



# Model-Based Testing of an Interactive Music System

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## Mutant Team Team leader: Arshia **Cont**

#### **3 permanents and 3 Phd students**

### Realtime Recognition and Extraction of musical data from audio signals. Realtime Synchronous Programming in Computer Music.

#### **Publications** <u>http://repmus.ircam.fr/mutant/publications</u>



ircam Vientre



MUSIQUE

INTERAGIR

INEDIT project







### Introduction

**O** Antescofo an Interactive Music System **O** A Model-Based Testing application

#### A running method for testing

**o** Offline and Automatic timed conformance Testing **O** An IMS Model: The Intermediate Representation

#### Conclusion

**o** Conclusion & Future works

## Outline

### Instrumental Music A play between the composition and the performance time









### Instrumental Music A play between the composition and the performance time









# Mixed music

# realtime interaction between acoustic and electronic instruments



# Mixed music

# realtime interaction between acoustic and electronic instruments



## Automatic Accompaniment polyphonic score following and audio accompaniment



## Automatic Accompaniment polyphonic score following and audio accompaniment





Hardly Timed reactions



Unpredictable inputs

## Antescofo an Interactive Music System

Freq. Shift.



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## Antescofo an Interactive Music System



## Antescofo an Interactive Music System



. . .



Ideas

Score

## Piece creation

#### Concert?



## Testing a piece Prepare the IMS for a concert







#### no time for debugging!



## Testing a piece Prepare the IMS for a concert







#### **Manual method**

**Test for one performance** 

**Tedious (perform the whole piece)** 

Not precise



#### **Model Based Testing**

**Covering generation** 

**Automatic and Virtual Clock** 

**Formal (accurate and informative)** 











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Mixed Score

) () 2342-Ponce	TestOffline bash 80x24     x <sup>n</sup> 0 0 0     1       celet:TestOffline poncelet\$     Précédent Présentation Action Dropbox Organ	Nesure4 Iser par Partager Mod
	Emiliana di tet	1.00
T +	File Path + : ~/Desktop/folder/Migration_Ircam/Model_Tests/generation_Offline/TestOffline/Demo/Mesure4/Enspielung_4.txt	
	A P D Einspielung_4.txt C (no symbol selected)	
200 209 210 211 212 213	Mac-1 ADC3-del 30 Oname a4_0_3 Mac-1 ADC4-del 0 Oname a4_0_4 Mac-1 ADC5-del 0 Oname a4_0_5 Mac-1 ADC5-del 0 Oname a4_0_6	
214 215 216 237 258	GFWD m4 { Mac-1 ADC1 119 0 grun-l direct @name a4_1_1 Mac-1 ADC2 119 1 dim harmo 500 amp 9 fac 0.7 @name a4_1_2 Mac-1 ADC3 119 2 rond harmo 0 0 500 0.0.68.57 amp 9 @name a4_1_3	
219 220 221 222 223 224	1/6 Mac-1 ADC1 119 8 grun-l direct @name a4_2_1 Mac-1 ADC2 119 8 dim harmo 400 amp 9 fac 0.7 @name a4_2_2 Mac-1 ADC3 119 8 rond harmo 900 0.0.80 amp 9 @name a4_2_3	
225 226 227 228 229	1/6 Mac-1 ADC1 119 7 grun-l direct @name a4_3_1 Mac-1 ADC2 119 10 dim harmo 600 amp 9 fac 0.7 @name a4_3_2 Mac-1 ADC3 119 3 rond harmo 1500 0.0.00 amp 9 @name a4_3_3	
230 231 232 233 234 235	1/6 Mac-1 ADC1 119 9 grun-c direct @name a4_4_1 Mac-1 ADC2 119 9 dim harmo -700 amp 9 amp -6 fac 0.7 @name a4_4_2 Mac-1 ADC3 119 9 rond harmo 800 0.0.80 amp 9 @name a4_4_3	
236 237 238 239 248	<pre>/*1/6 a4_5_1 Mac-1 ADC1 119 6 carre2 direct @name a4_5_2 Mac-1 ADC2 119 5 dim harmo -600 amp 9 amp -6 fac 0.7 @name a4_5_3 Mac-1 ADC3 119 4 rond harmo 200 0.0.00 amp 9 @name</pre>	
241	1/6 a4 6 1 Mac-1 ADC1 119 1 carre2 direct @name	
243	a4_6_2 Mac-1 A0C3 119 1 rond harmo 200 0.0.80 amp 9+/	
244 - 245 246 247 248 249 250 250 251 252 253 253 255 255 255 258	CHORD ( 7300 6200 ) 1/6 e4_1 CHORD ( 7700 6200 ) 1/6 e4_2 CHORD ( 8300 6200 ) 1/6 e4_3 CHORD ( 7600 6800 ) 1/6 e4_4 Mac-1 ADC1 119 6 carre2 direct @name a4_5_1 Mac-1 ADC2 119 5 dim harmo -600 amp 9 amp -6 fac 0.7 @name a4_5_2 Mac-1 ADC3 119 4 rond harmo 200 0.0.80 amp 9 @name a4_5_3 CHORD ( 7000 6800 ) 1/6 e4_5 Mac-1 ADC3 119 1 rond harmo 200 0.0.80 amp 9 @name a4_6_2 NOTE 7100 3.5000 e5	





