework for dynamic mixed music notation.
Journal of New Music Research (JNMR, 2016).

C. Poncelet, F. Jaquemard.
An automatic test framework for interactive music systems.
Journal of New Music Research (JNMR), 2016.

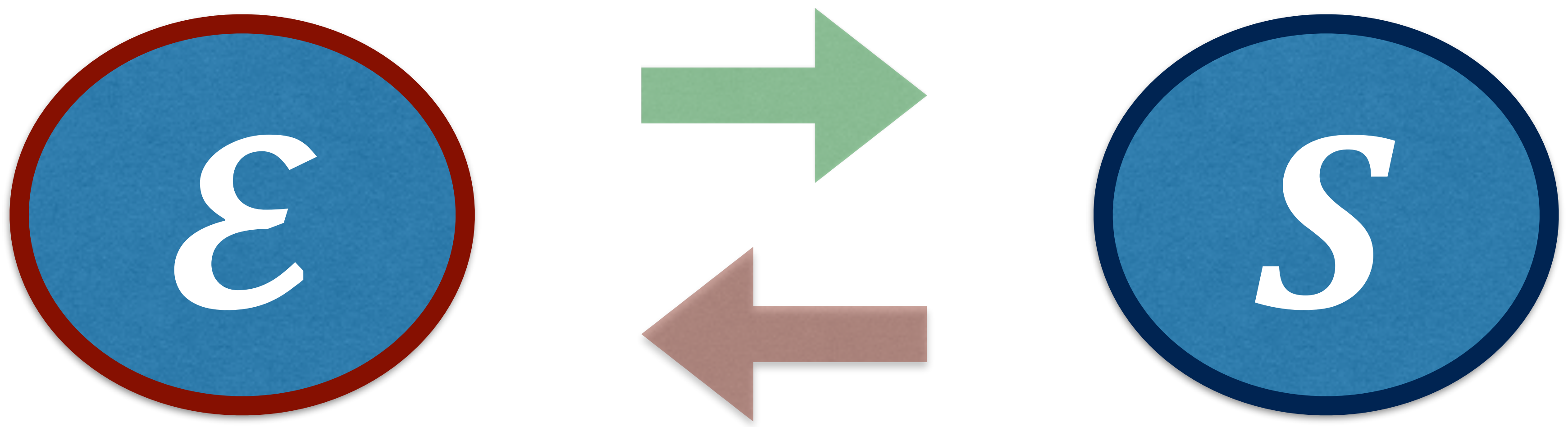
conferences

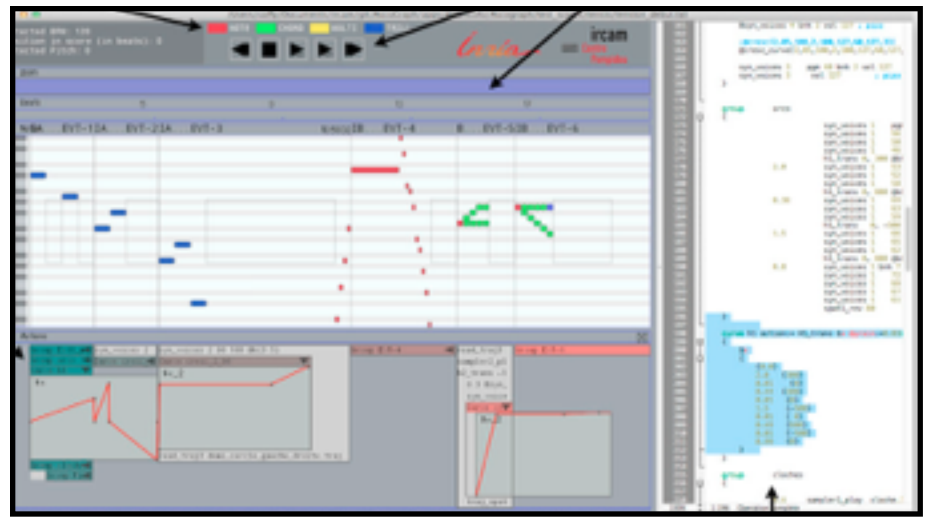
Poncelet, Jacquemard.
Model Based Testing of an Interactive Music System. 30th ACM/SIGAPP Symposium Computing (ACM SAC, 2015).

C. Poncelet, F. Jaquemard.
Test Methods for Score-Based Interactive Music Systems.
ICMC - SMS, 2014.

Developments

- **Application to Antescofo + Regression tests**
- **front-end compiler of AntescofoDSL (C++, 13.000 loc).**
- **Antescofo adaptors (C++).**
- **~ 20 Scripts for test execution (Perl).**
- **Conformance and trace manager (C++, 4.000 loc).**
- **Virtual Machine (C++, 3.000 loc).**





Perspectives

Applications:

- Visual tool for improving framework uses
  - A debug environment with Ascograph
- Application to other IMS (or timed-cyber systems)

Testing Framework:

- Improve Fuzz Testing
  - White-fuzzing Guided-Random (DART)
- Specify a concrete specification language
  - Based on a *Given-When-Then* like paradigm (Gherkin)

Interactive Real-Time Model:

- Translate IRTM into Hybrid Automata
  - add constraints on tempo
- Translate IRTM into Stochastic Automata
  - Improve the input generation

Other Applications:

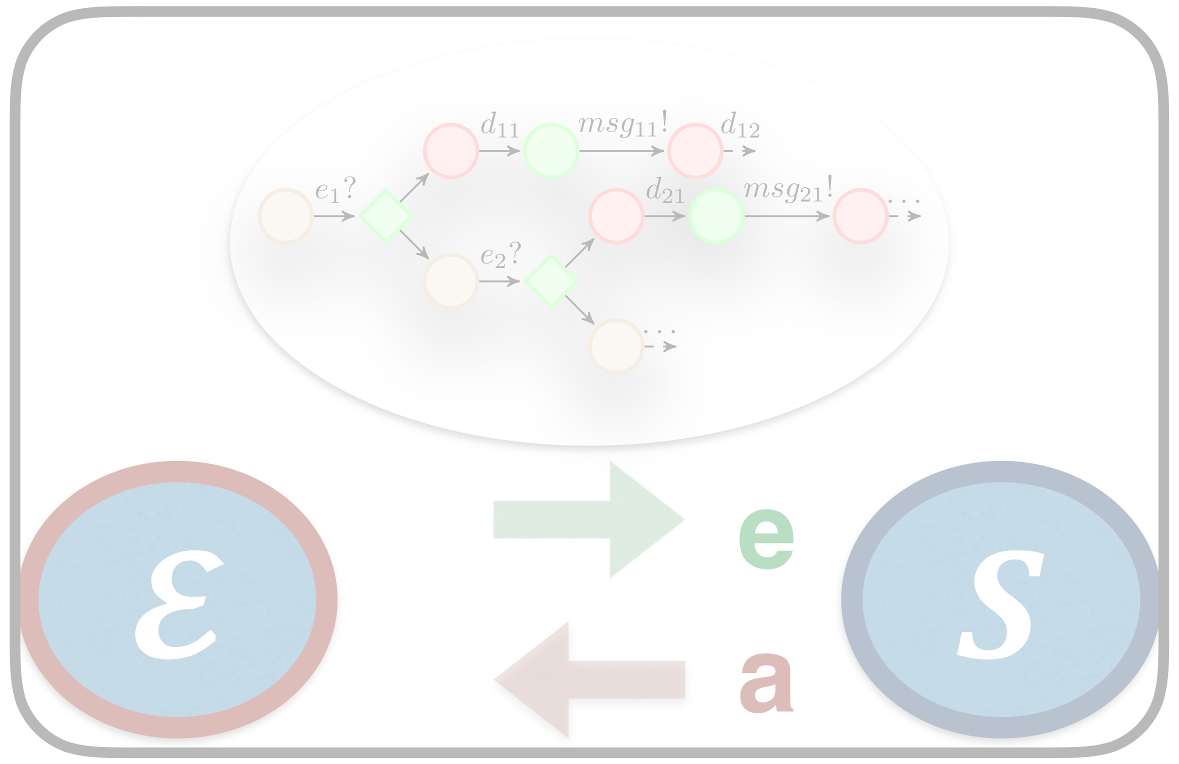
- Static Analysis of Mixed Score
- Verification of properties

```
pc7:TestOffline poncelet$
```

Testing Framework Overview

Mixed Score

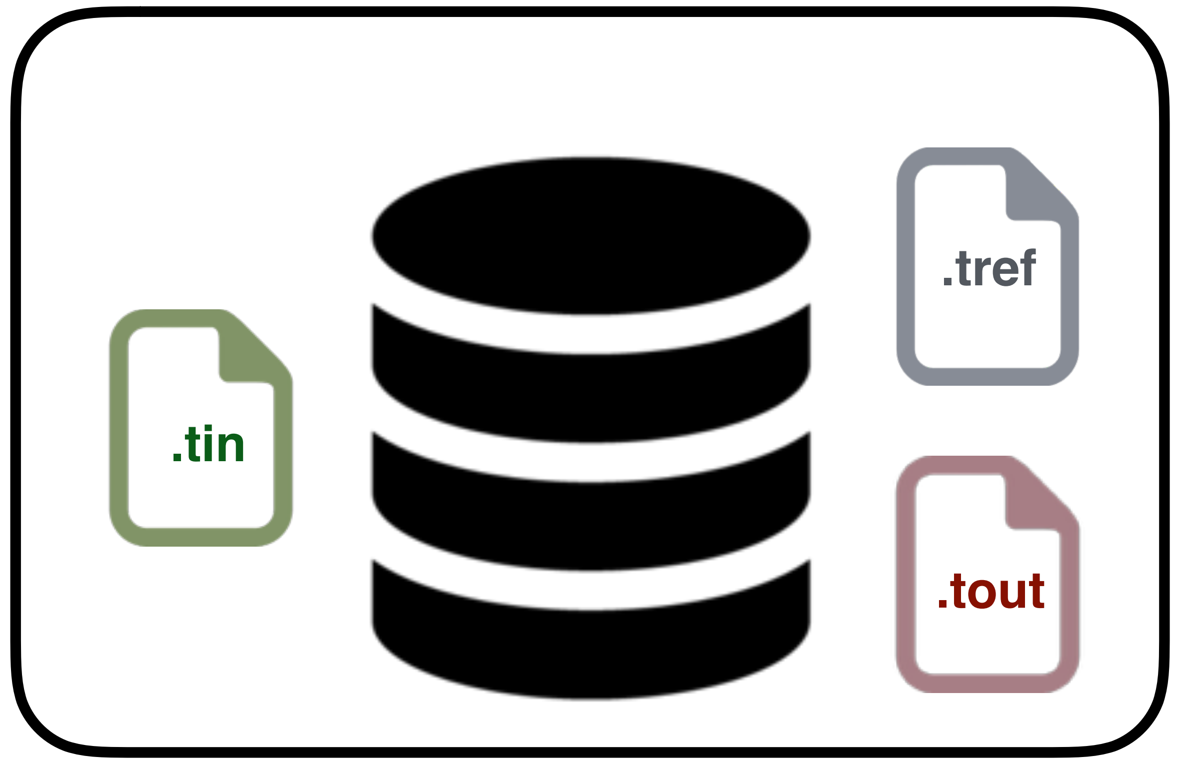
Models

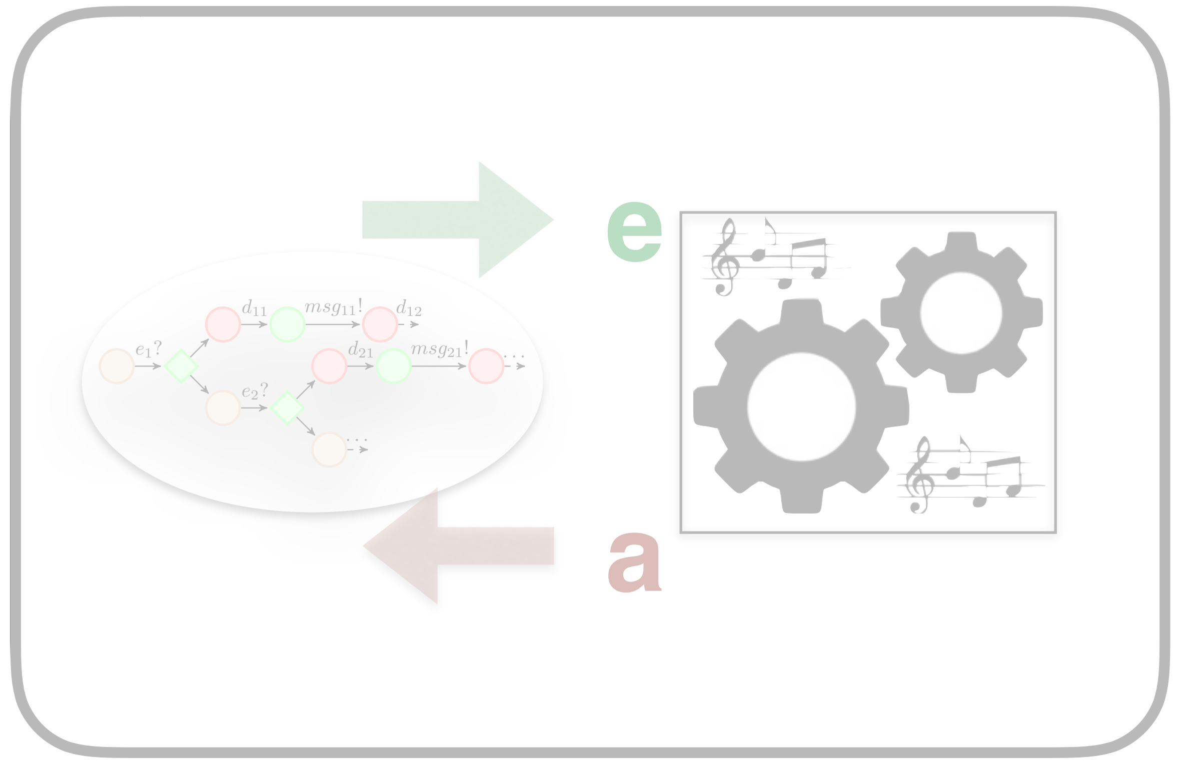


Construction:
from high level to model

Model-Based Testing:
from model to verdict

Offline Approach





Online Approach

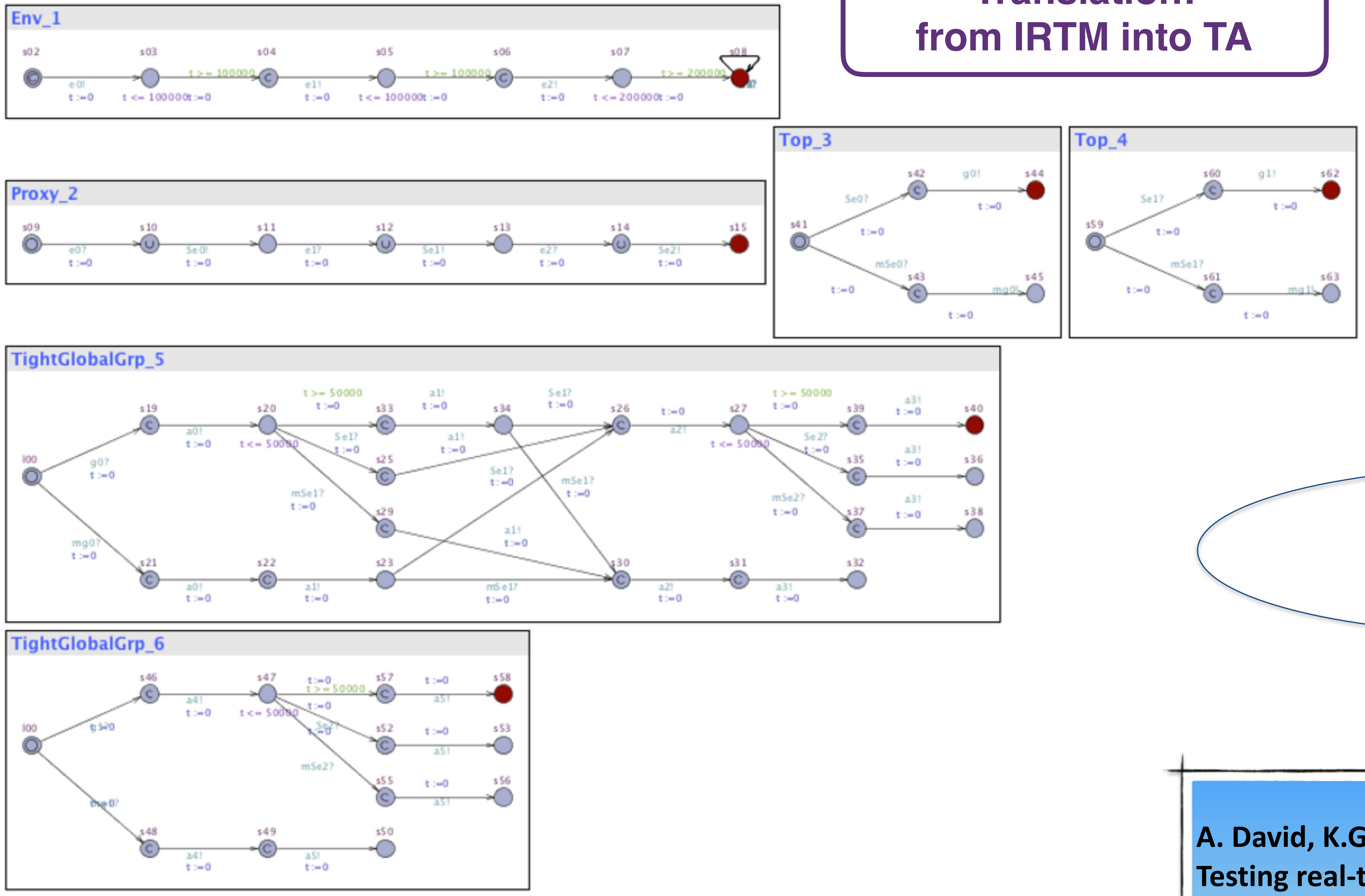
Verdict

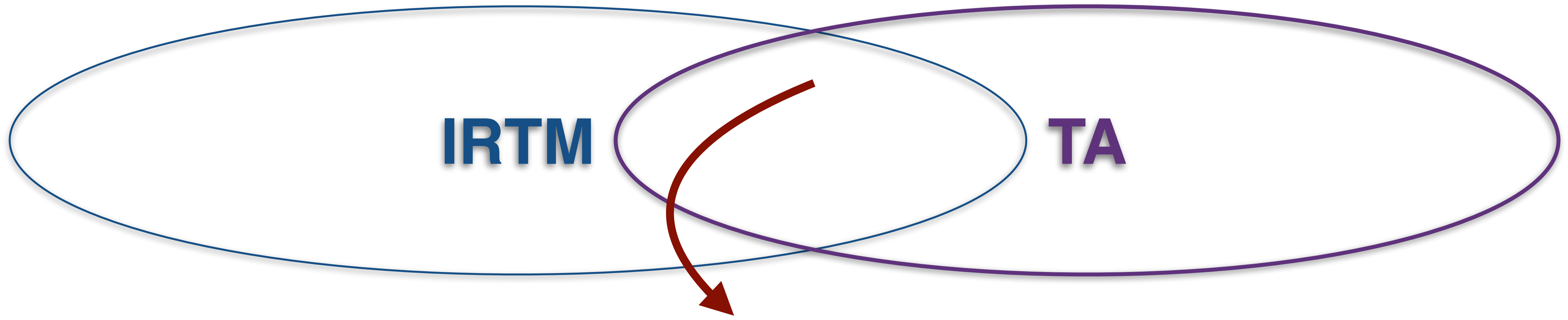
C. Poncelet, F. Jaquemard.
An automatic test framework for interactive music systems.
Journal of New Music Research (JNMR), 2016.

Uppaal

Translation: from IRTM into TA

Build Simulate Verify





under restrictions

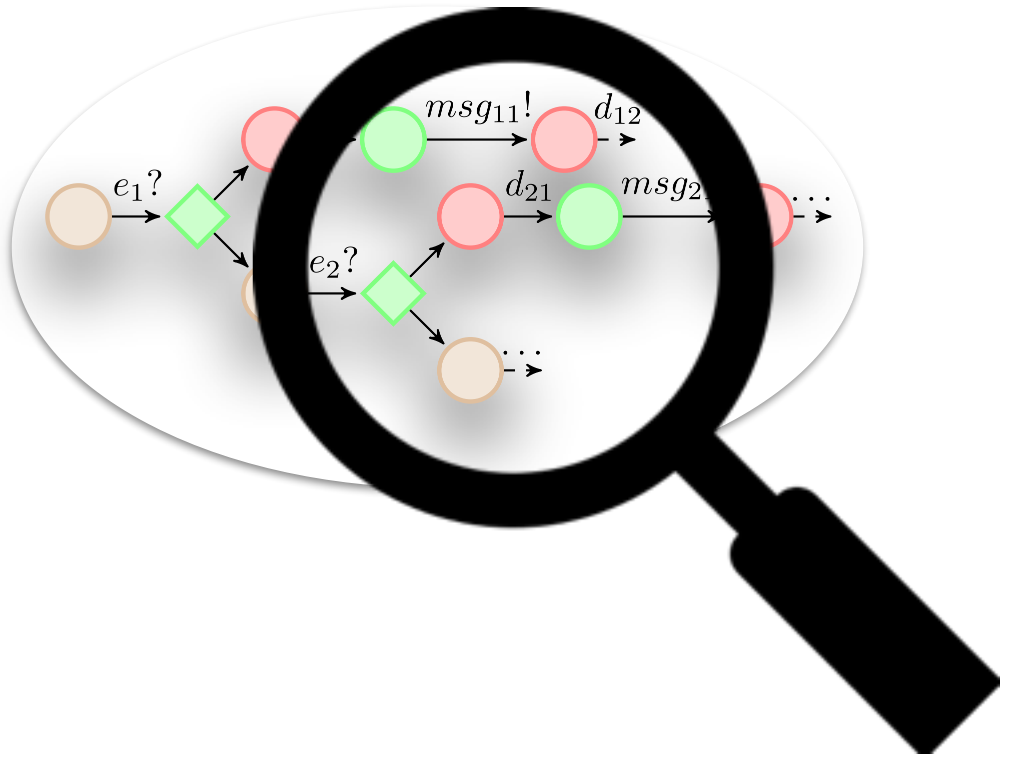
A. David, K.G. Larsen, S. Li, M. Mikucionis, B. Nielsen. Testing real-time systems under uncertainty. FMCO'10.

Covering Input Generation

& CoVer

- Covering generation
- Existing Tools

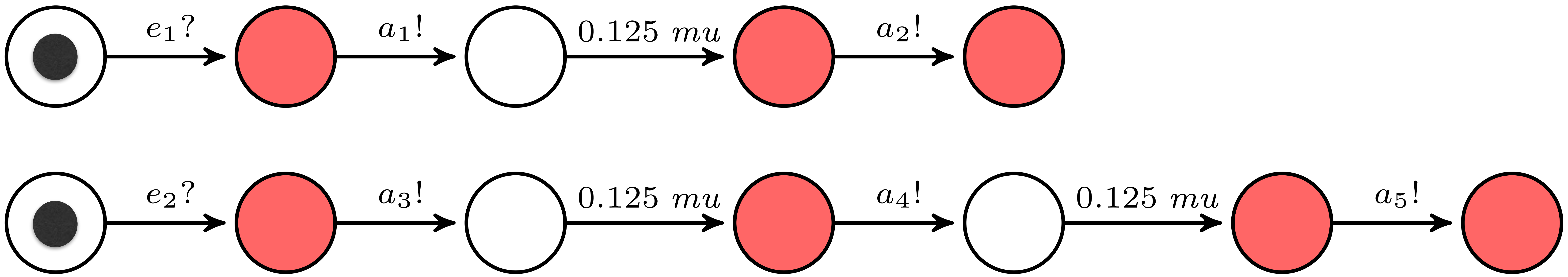
- Translation into Timed Automata
- Generates lowest durations



covering queries

observers

Location/Transition/Path

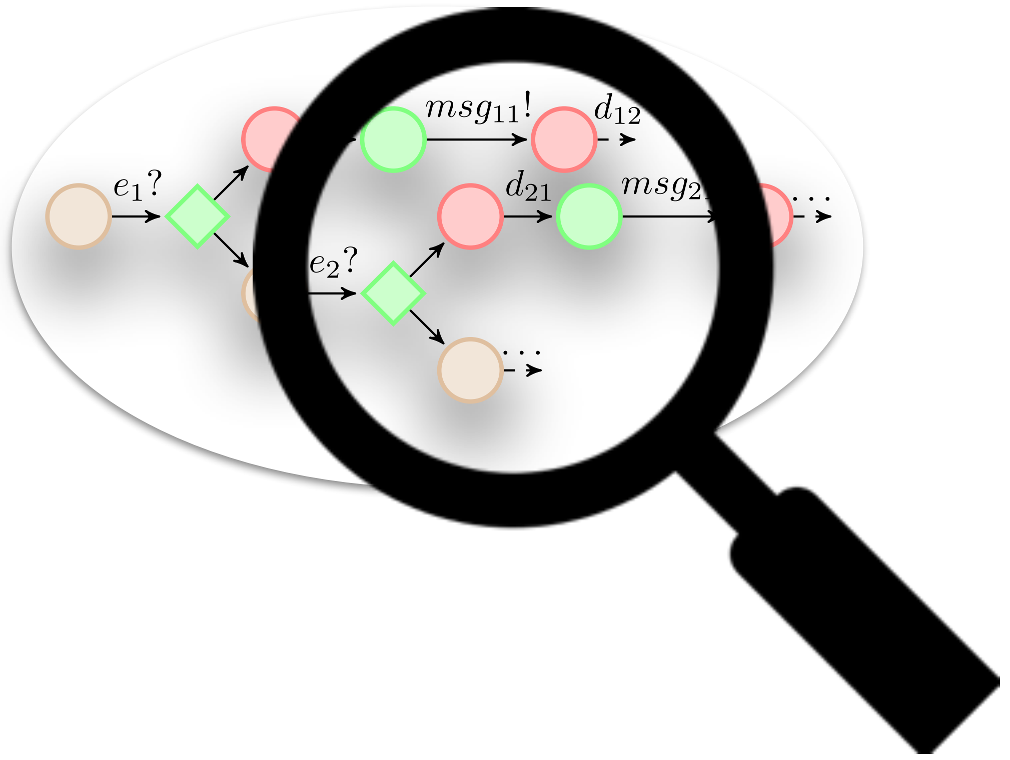


C. Poncelet, F. Jaquemard.
Test Methods for Score-Based Interactive Music Systems.
ICMC - SMS, 2014.

Blom, Hessel, Jonsson, Peterson.
Specifying and Generating Test Cases Using Observer Automata.
FATES'04.

Covering Input Generation

UPPAAL & **CoVer**



covering queries

observers

Location/Transition/Path

- Covering generation
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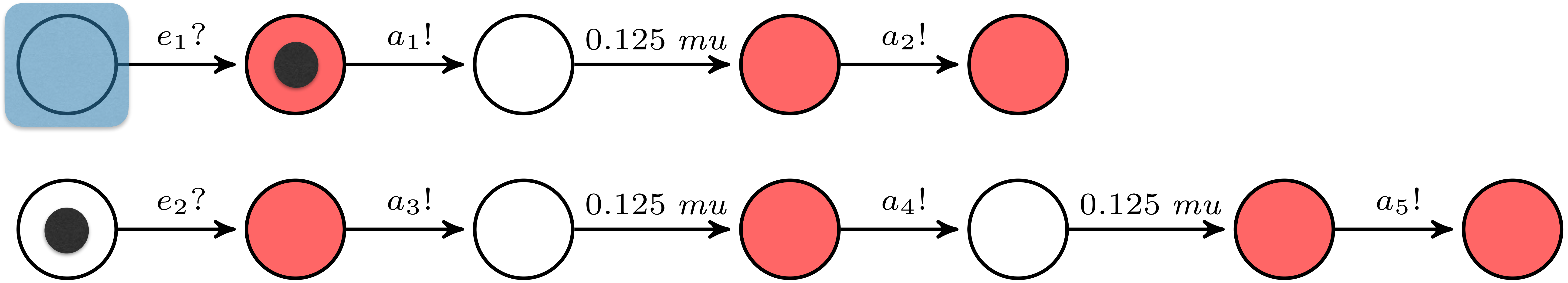
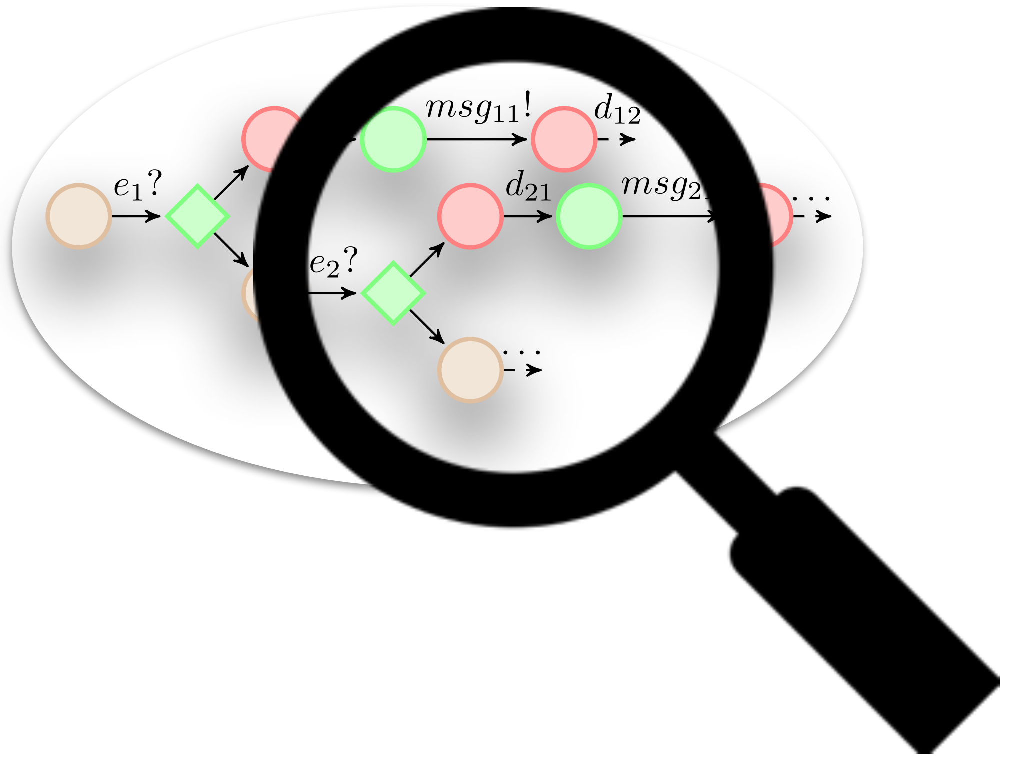


Blom, Hessel, Jonsson, Peterson.
Specifying and Generating Test Cases Using Observer Automata.
FATES'04.

Covering Input Generation

UPPAAL & **CoVer**



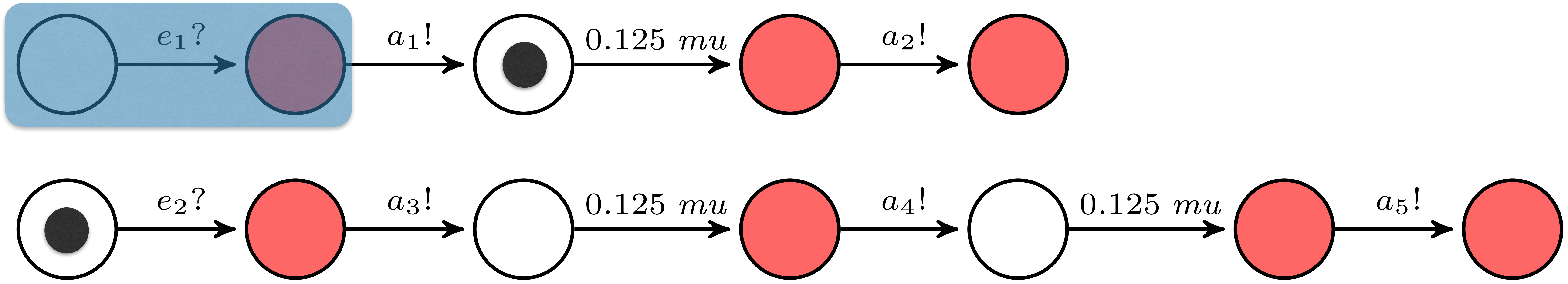
covering queries

observers

Location/Transition/Path

- **Covering generation**
- **Existing Tools**

- **Translation into Timed Automata**
- **Generates lowest durations**



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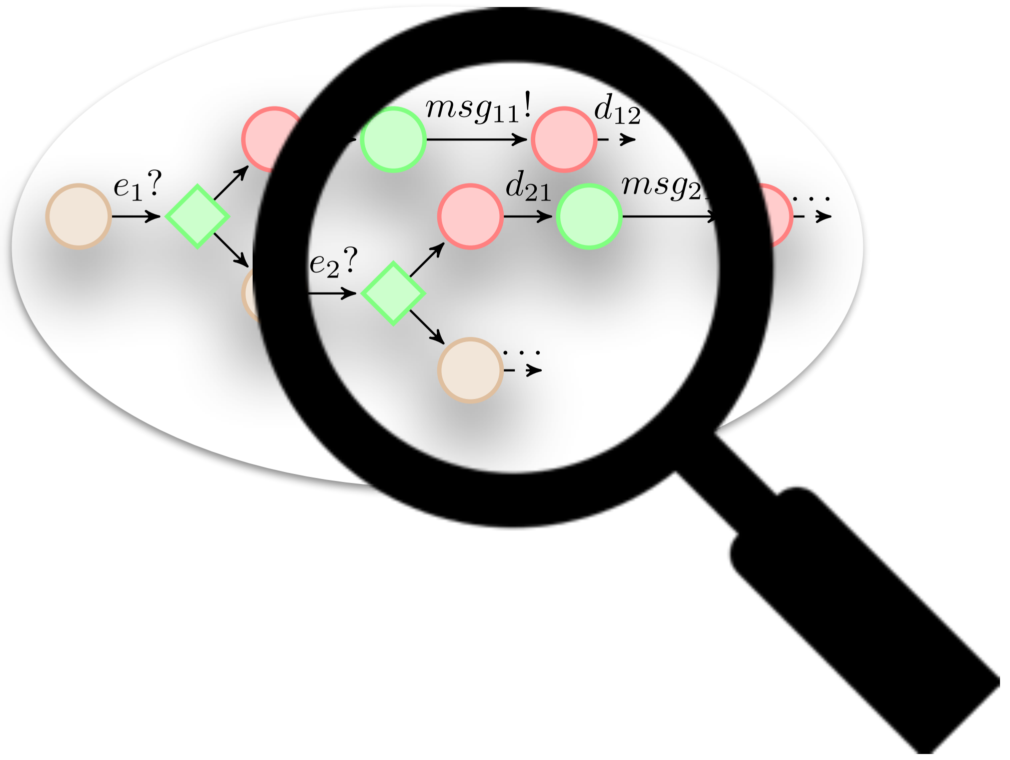
Covering Input Generation