Mixed Score

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214 215 216 237 258	GFWD m4 { Mac-1 ADC1 119 0 grun-l direct @name a4_1_1 Mac-1 ADC2 119 1 dim harmo 500 amp 9 fac 0.7 @name a4_1_2 Mac-1 ADC3 119 2 rond harmo 0 0 500 0.0.68.57 amp 9 @name a4_1_3	
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244 - 245 246 247 248 249 250 250 251 252 253 253 255 255 255 258	CHORD ( 7300 6200 ) 1/6 e4_1 CHORD ( 7700 6200 ) 1/6 e4_2 CHORD ( 8300 6200 ) 1/6 e4_3 CHORD ( 7600 6800 ) 1/6 e4_4 Mac-1 ADC1 119 6 carre2 direct @name a4_5_1 Mac-1 ADC2 119 5 dim harmo -600 amp 9 amp -6 fac 0.7 @name a4_5_2 Mac-1 ADC3 119 4 rond harmo 200 0.0.80 amp 9 @name a4_5_3 CHORD ( 7000 6800 ) 1/6 e4_5 Mac-1 ADC3 119 1 rond harmo 200 0.0.80 amp 9 @name a4_6_2 NOTE 7100 3.5000 e5	





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241	1/6 a4 6 1 Mac-1 ADC1 119 1 carre2 direct @name	
243	a4_6_2 Mac-1 A0C3 119 1 rond harmo 200 0.0.80 amp 9+/	
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225 226 227 228 229	1/6 Mac-1 ADC1 119 7 grun-l direct @name a4_3_1 Mac-1 ADC2 119 10 dim harmo 600 amp 9 fac 0.7 @name a4_3_2 Mac-1 ADC3 119 3 rond harmo 1500 0.0.00 amp 9 @name a4_3_3	
230 231 232 233 234 235	1/6 Mac-1 ADC1 119 9 grun-c direct @name a4_4_1 Mac-1 ADC2 119 9 dim harmo -700 amp 9 amp -6 fac 0.7 @name a4_4_2 Mac-1 ADC3 119 9 rond harmo 800 0.0.80 amp 9 @name a4_4_3	
236 237 238 239 248	<pre>/*1/6 a4_5_1 Mac-1 ADC1 119 6 carre2 direct @name a4_5_2 Mac-1 ADC2 119 5 dim harmo -600 amp 9 amp -6 fac 0.7 @name a4_5_3 Mac-1 ADC3 119 4 rond harmo 200 0.0.00 amp 9 @name</pre>	
241	1/6 a4 6 1 Mac-1 ADC1 119 1 carre2 direct @name	
243	a4_6_2 Mac-1 A0C3 119 1 rond harmo 200 0.0.88 amp 9*/	
244 - 245 246 247 248 249 250 250 251 252 253 253 255 255 255 258	CHORD ( 7300 6200 ) 1/6 e4_1 CHORD ( 7700 6200 ) 1/6 e4_2 CHORD ( 8300 6200 ) 1/6 e4_3 CHORD ( 7600 6800 ) 1/6 e4_4 Mac-1 ADC1 119 6 carre2 direct @name a4_5_1 Mac-1 ADC2 119 5 dim harmo -600 amp 9 amp -6 fac 0.7 @name a4_5_2 Mac-1 ADC3 119 4 rond harmo 200 0.0.80 amp 9 @name a4_5_3 CHORD ( 7000 6800 ) 1/6 e4_5 Mac-1 ADC3 119 1 rond harmo 200 0.0.80 amp 9 @name a4_6_2 NOTE 7100 3.5000 e5	