& **CoVer**



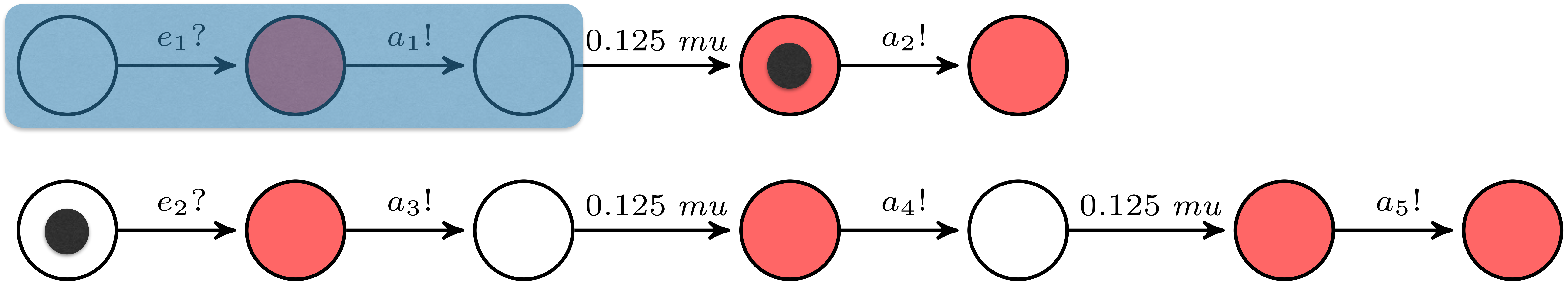
covering queries

observers

Location/Transition/Path

- **Covering generation**
- **Existing Tools**

- **Translation into Timed Automata**
- **Generates lowest durations**



Blom, Hessel, Jonsson, Peterson.
Specifying and Generating Test Cases Using Observer Automata.
FATES'04.

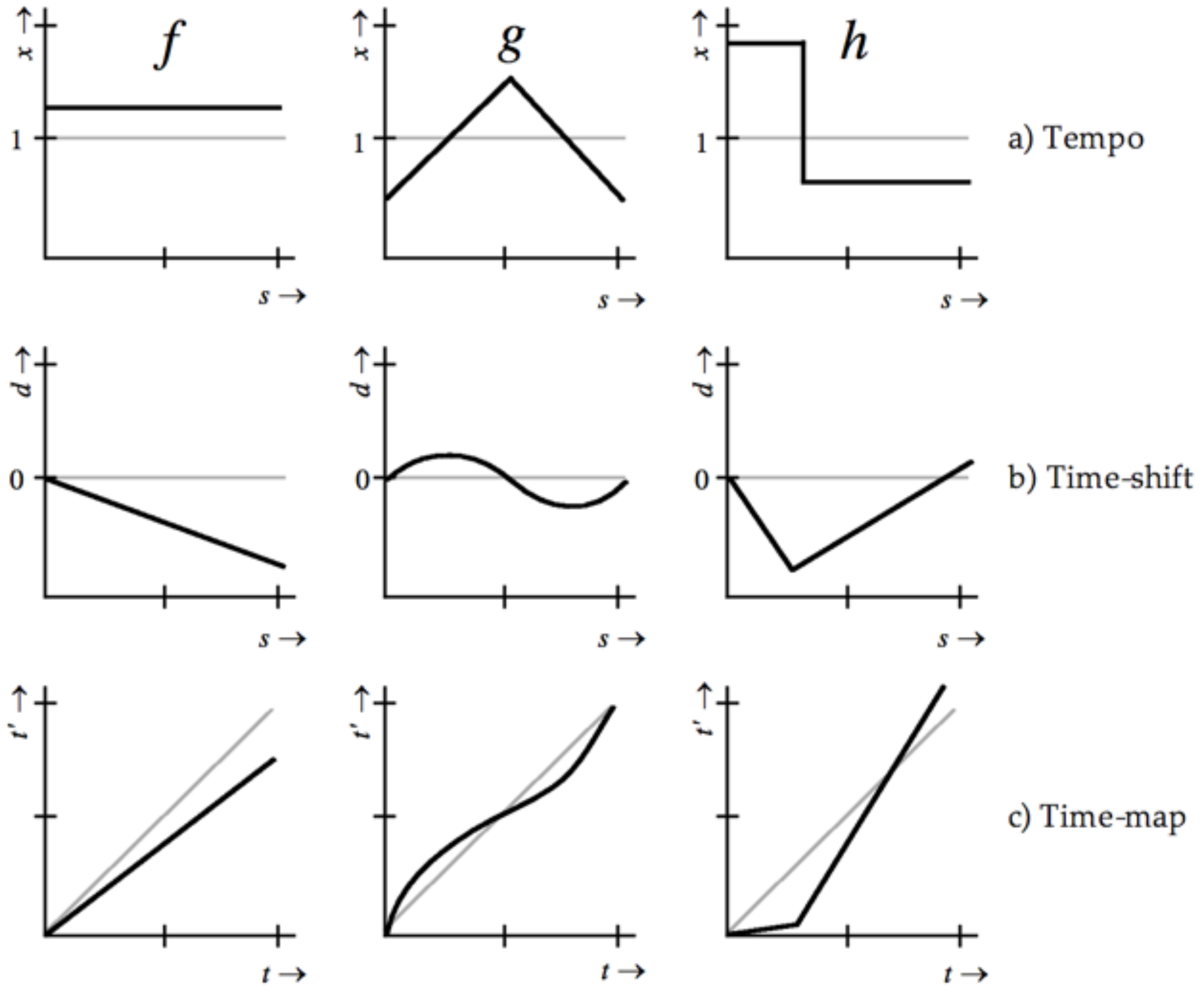
Fuzz Generation

Random

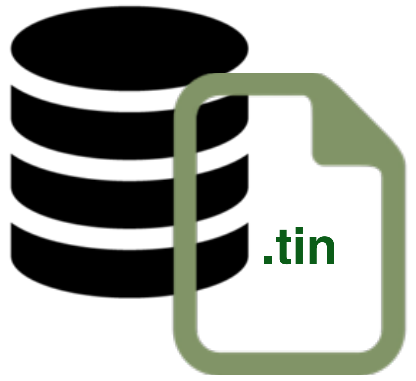
Time Functions (TIF)

- **Musically relevant**
- **No translation**

- **No coverage guarantee**



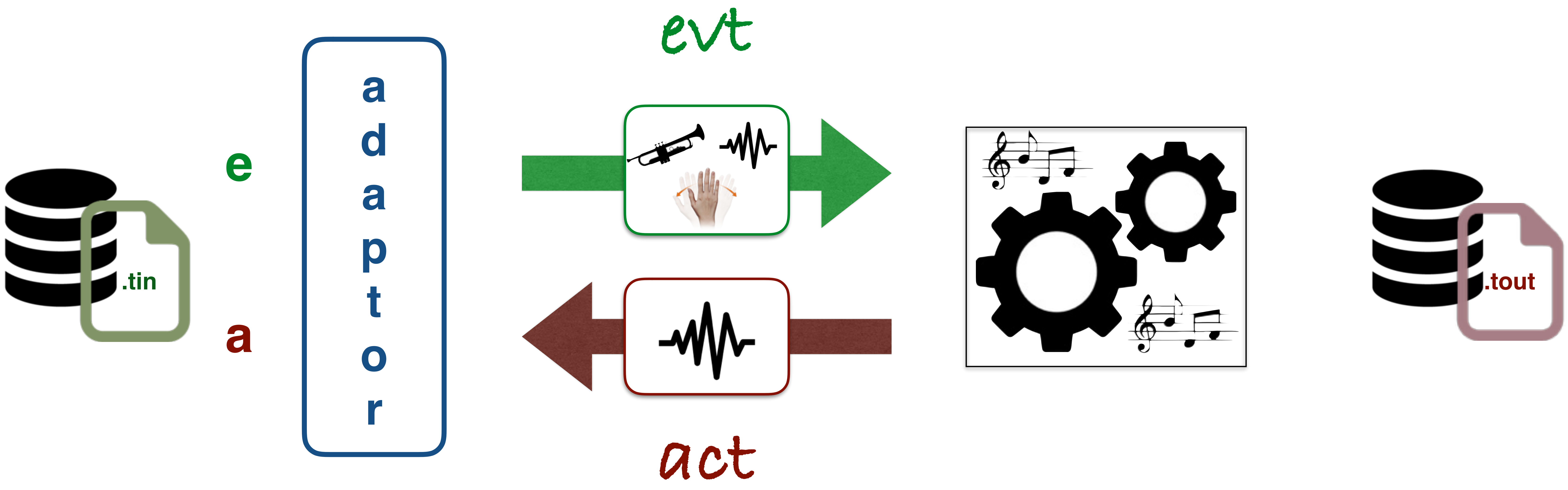
reference trace

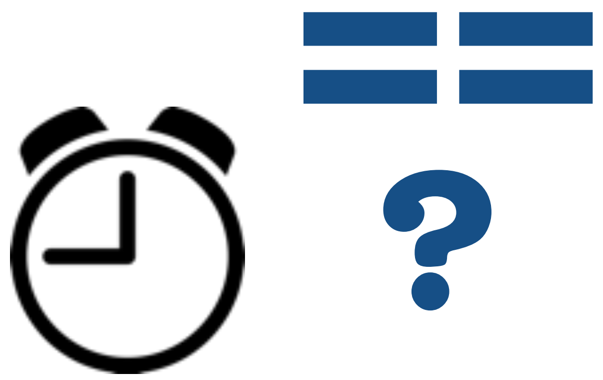


Interpretation = local shift and global tempo changes

Henkjan Honing.
From Time to Time: The Representation of Timing and Tempo. Computer Music Journal. 2001.

Execution





Timed Conformance

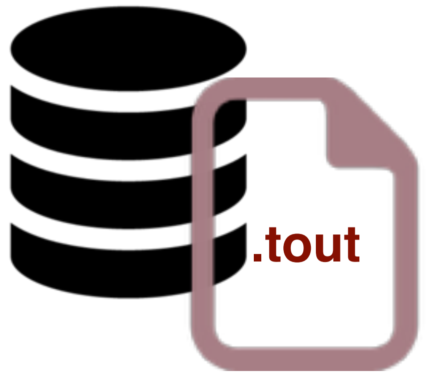
Definition:

Timed conformance:

Set inclusion of real timed output traces into the expected timed output traces

$\langle a_1, 0 \rangle \langle a_2, 0.040 \rangle \langle a_3, 0.080 \rangle$

Expected Trace



$\langle a_1, 0 \rangle \langle a_2, 0.040 \rangle \langle a_3, 0.080 \rangle$

Real Trace

Timed Conformance

Definition:

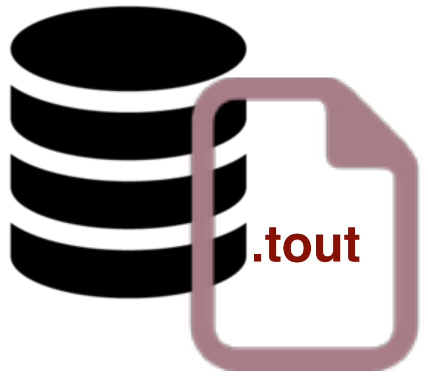
Timed conformance:

Set inclusion of real timed output traces into the expected timed output traces

Missed actions

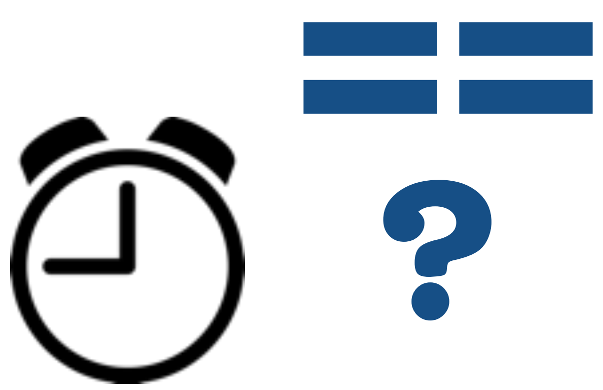
$\langle a_1, 0 \rangle \langle a_2, 0.040 \rangle \langle a_3, 0.080 \rangle$

Expected Trace



$\langle a_1, 0 \rangle \quad \langle a_3, 0.080 \rangle$

Real Trace



Timed Conformance

Definition:

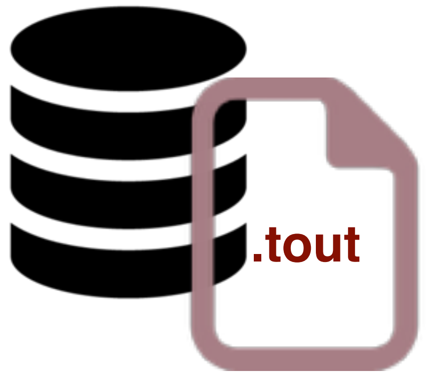
Timed conformance:

Set inclusion of real timed output traces into the expected timed output traces

Unexpected actions

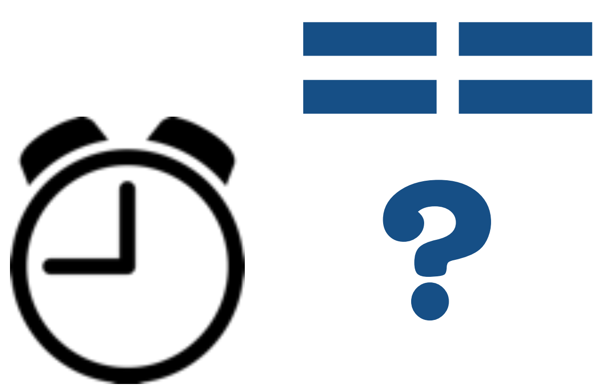
$\langle a_1, 0 \rangle$ $\langle a_3, 0.080 \rangle$

Expected Trace



$\langle a_1, 0 \rangle \langle a_2, 0.040 \rangle \langle a_3, 0.080 \rangle$

Real Trace



Timed Conformance

Definition:

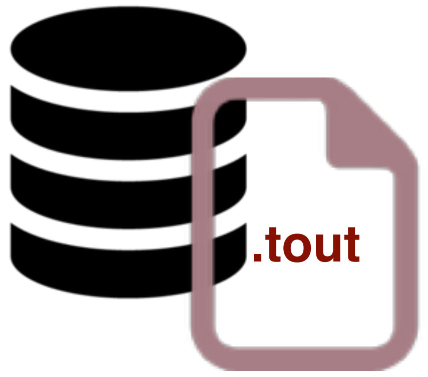
Timed conformance:

Set inclusion of real timed output traces into the expected timed output traces

Delta > ε

$\langle a_1, 0 \rangle \langle a_2, 0.040 \rangle \langle a_3, 0.080 \rangle$

Expected Trace



$\langle a_1, 0 \rangle \langle a_2, 0.040 \rangle \langle a_3, 0.090 \rangle$

Real Trace

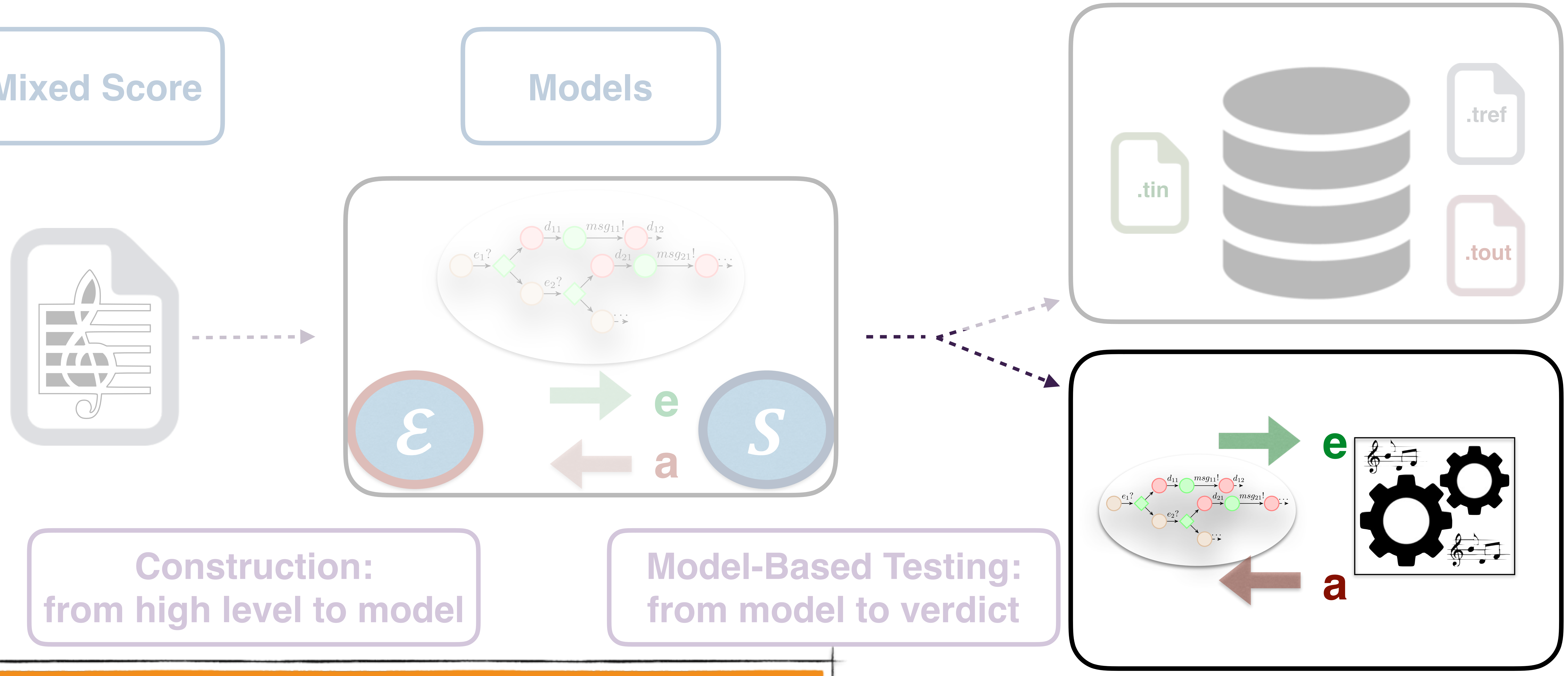
Testing Framework Overview

Offline Approach

Mixed Score

Models

Verdict



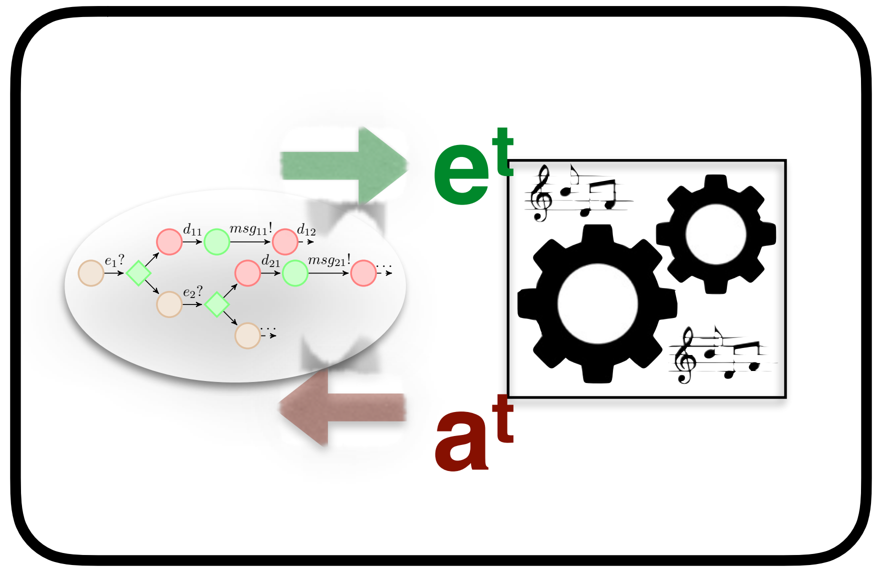
Construction:
from high level to model

Model-Based Testing:
from model to verdict

Online Approach

C. Poncelet, F. Jaquemard.
An automatic test framework for interactive music systems.
Journal of New Music Research (JNMR), 2016.