**Timed traces:**  $\langle a, t \rangle$  with  $a \in \Sigma_{in} \cup \Sigma_{out}$ and  $t \in \mathbb{R}^+$  real output trace

	TestOffline bash 80x24	2000	Mesure4
342-Ponce	elet:TestOfflime poncelet% []	Précédent Trésentation Actio	m Dropbox Organiser par Partager Modifie
		cmTest	🔛 Mesure4 🔰 🐑 B
		Einspielung_4.txt	
T. 21	File Path + : -/Desktop/folder/Migration_ircam/Model_Tests/generation_Offline/Te	stOffline/Demo/Mesure4/Einspielung	L4.txt
	- +   > Einspielung_4.txt 0   (no symbol selected) 0		
.201	Mac-1 ADC3-del 30 @name a4_8_3		
209	Mac-1 ADC4-del 0 (mame a4_0_4 Mac-1 ADC5-del 0 (mame a4_0_5		
211	Mac-1 ADC6-del 0 (name a4_0_6		
212			
213	GP40 m4		
215 ¥	{		
216	Mac-1 ADC1 119 0 grun-l direct @name a4_1_1		
	Mac-1 ADC2 119 1 dim harmo 500 amp 9 fac 0.7	name a4_1_2	
219		and areas	
220			
221	1/6 Mac-1 ADC1 119 8 grun-1 direct gname a4_2_1 Mac-1 ADC2 119 8 dim barms 488 amp 9 fac 8.7	drame ad 2.2	
223	Mac-1 ADC3 119 8 rond harmo 980 0.0.80 amp 9	(mane a4_2_3	
224			
225	1/6 Mar. 1 40/1 110 7 area. 1 direct drame ad 3.1		
227	Mac-1 ADC2 119 10 dim harmo 600 amp 9 fac 0.7	dname a4 3 2	
228	Mac-1 ADC3 119 3 rond harmo 1500 0.0.80 amp 9	ename a4_3_3	
229			
230	1/6 Mac-1 ADC1 119 9 grup-c direct grame a4 4 1		
232	Mac-1 ADC2 119 9 dim harmo -700 amp 9 amp -6	fac 0.7 @name a4_4_2	
233	Mac-1 ADC3 119 9 rond harmo 800 0.0.80 amp 9	gnane a4_4_3	
234			
236	/#1/6 a4_5_1 Mac-1 ADC1 119 6 carre2 direct @name		
237	a4_5_2 Mac-1 ADC2 119 5 dim harmo -600 amp 9	amp -6 fac 0.7 @name	
	a4_5_3 Mac-1 ADC3 119 4 rond harmo 200 0.0.80	amp 9 @name	
248			
243			
242	1/6 a4_6_1 Mac-1 ADC1 119 1 carre2 direct @name	and Bal	
243	84_0_2 Mac-1 Aut 3 119 1 rond harmo 200 0.0.00	amp sey	
245	1.122/111111111111111111111111111111111		
246	CURREN ( 1700 4700 ) 1 1 4 4		
247	CHORD ( 7388 5288 ) 1/6 e4_1 CHORD ( 7788 5288 ) 1/6 e4_2		
249	CHORD ( 8308 6208 ) 1/6 e4_3		
250	CHORD ( 7688 6888 ) 1/6 e4_4		
	Mac-1 ADC1 119 6 carre2 direct gname a4_5_1 Mac-1 ADC2 110 5 die barmo -600 amp 0 amp -6	fac 8.7 mane ad 5.2	
253	Mac-1 ADC3 119 4 rond harmo 200 0.0.80 ano 9	gnane a4 5 3	
254	CHORD ( 7000 6500 ) 1/6 e4_5		
255	Mac-1 ADC1 119 1 carre2 direct @name a4_6_1	(man +1 + 1	
257	Mac-1 Aut.3 119 1 rond harmo zee e.e.80 anp 5	grame a4_0_2	
258	NOTE 7100 3,5000 e5		





0	D11 T	estOffline hash 80x24	2000	Con Marcol	and a
42-Ponce	let:TestOffline	poncelets	Précédent Stésentat	tion Action Dropbox Organiser p	ar Partager Modifie
11111			cmTest	Mesure4	P 🐑 B
			C Einspielung 4.txt	-	
T +	File Path + : ~/Deski	top/folder/Migration_ircam/Model_Tests/generation_C	Mine/TestOffline/Demo/Mesure4/E	inspielung, 4.txt	
·	4 Emple	elung 4.txt 2 (no symbol selected) 2		and the second se	
200	Mac-1 ADC3	-del 30 gname a4_0_3			
209	Mac-1 ADC4	-del 0 gname a4_0_4			
210	Mac-1 ADC6	i-del 0 (mame a4_0_5			
.212					
213	GPMD m4				
215 9	{	and the second			
218	Mac-1 Mac-1	ADC1 119 0 grun-1 direct @name a4_1_1 ADC2 119 1 dim harmo 500 amo 9 fac 0.7	drame a4 1.2		
218	Mac-1	ADC3 119 2 rond harmo 0 0 500 0.0.68.57	amp 9 gname a4_1_3		
219					
221	1/6	Mac-1 ADC1 119 8 grun-1 direct @name	a4_2_1		
222		Mac-1 ADC2 119 8 dim harmo 400 amp 9 f Mac-1 ADC3 119 8 rond harmo 900 8.0.80	ac 0.7 (mane a4_2_2 ano 9 (mane a4_2_3		
224					
225	1/6	Mac-1 ADC1 119 7 grup-1 direct drame	111		
227	170	Mac-1 ADC2 119 10 dim harmo 600 amp 9	fac 8.7 @name a4_3_2		
228		Mac-1 ADC3 119 3 rond harmo 1500 0.0.8	8 anp 9 (ename a4_3_3		
238					
231	1/6	Mac-1 ADC1 119 9 grun-c direct ename a Mac-1 ADC2 119 9 dim harmo -788 amp 9	4_4_1	4.2	
233		Mac-1 ADC3 119 9 rond harmo 800 0.0.80	anp 9 (name a4,	43	
234					
236	/#1/6	a4_5_1 Mac-1 ADC1 119 6 carre2 direct	Qname		
237		a4_5_2 Mac-1 ADC2 119 5 dim harmo -680	anp 9 anp -6 fac 0.7 (name		
239		84_9_5 Het-1 Hets 115 4 Tullo Herbo 246	ereroe anh a firanc		
248					
242	1/6 a4	_6_1 Mac-1 ADC1 119 1 carre2 direct @n	ane		
243		a4_6_2 Mac-1 ADC3 119 1 rond harmo 200	0.0.88 amp 9*/		
245	1.1				
246	CHORD / 7388 6	1 ha 3/1 4 60			
248	CHORD ( 7788 6	280 ) 1/6 e4_2			
249	CHORD ( 8388 6	2200 ) 1/6 e4_3			
	Mac-1 ADC	1 119 6 carre2 direct @name a4_5_1			
		Mac-1 ADC2 119 5 dim harmo -600 amp 9 1	amp -6 fac 0.7 gname a4_	5_2	
254	CHORD ( 7888 6	isee ) 1/6 e4_5	france and	~	
255	Mac-1 ADC	1 119 1 carre2 direct @name a4_6_1	C 3 by manh 6 and 6		
257		HAC-1 MACO 110 1 10H0 Harmo 146 6.6.8	and a fame ad 0's		
258	NOTE 7100 3.50	00 e5			