Online Approach

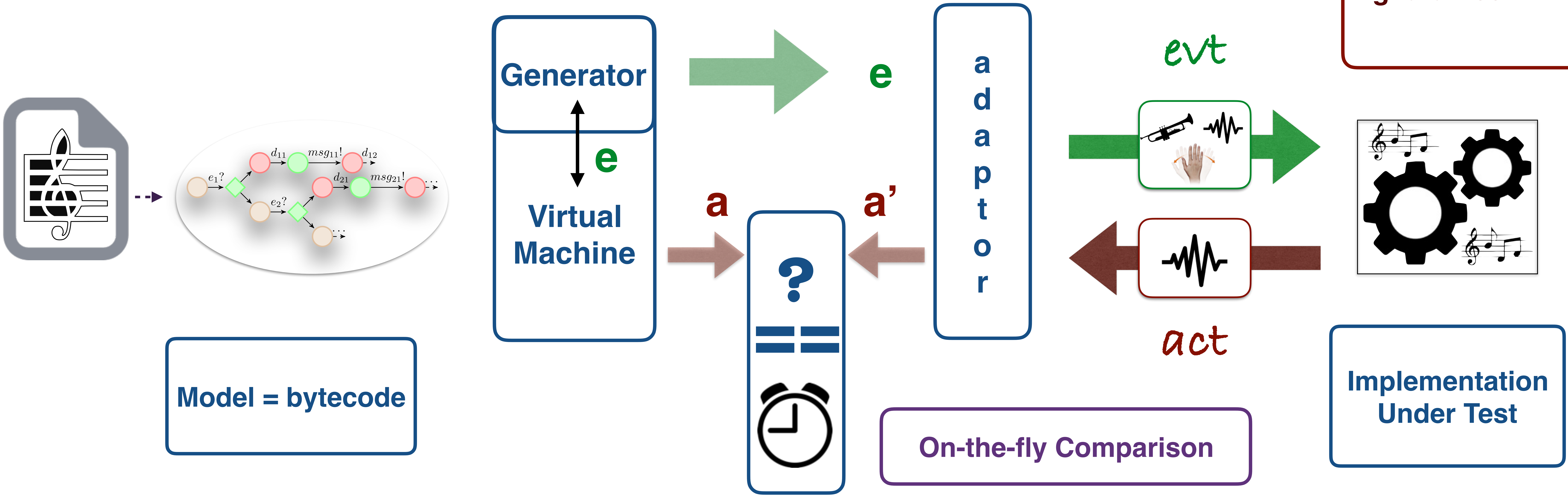


- No translation
- No coverage guarantee

(Simulation) Compute Expected Outputs

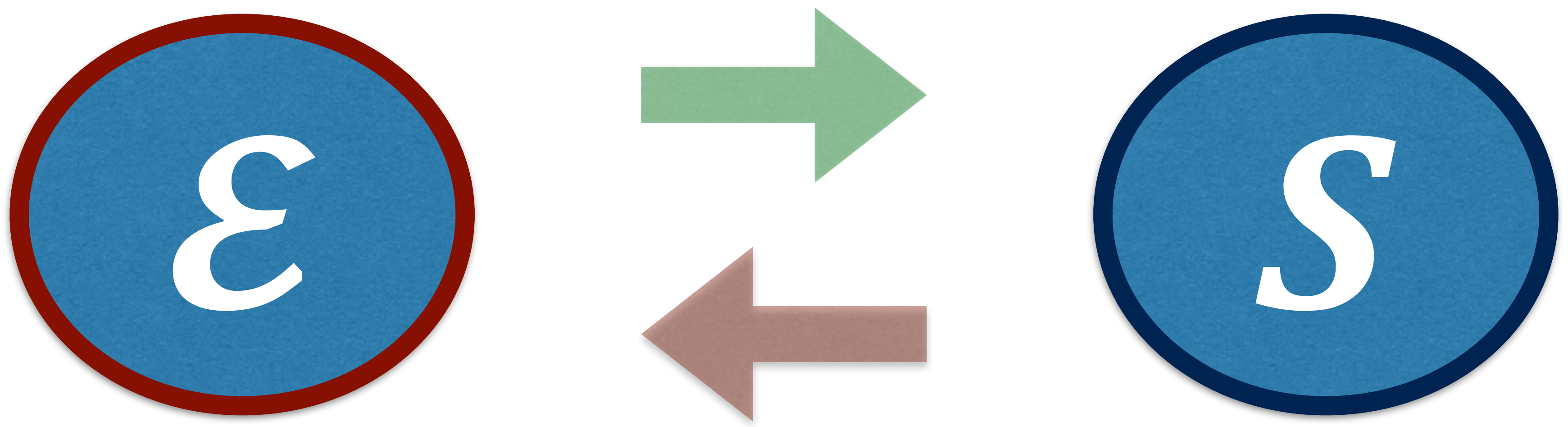
On-the-fly Inputs Generation

(Execution) Compute Real Outputs



Outline

1. Objectives



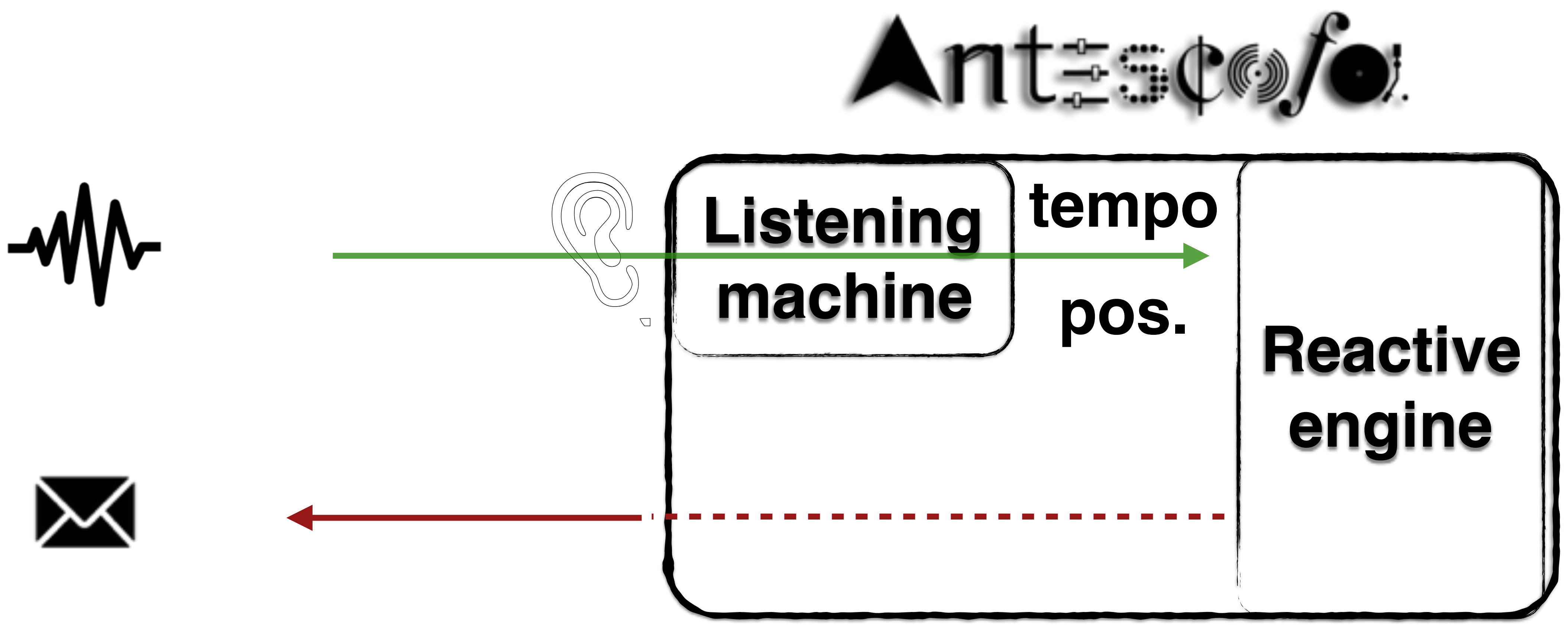
2. Interactive Real-Time Model

3. Testing Framework

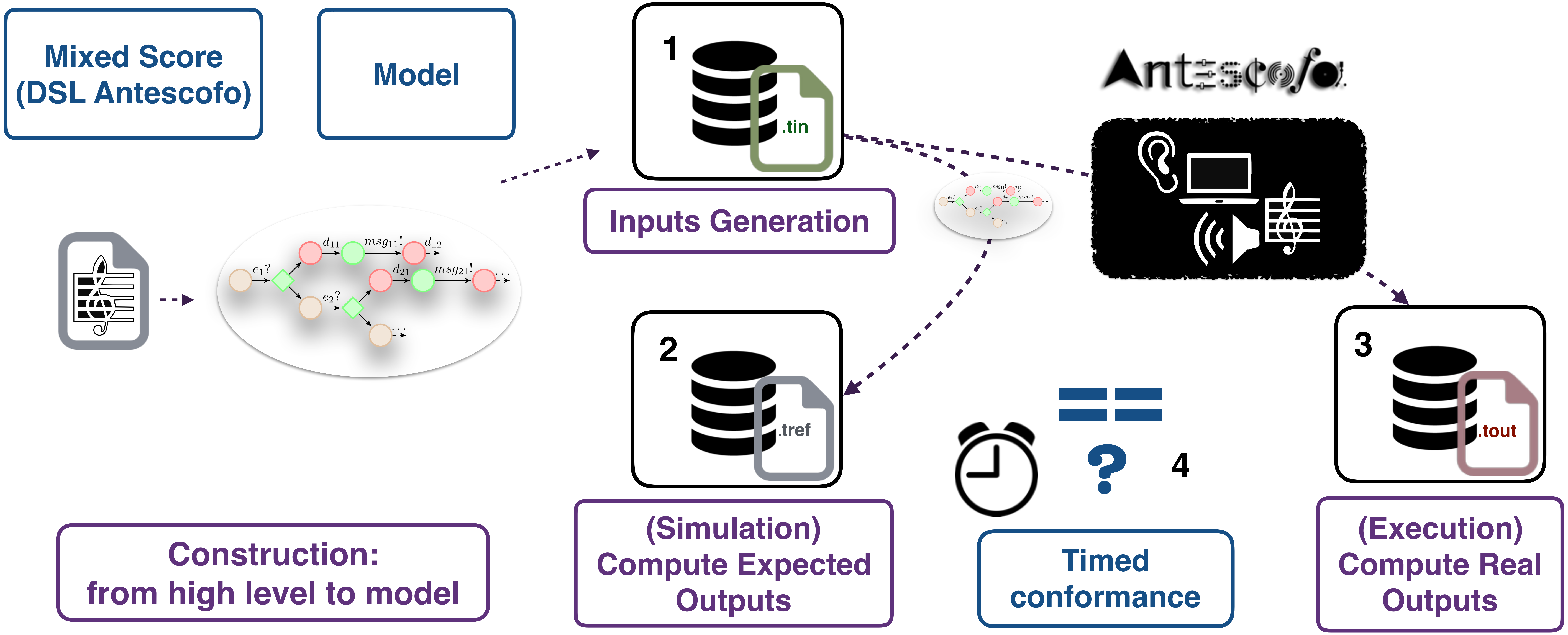
4. Application to Antescofo

Application to Antescofo

Antescofo



Offline Approaches application

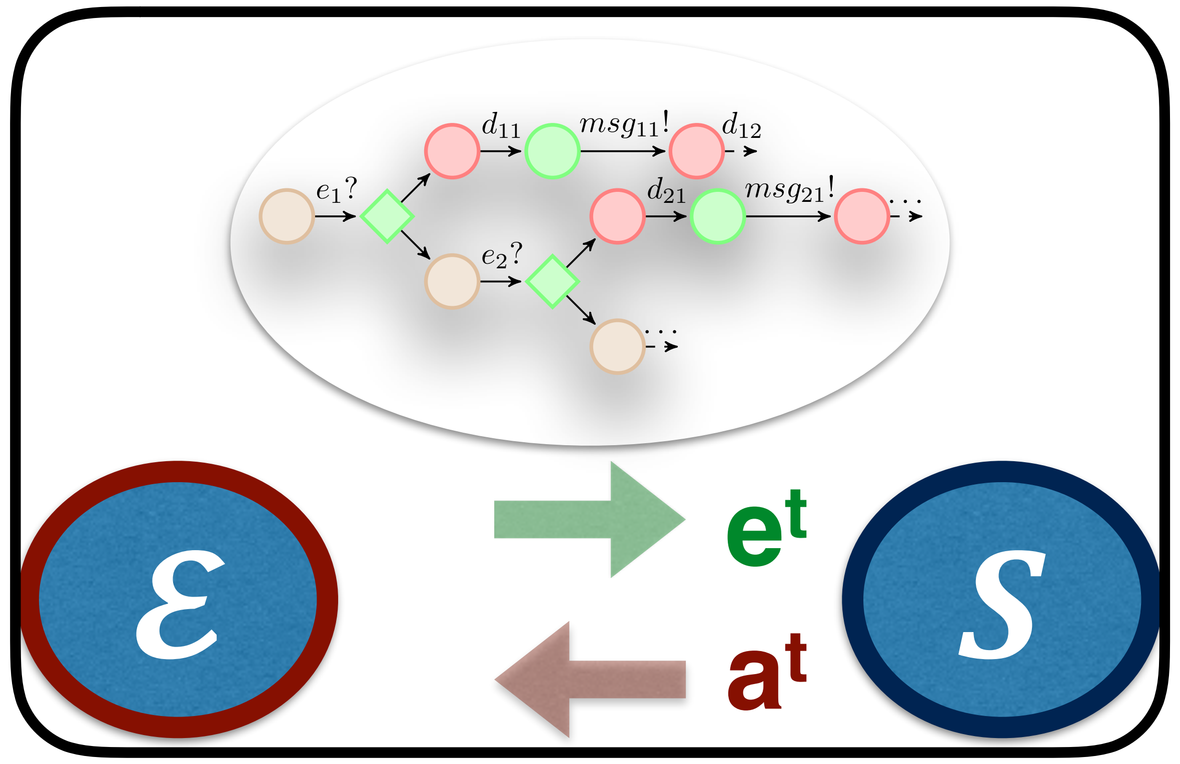


Construction

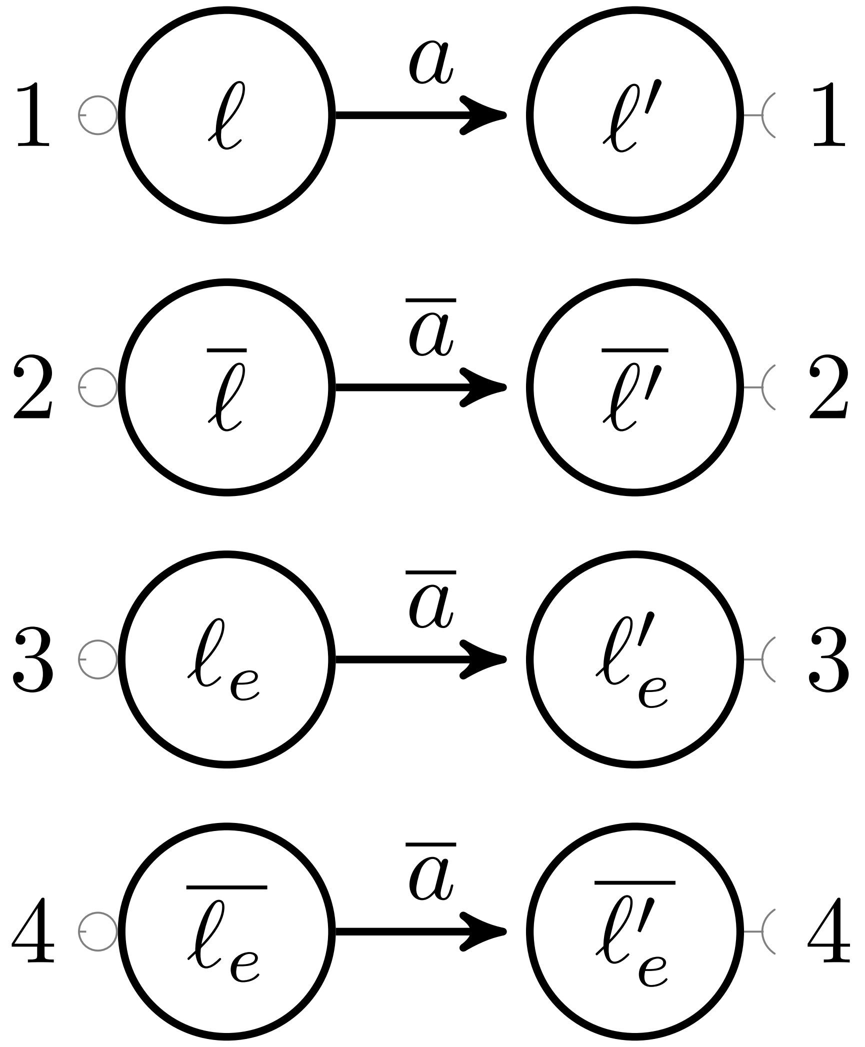
Construction: from high level to model

Automatic

Domain Specific Language Antescofo



Interactive Real-Time Model

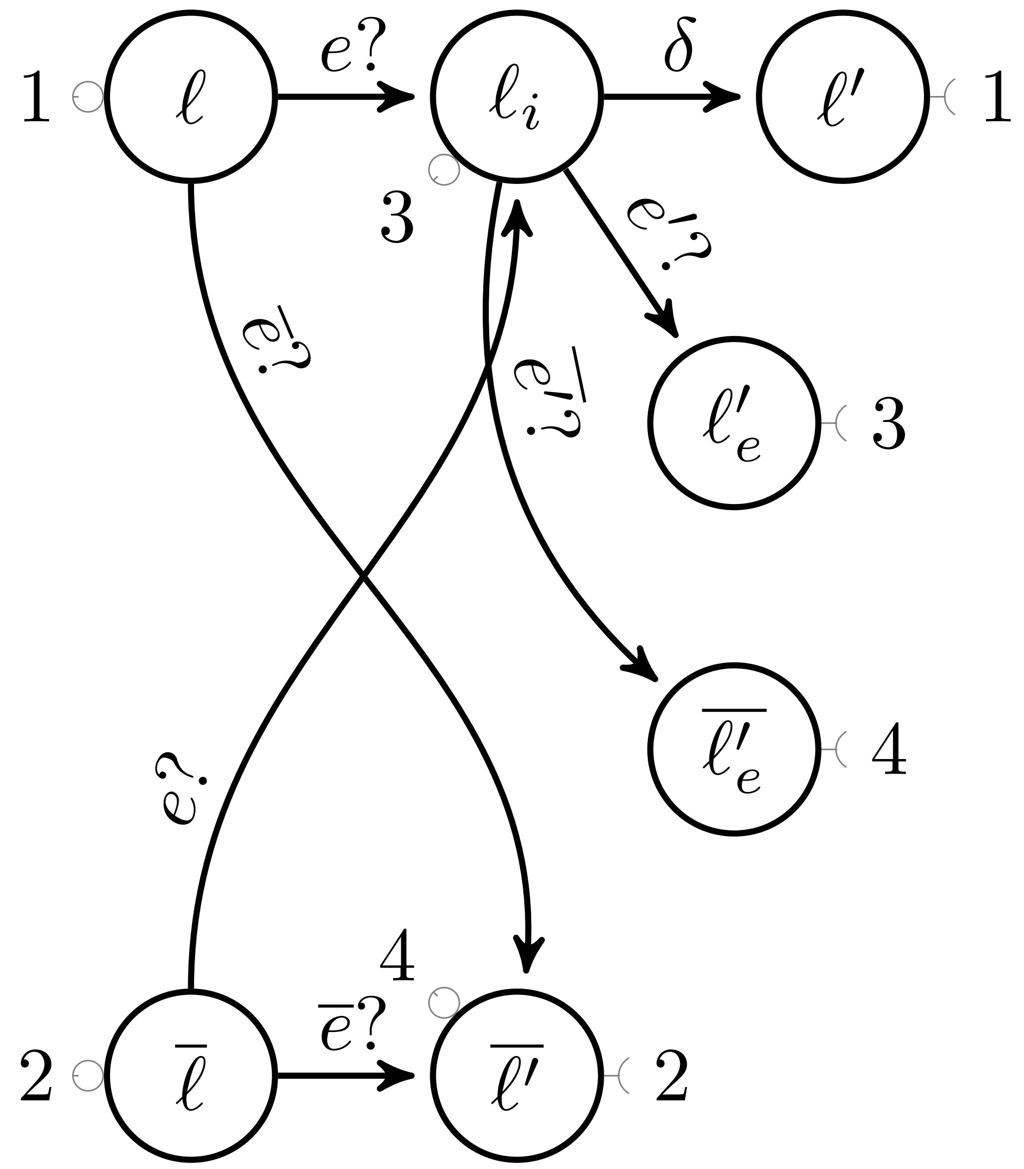


$$\frac{}{:\ \emptyset \vdash_{\text{all}} \mathcal{A}_\emptyset}$$

Inference Rules

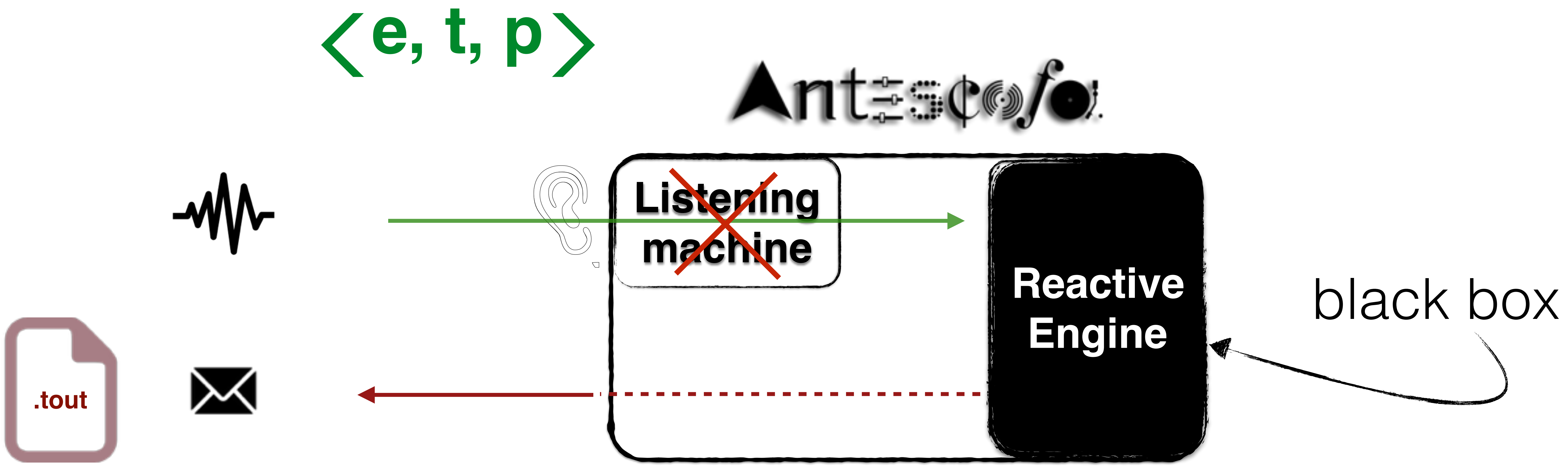
FSM Parts & Connectors + Operators

$$\frac{:\ ms \vdash_{\text{env}} \mathcal{M}_{\text{env}} \qquad :\ ms \vdash_{\text{proxy}} \mathcal{P} \qquad :\ ms \vdash_{\text{sys}} \mathcal{A}}{:\ ms \vdash_{\text{all}} \mathcal{M}_{\text{env}} \| \mathcal{P} \| \mathcal{A}}$$

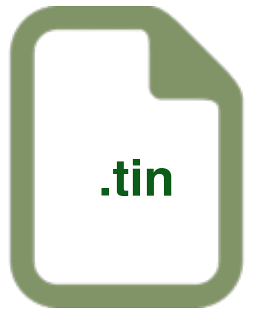


Antescofo Execution

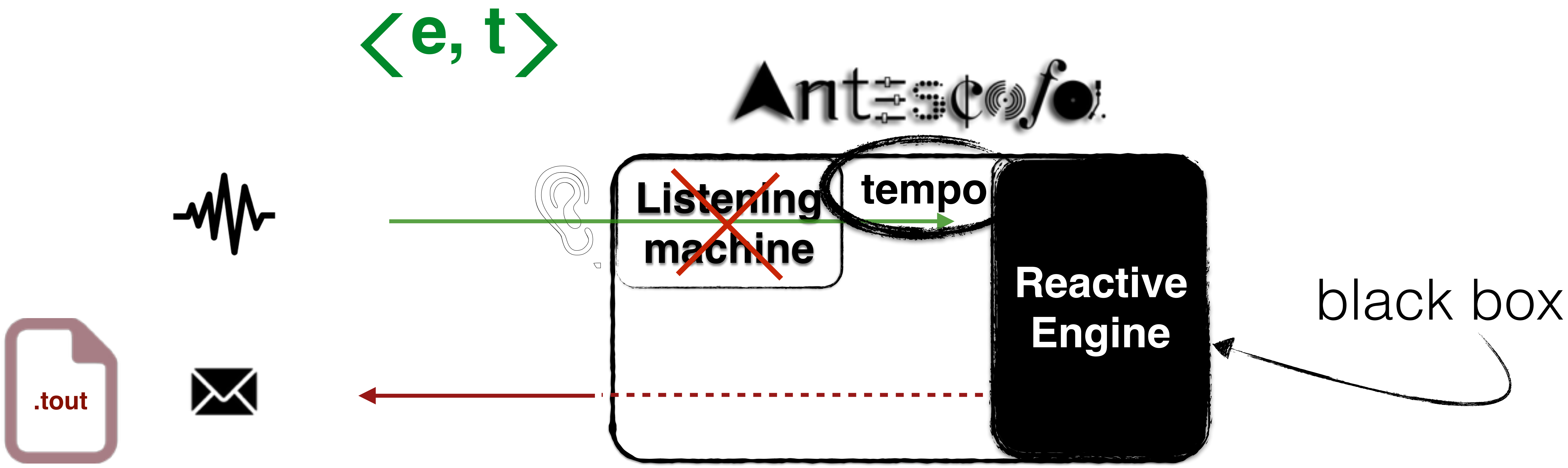
.tin $\langle e_1, 0, 120 \rangle\langle e_2, 0.5, 120 \rangle\langle e_3, 1, 120 \rangle$



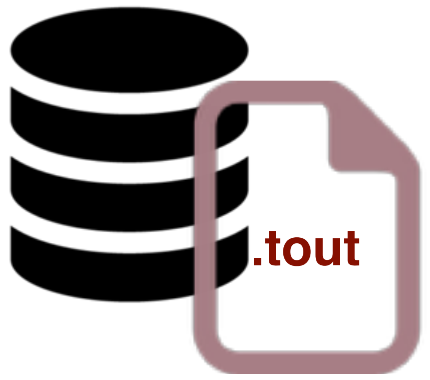
Antescofo Execution



$\langle e_1, 0, \_ \rangle \langle e_2, 0.5, \_ \rangle \langle e_3, 1, \_ \rangle$