#### Introduction

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#### A running method for testing

**o** Offline and Automatic timed conformance Testing **O** An IMS Model: The Intermediate Representation Conclusion

**o** Conclusion & Future works

## Outline



```
; Antheme 2 INTRO
BPM 92 ; tempo a la croche attention
```

[...]

PFWD 0.1 s1-t1-trait2 bang

; BPM 46;

TEMPO OFF 8.0 Q2 ;second\_trait ; old\_e2; Trill\_1 TRILL ( 7400 7500 ) cue\_nb 2; ir2-param reverb tr0 25 A2\_samples\_in 74 120 15 0.1 A2\_samples\_in 73 120 15 0.1 A2\_samples\_in 70 120 15 0.1 A2\_samples\_in 69 120 15 0.1 A2\_samples\_in 68 120 15 0.1 A2\_samples\_in 120 15 67 0.1 A2\_samples\_in 120 15 66 0.1 A2\_samples\_in 63 120 15 fd 1 del 25; fd 1 fre -347; fd 1 db 0; ir1 99 500; start decrescendo reverb inf 1



; Antheme 2 INTRO BPM 92 ; tempo a la croche attention

[...]

PFWD 0.1 s1-t1-trait2 bang

input events expected

; BPM 46;

TEMPO OFF TRILL ( 7400 7500 ) 8.0 Q2 ;second\_trait ; old\_e2; Trill\_1 cue nb 2; ir2-param reverb tr0 25 A2\_samples\_in 74 120 15 0.1 A2\_samples\_in 73 120 15 0.1 A2\_samples\_in 70 120 15 0.1 A2\_samples\_in 69 120 15 0.1 A2\_samples\_in 120 15 68 0.1 A2\_samples\_in 120 15 67 0.1 A2\_samples\_in 120 15 66 0.1 A2\_samples\_in 63 120 15 fd 1 del 25; fd 1 fre -347; fd 1 db 0; ir1 99 500; start decrescendo reverb inf 1







durations delays beats of tempo beats

## An IMS Specification Antescofo Domain Specific Language



durations delays beats of tempo beats

+ High level Synchronisation, error management dynamic processes ... features:



## Intermediate Representation the syntax

input output r internal

Representable with **Finite State Machine** + variables & time

symbols  $\Sigma = \Sigma_{in} \uplus \Sigma_{out} \uplus \Sigma_{sig}$ 

events	$\Sigma_{in}$
nessages	$\Sigma_{out}$
l signals	$\Sigma_{\sf sig}$



# Intermediate Representation

symbols  $\Sigma = \Sigma_{in} \uplus \Sigma_{out} \uplus \Sigma_{sig}$ 

events	$\Sigma_{in}$
nessages	$\Sigma_{out}$
l signals	$\Sigma_{\sf sig}$

Representable with **Finite State Machine** + variables & time



## Intermediate Representation the semantics with example



NOTE el dl d11 msg11 d12 msg12

NOTE e2 d2 d21 msg21

#### Antescofo score

#### **IR** representation













 $acc+d, sc, \tilde{e} \vdash_{al} sa : \mathcal{G}_{sa}$  $acc, sc, e \vdash_{al} \mathsf{act}(d, sa', al') :: sa : \tilde{\mathcal{G}} + \mathcal{G}_{sa} \parallel \mathcal{T}(g') + \mathcal{G}'_{sa}$ 

 $\frac{acc+d, sc, closest(acc+d, sc) \vdash_{al} sa: \mathcal{G}_{sa}}{acc, sc, e \vdash_{al} \mathsf{act}(d, a, al')::sa: \mathcal{G}(a, d, al, sc, e) + \mathcal{G}_{sa}} \text{ }^{\mathsf{MSG}}$ 

 $\mathcal{G}(\tau, d, [\mathsf{loose}, \mathsf{local}], sc, e) = 10$ au!



## Environment model





# Conclusion & Perspectives

Model-Based Testing an IMS with automatic model construction Automatic generation of test cases with CoVer and alternative methods

Visualisation for IR (Assistance for composition) Using Ascograph, Ptolemy, SpaceEx

Conclusion

Future Works

#### IR

- VM = IR interpreter.
- Analyse robustness, race conditions, time safety...
  - Dnline
- TRON-like framework: On-the-fly test suite generation





[David, Larsen, Li, Mikucionis, Nielsen12] **Testing Real-Time Systems under Uncertainty.** 2012

[Blom, Hessel, Jonsson, Peterson 04] Specifying and Generating Test Cases Using Observer Automata. 2004

[Hessel, Larsen, Mikucionis, Nielsen, Pettersson, Skou08] **Testing Real-Time Systems Using Uppaal.** 2008

[Dannenberg 97] Abstract Time Warping of Compound Events and Signals. Computer Music Journal 1997

[Honing01] From time to time: The Representation of timing and tempo. Computer Music Journal 2001

[Larsen, Mikucionis, Nielsen 04] **Online Testing of Real-time Systems Using Uppaal.** 2004

## Automatic construction of models







# Generation of Input traces



**Audio files** 



### Generation with & CoVer

#### Uppaal extension for Offline generation [Blom, Hessel, Jonsson, Peterson 04]



#### **Conclusion Cover**

- + Well suited for debugging
- Shortest delays  $\rightarrow$  tempo explosion
- Scalability problem (small scores/extracts)

Generation

 observers = FSA motoring the simulation • exploration of the symbolic state set keep the trace with maximal number



exhaustive







# - Lack of coverage criteria

# From recorded audio file



Audio file



#### Conclusion User File + Well suited for Composition assistance - Input score specifiable





#### bounds:

#### reactive machine







#### Black-Box execution audio signal **3** Scenarios



#### bounds:

#### whole Antescofo





Testing Real-Time Systems Using Uppaal [Hessel, Larsen, Mikucionis, Nielsen, Pettersson, Skou08]



note0 --> 0.77 --> note1\_1.00 --> 0.385 --> note2\_1.50 --> 0.1925 --> note3\_1.75 --> 0

)	Trace	Expecte	ed Trace -	-1
	[Estimate Beat]	TimeStamp	[Beat] -	-
-			·	-
)	[ 0]	a0 0	[ 0]	
)	[ 0]	e0 0	[ 0]	* T: 60 BPM
j	[ 0.5]	a1 0.5	[ 0.5]	
	[0.77]	a2 0.77	[0.77]	
	[0.824]	e1 0.77	7 [0.77]	* T: 64.2 BPM
	[0.95]	a3 0.887	[1.02]	
	[1.21]	e2 0.95047	[1.16]	* T: 128 BPM
)	[1.29]	a4 0.95	[1.16]	x delta: 0.04
2	[1.35]	a5 0.985	[1.25]	x delta: 0.0321
2	[1.35]	a6 1.02	[1.35]	
ŀ	[ 1.4]	e3 1.0174	[1.35]	* T: 173 BPM
ŀ	[ 1.4]	e4 1.0174	[1.35]	* T: 203 BPM
3	[ 2.3]	a7 1.28	[2.31]	
	[2.38]	e5 1.2831	[2.31]	* T: 220 BPM
				-