Verdict

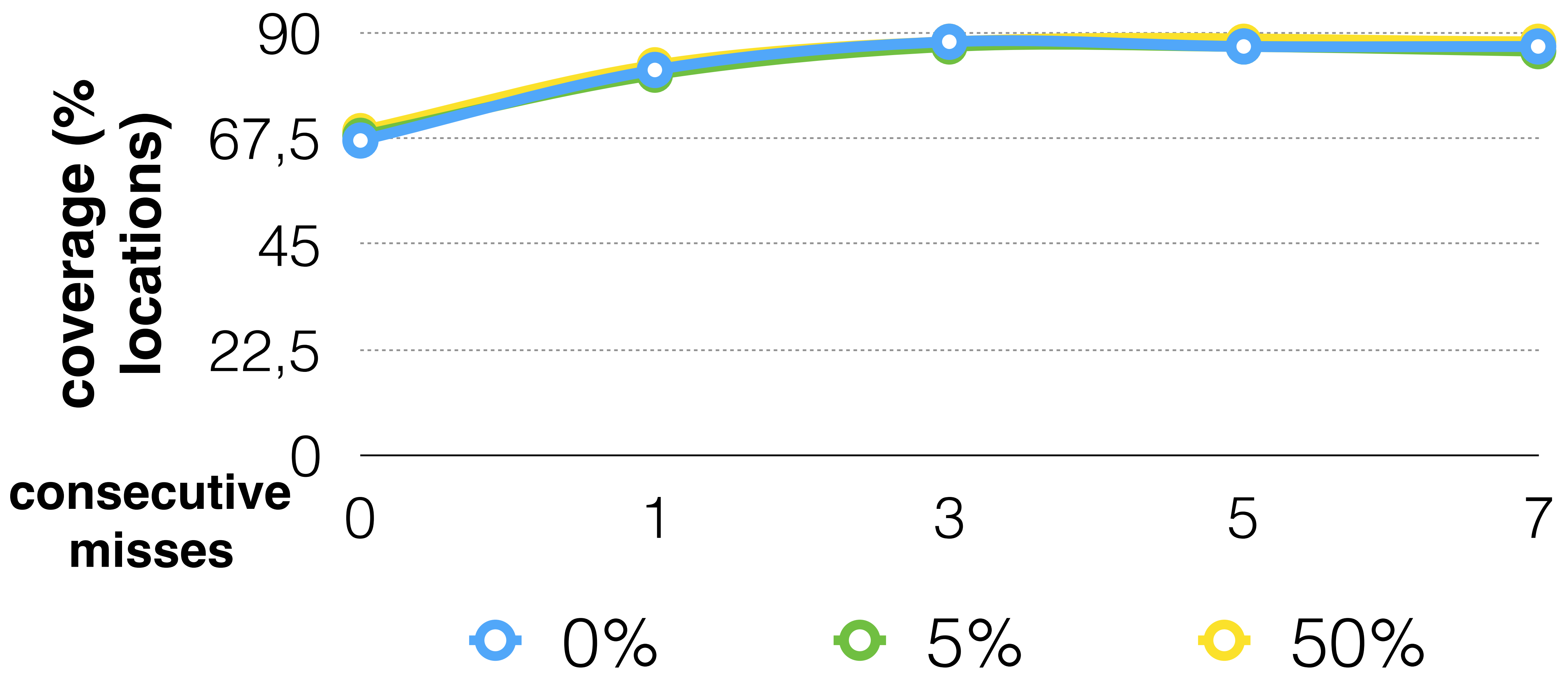


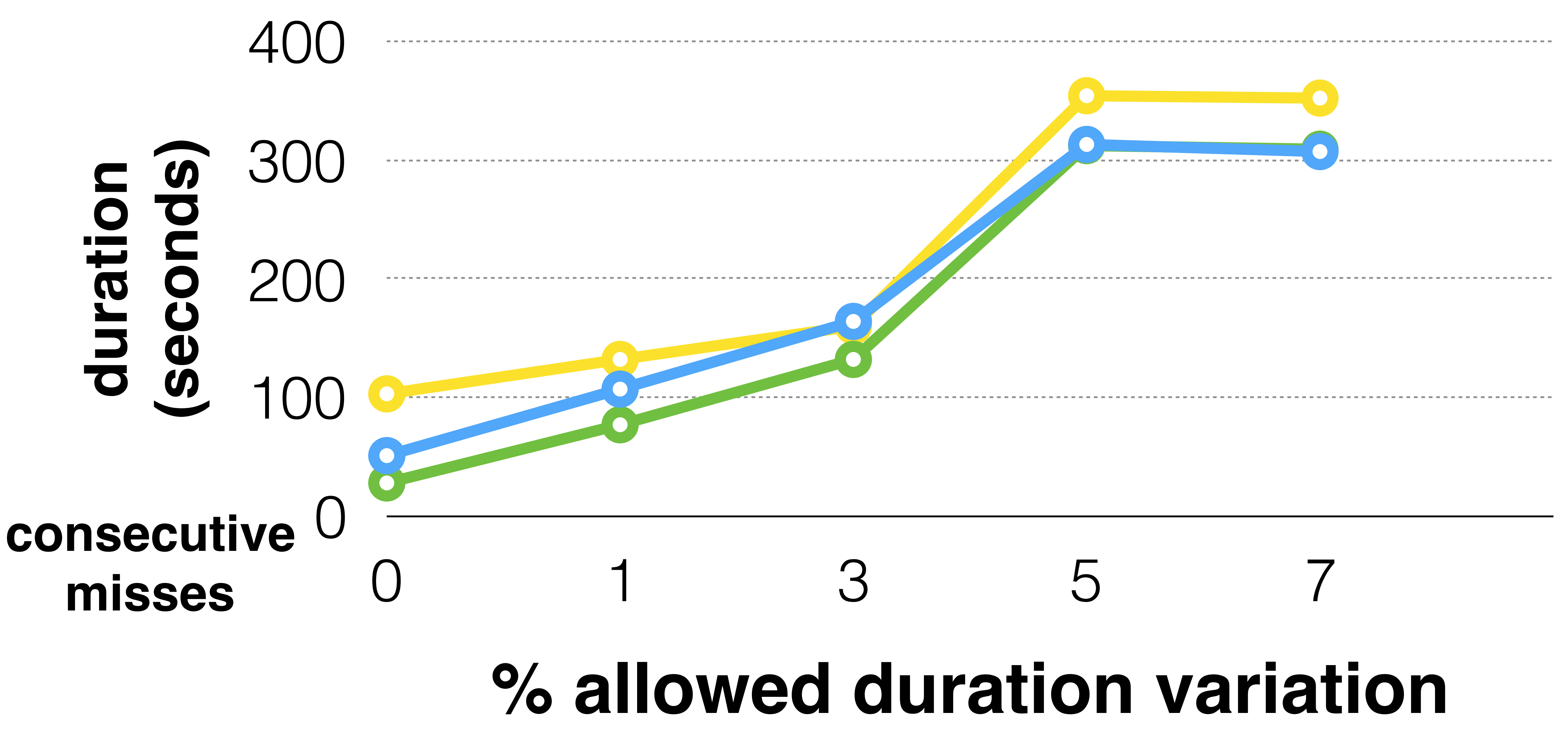

```
start of tests
note0 --> 0.77 --> note1_1.00 --> 0.385 --> note2_1.50 --> 0.1925 --> note3_1.75 --> 0
____________________________________________________________________
|-          Antescofo Trace                 Expected Trace          -|
|-     TimeStamp      [Estimate Beat]   TimeStamp       [Beat]      -|
|--------------------------------------------------------------------|
          a0        0 [    0]           a0        0 [    0]
*      note0        0 [    0]           e0        0 [    0]             * T: 60 BPM
          a1      0.5 [ 0.5]            a1      0.5 [ 0.5]
          a2     0.77 [0.77]            a2     0.77 [0.77]
*note1_1.00      0.77 [0.824]            e1     0.77 [0.77]             * T: 64.2 BPM
          a3    0.887 [0.95]            a3    0.887 [1.02]
*note2_1.50 0.95047 [1.21]              e2  0.95047 [1.16]             * T: 128 BPM
          a4     0.99 [1.29]            a4     0.95 [1.16]             x delta: 0.04
          a5     1.02 [1.35]            a5    0.985 [1.25]             x delta: 0.0321
          a6     1.02 [1.35]            a6     1.02 [1.35]
*note3_1.75    1.0174 [ 1.4]            e3   1.0174 [1.35]             * T: 173 BPM
*note4_1.75    1.0174 [ 1.4]            e4   1.0174 [1.35]             * T: 203 BPM
          a7     1.28 [ 2.3]            a7     1.28 [2.31]
*        END   1.2831 [2.38]            e5   1.2831 [2.31]             * T: 220 BPM
|--------------------------------------------------------------------|
Error :: Test KO
finito. ||
```

Experiments

Approach Offline: CoVer

Benchmark





- Covering generation
- Existing Tools

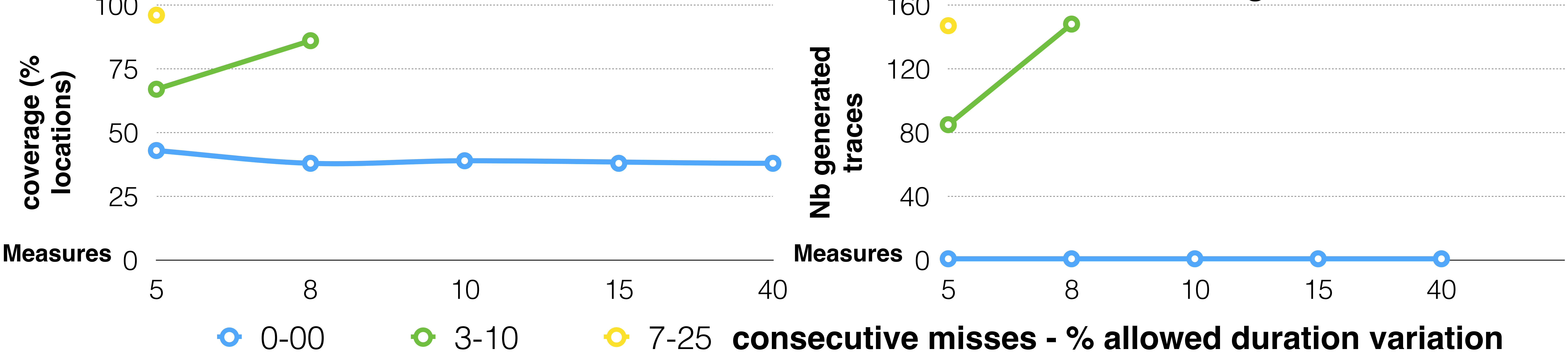
- Translation into Timed Automata
- No musically relevant

Experiments

Approach Offline: CoVer

misses - k

Sonata in F major
Georg Friedrich Händel



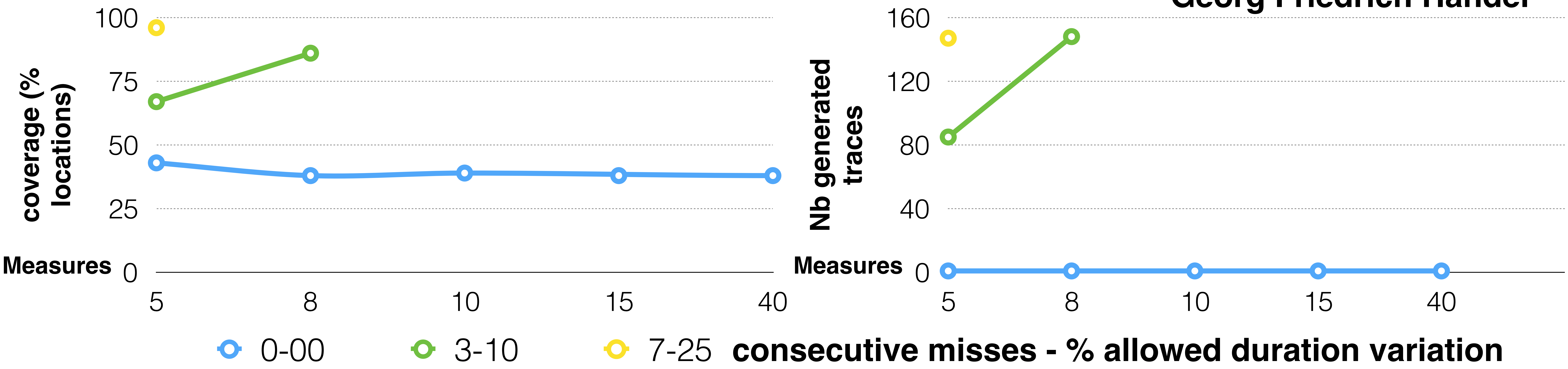
Measures 5	Measures 8	Measures 10	Measures 15	Measures 40
10s	16s	20s	30s	80s
25 events	48 events	74 events	122 events	360 events
84 actions	185 actions	264 actions	444 actions	1218 actions

Experiments

Approach Offline: CoVer

Sonata in F major
Georg Friedrich Händel

misses - k



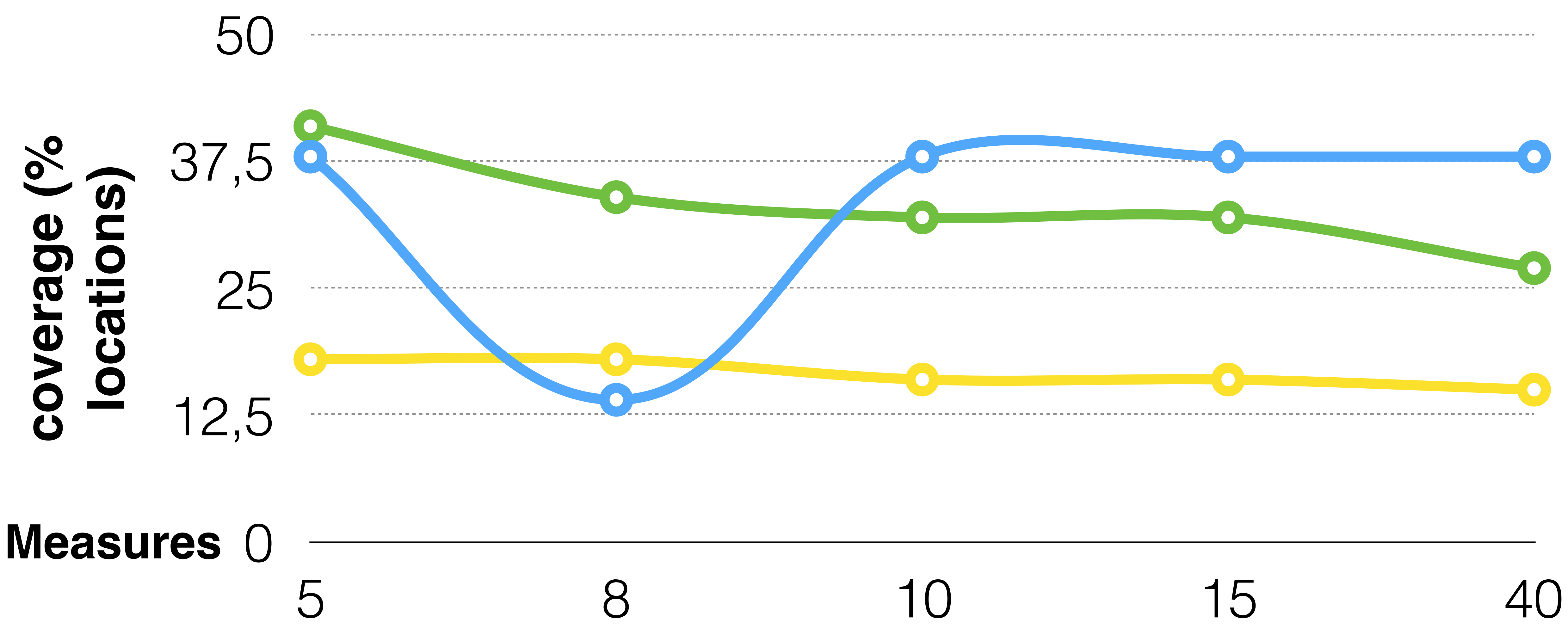
- **Not scalable**

Experiments

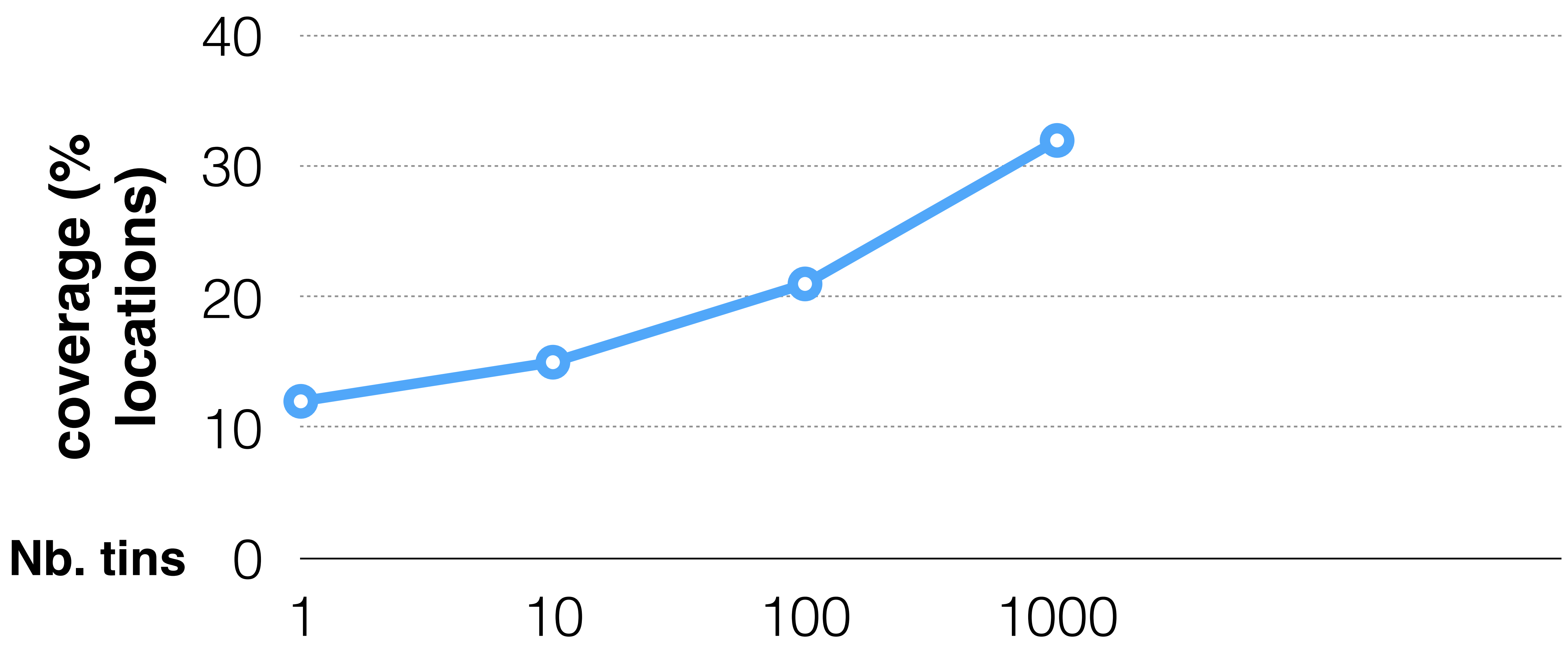
Approach Offline: Fuzz

Sonata in F major
Georg Friedrich Händel

10 traces



40 measures



0-00 3-10 7-25

consecutive misses - % allowed duration variation

- Musically relevant
- No translation

- No coverage guarantee

Measures 40
80s
360 events
1218 actions

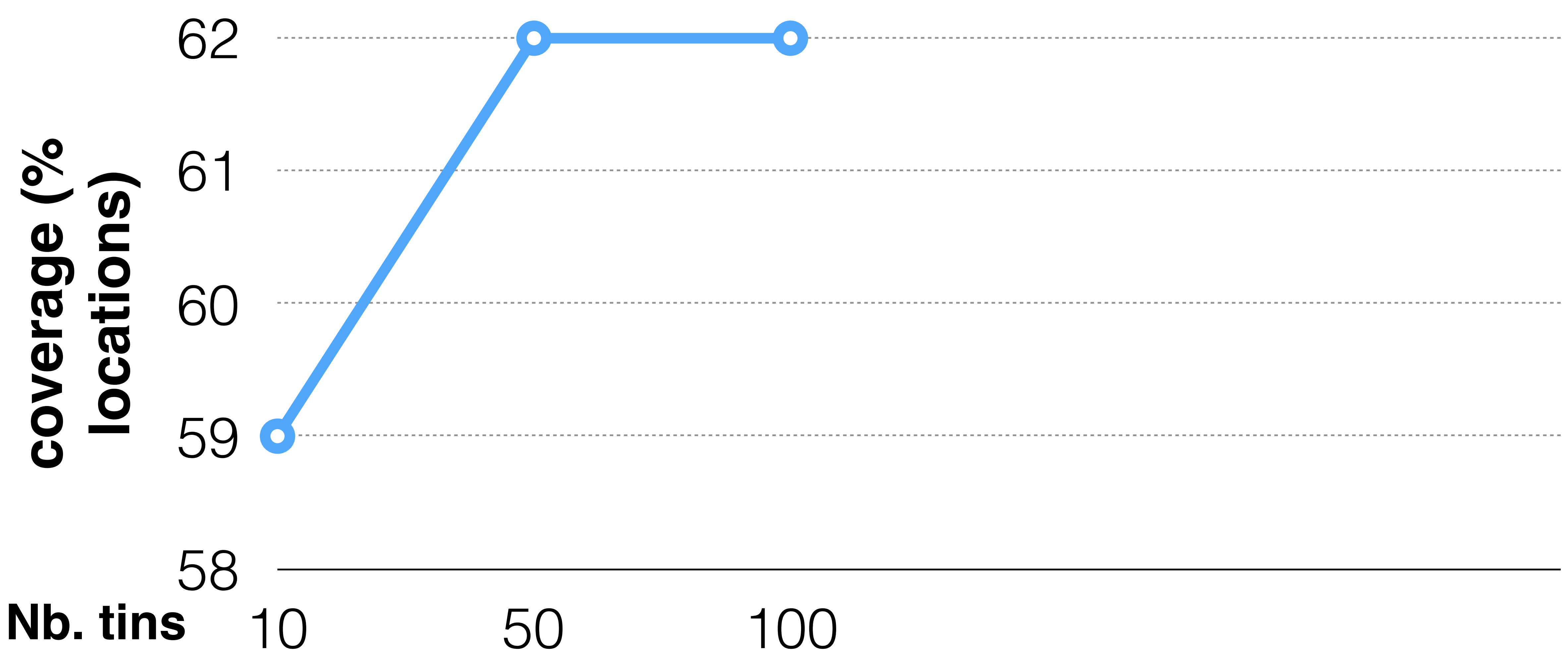
misses - k

Experiments

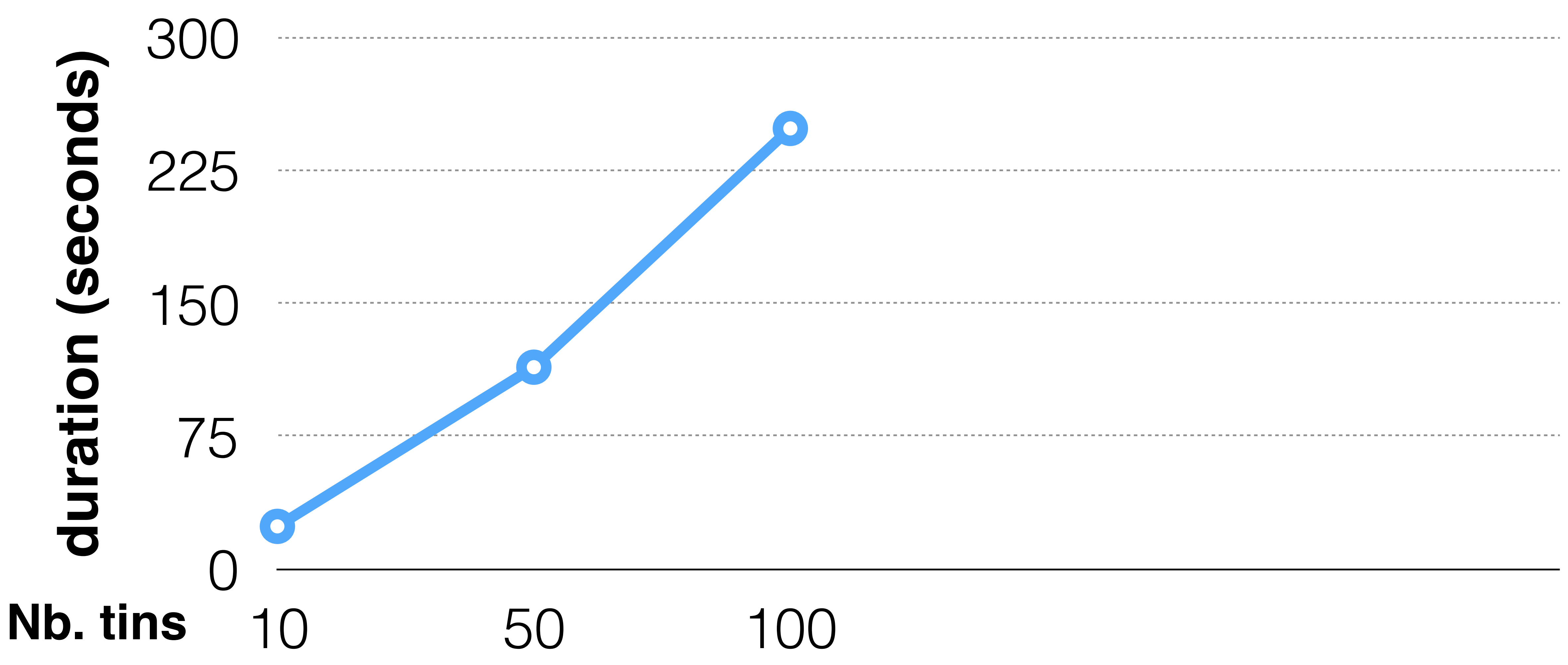
Approach Online

Sonata in F major
Georg Friedrich Händel

10 traces



Entire measures

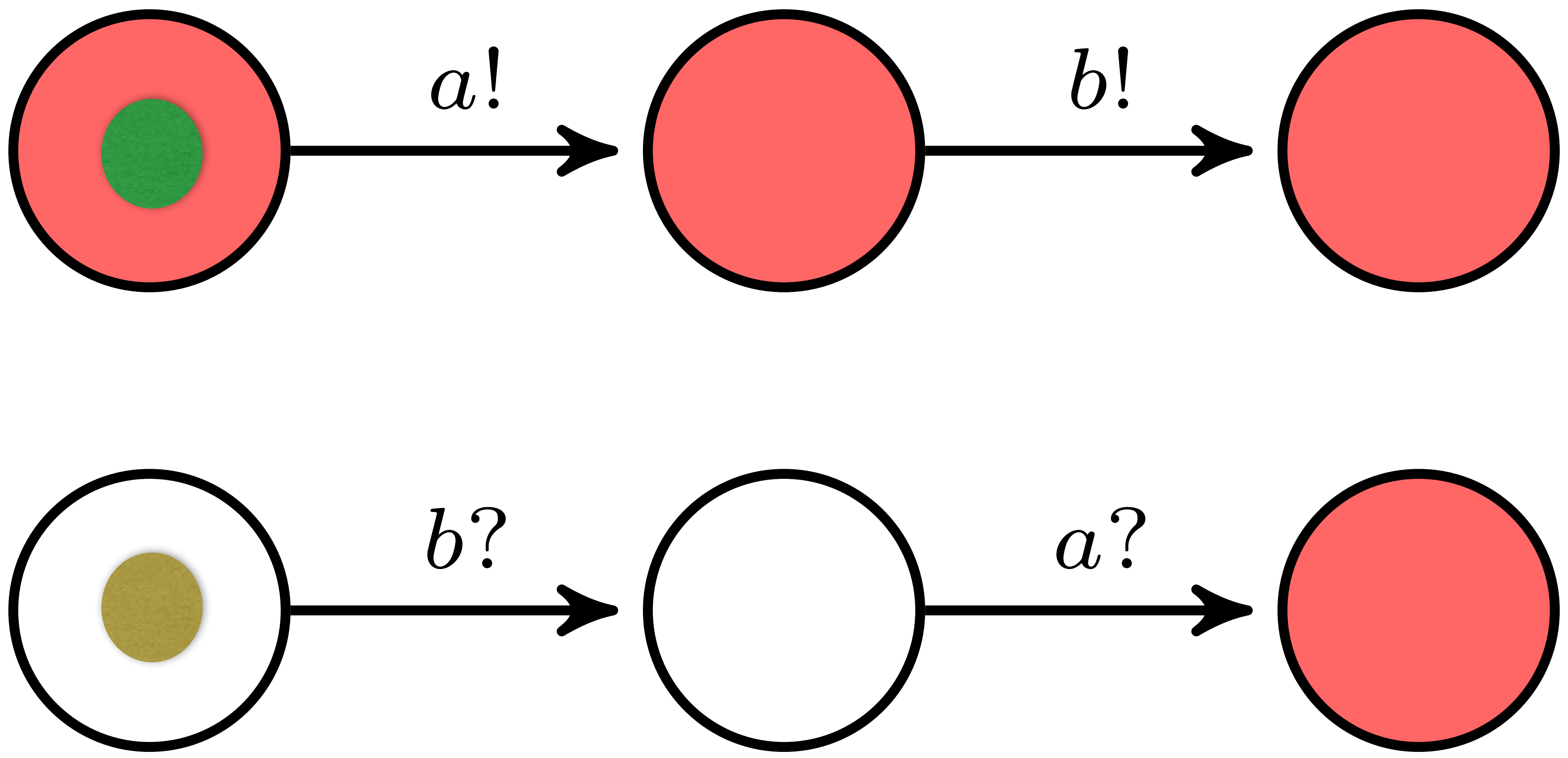


- Musically relevant
- No translation

- No coverage guarantee

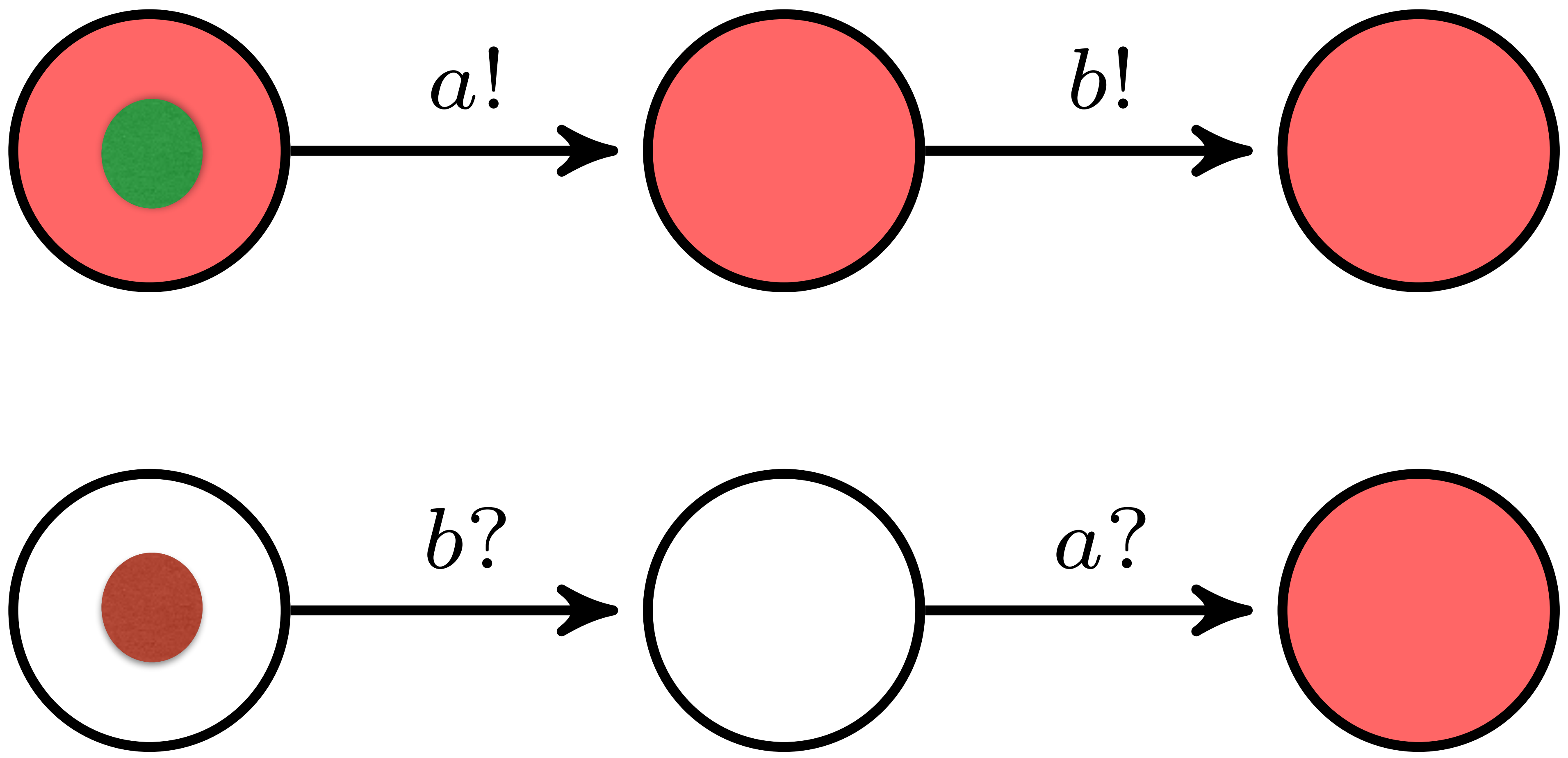
- Faster

Appendices



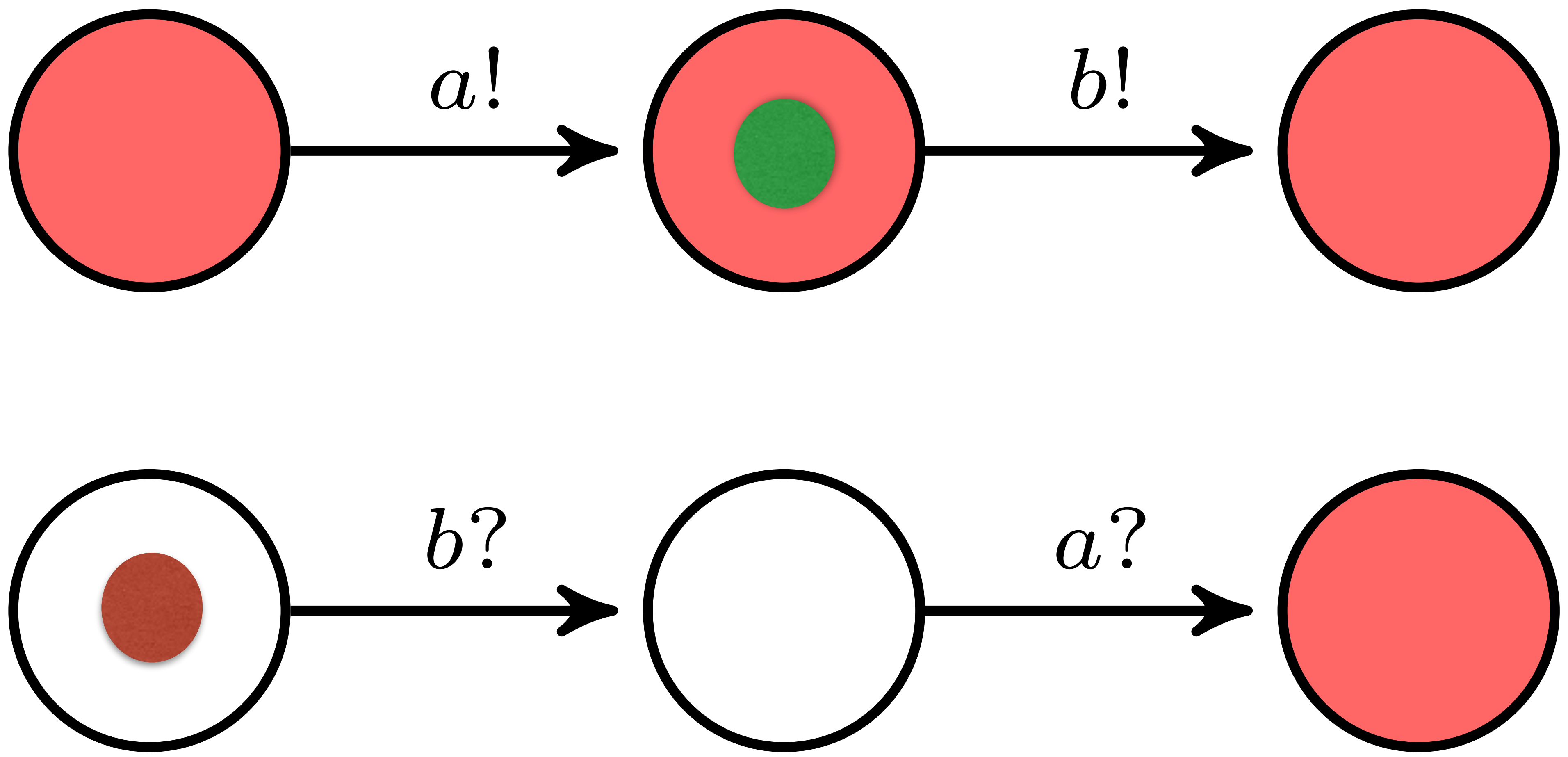
State: $\langle 0, 0 \rangle \left[C_1{=}0 :: C_2{=}0 \right] \{ \}$

Appendices



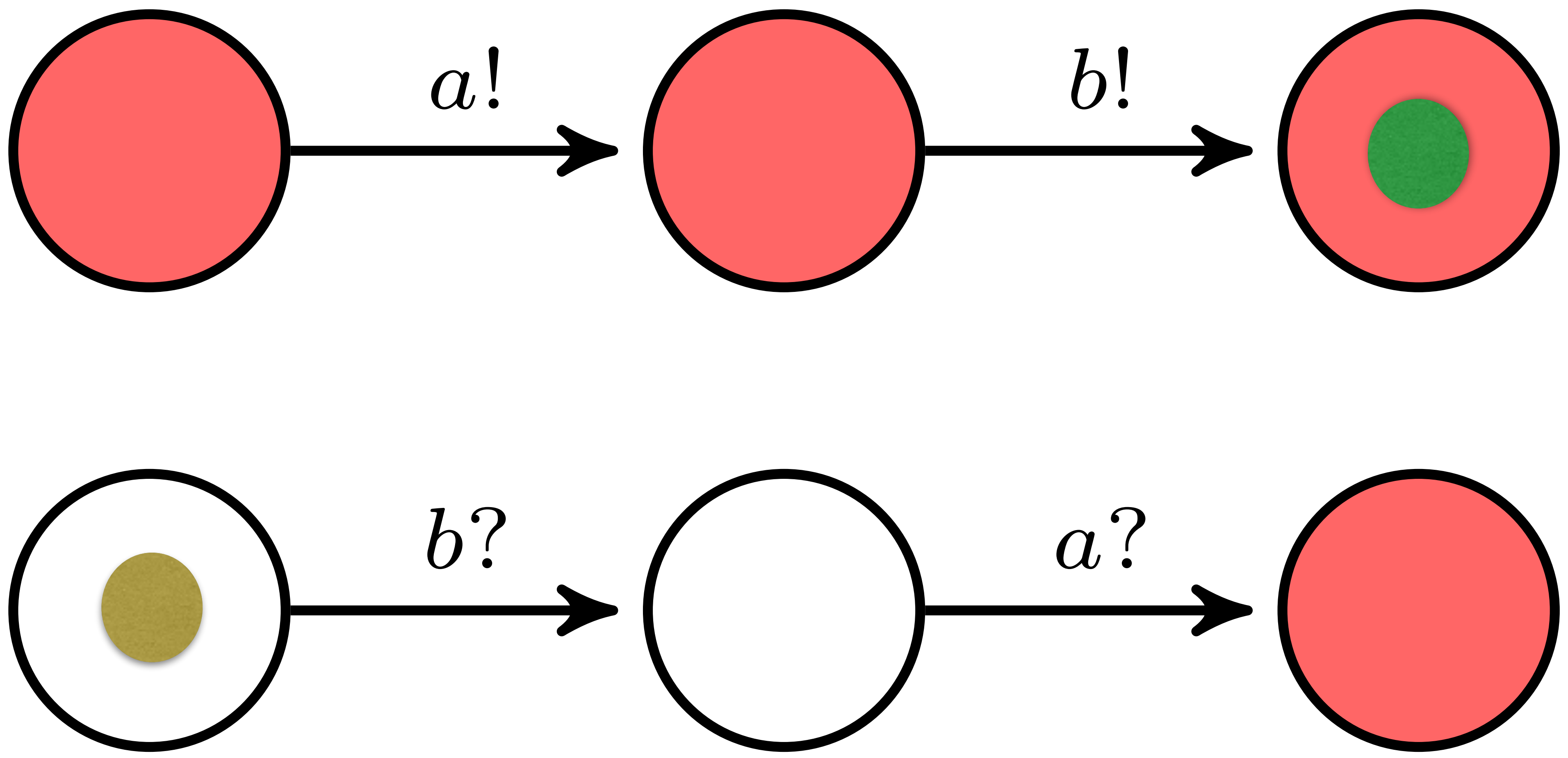
State: $\langle 0, 0 \rangle \left[\underline{C_1 = 0} :: C_2 = 0 \right] \{ \}$

Appendices



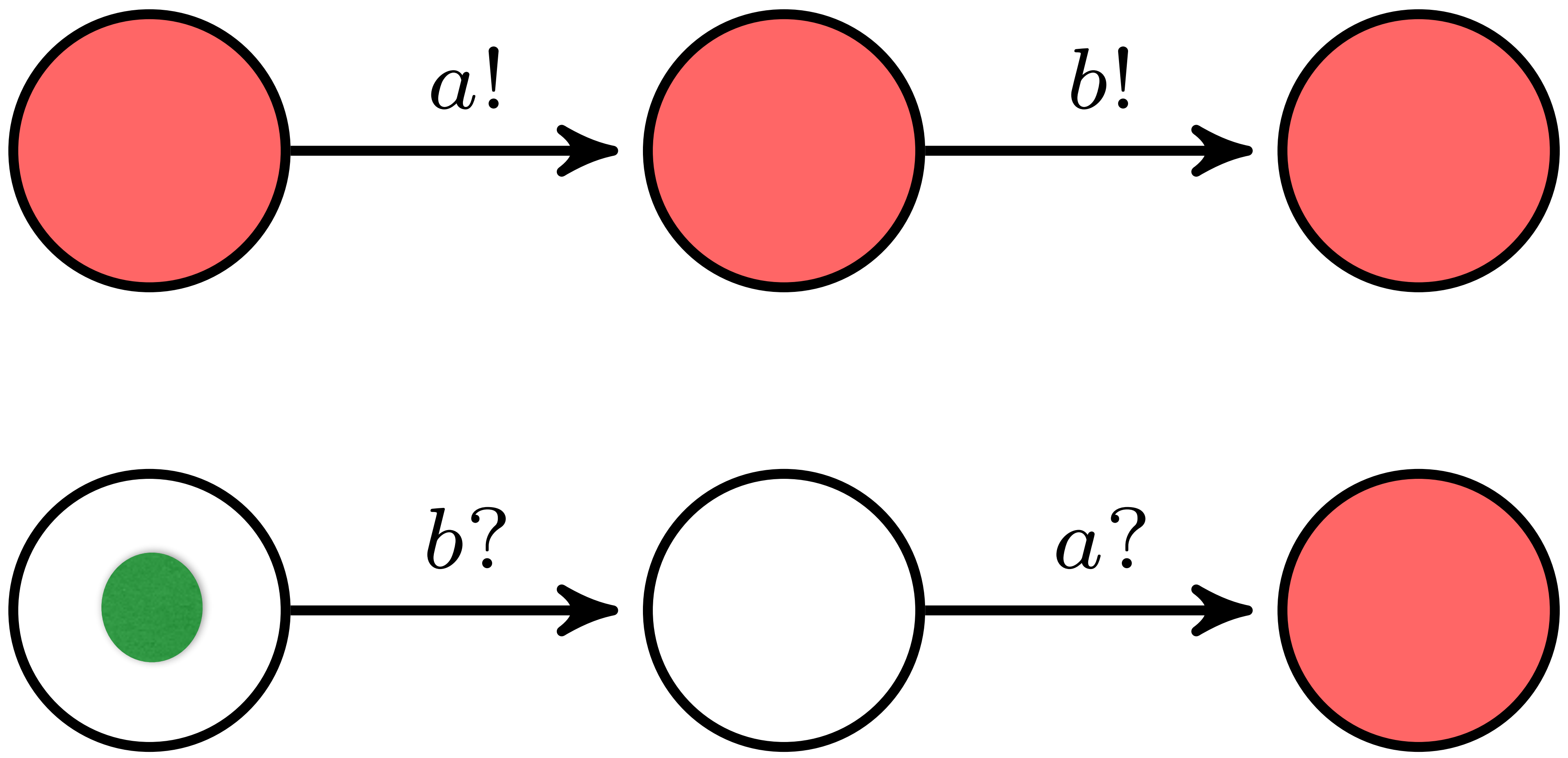
State: $\langle 0, 1 \rangle \left[\underline{C_1{=}0} :: C_2{=}0 \right] \{ a \}$

Appendices



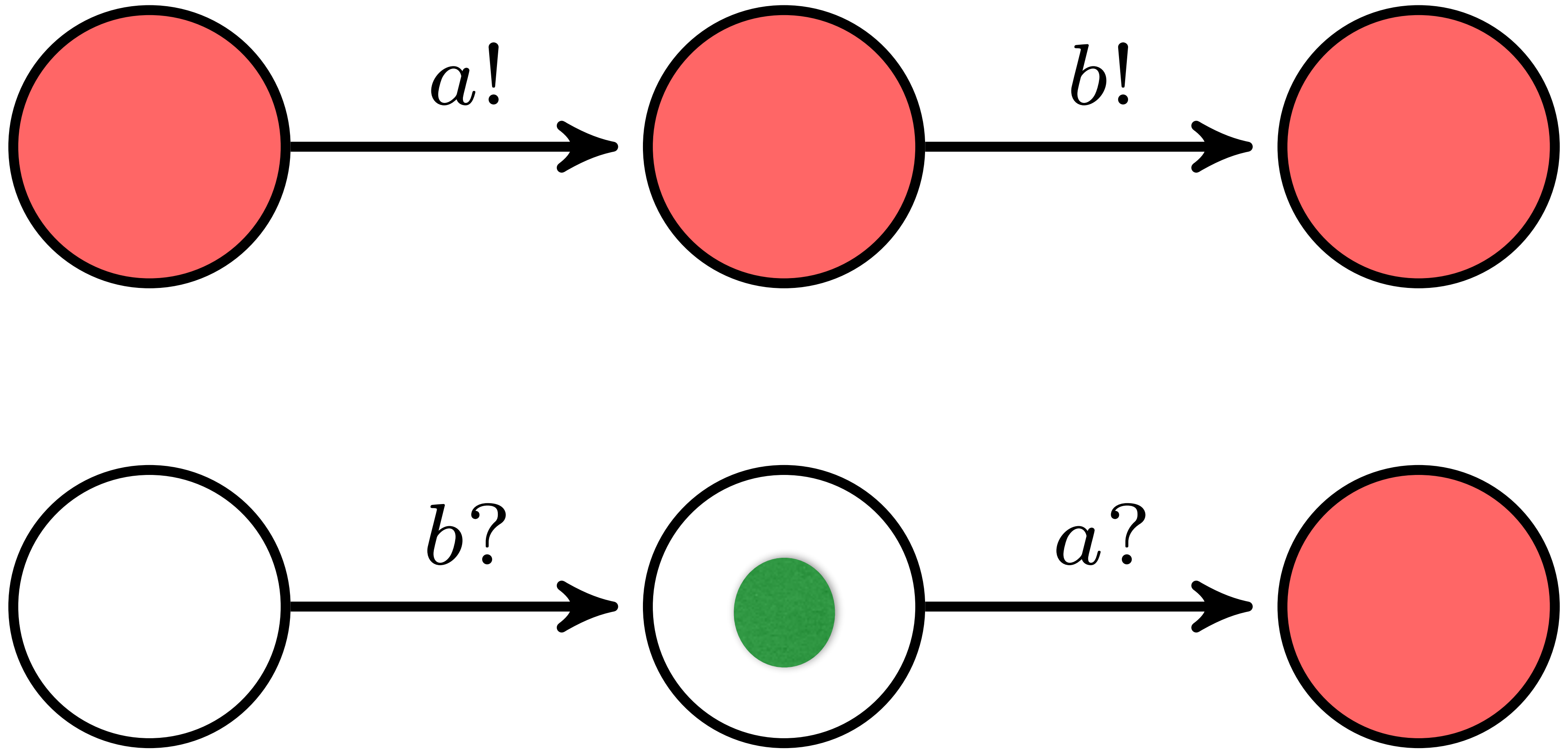
State: $\langle 0, 2 \rangle \left[\underline{C_1{=}0} :: C_2{=}0 \right] \{ a, b \}$

Appendices



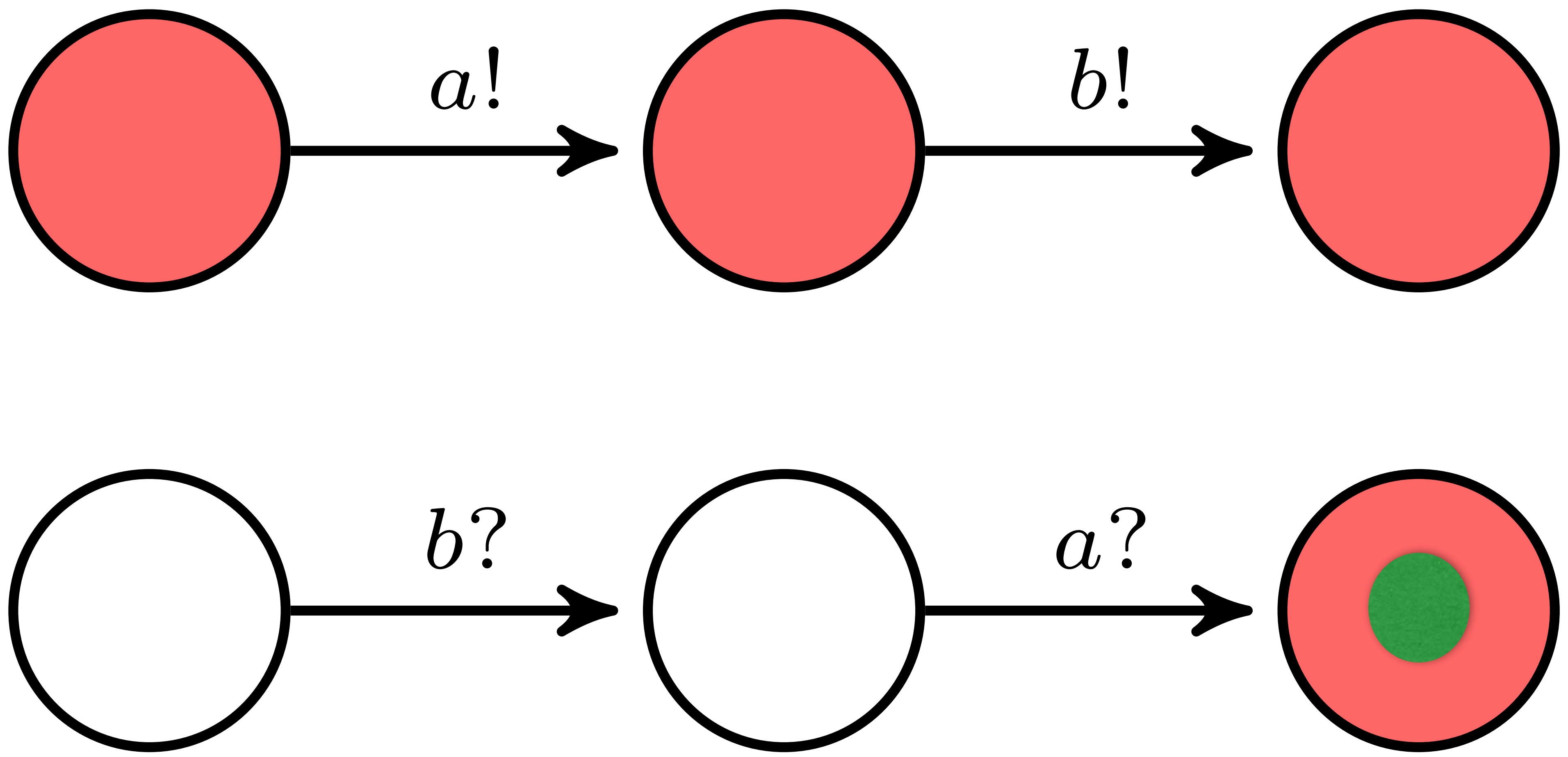
State: $\langle 0, 3 \rangle \; [\, \underline{C_2 = 0} \,] \; \{ a, b \}$

Appendices



State: $\langle 0, 4 \rangle \; [\, \underline{C_2 = 0} \,] \; \{ a, b \}$

Appendices



State: $\langle 0, 5 \rangle \; [\, \underline{C_2{=}0} \,] \; \{ a, b \}$