
Jean-Louis Giavitto
Programming Cyber-Temporal Musical Systems
accorder le temps de la machine à celui de l'homme
ircam
Centre
Pompidou
cnrs
UPMC
Inria

Un ordinateur peut-il…

- jouer aux échecs
- effectuer des raisonnements logiques
- trouver un itinéraire sur une carte routière
- …
- marcher sur deux jambes
- …
- reconnaître un sourire dans un visage
- …
- jouer de la musique avec des musiciens ?

Automatic Accompaniment using *Antescofo*

Concerto pour main gauche, Ravel. *Pianiste*: Jacques Comby
Orchestre: enregistrement de l'Orchestre de Paris modulé par *Antescofo* en temps réel

Tesla ou l'effet d'étrangeté Julia Blondeau (2014)

alto: Christophe Desjardins, électronique en temps réel: Antescofo

Antescofo

écouter

reconnaître

Synchronisation
des actions
électroniques
avec le jeu d'un musicien

réagir

A “Language Approach”

Authoring time:
- composition
- computing time

Author (composer)

write

Authoring time
in real-time

« read »

« eval »

« print »

interactive scenario
open score, virtual
score…

Analysis

Perception

Action

writer
pretty-printing

reader
parsing

Acquisition

interactive piece
mixed music,
time-art,
…

Production

Synthesis,
rendering

interact

Musicans
(& audience)

authoring interaction :
- performance
- computing in real-time

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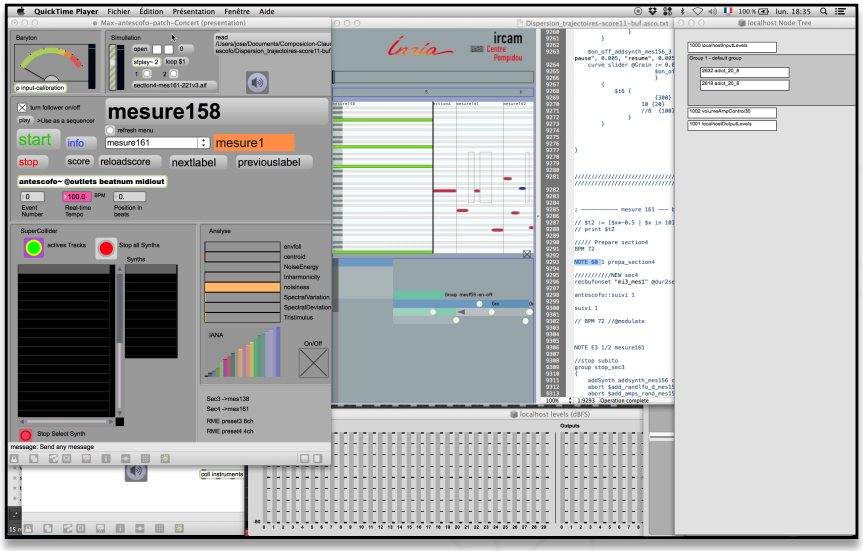
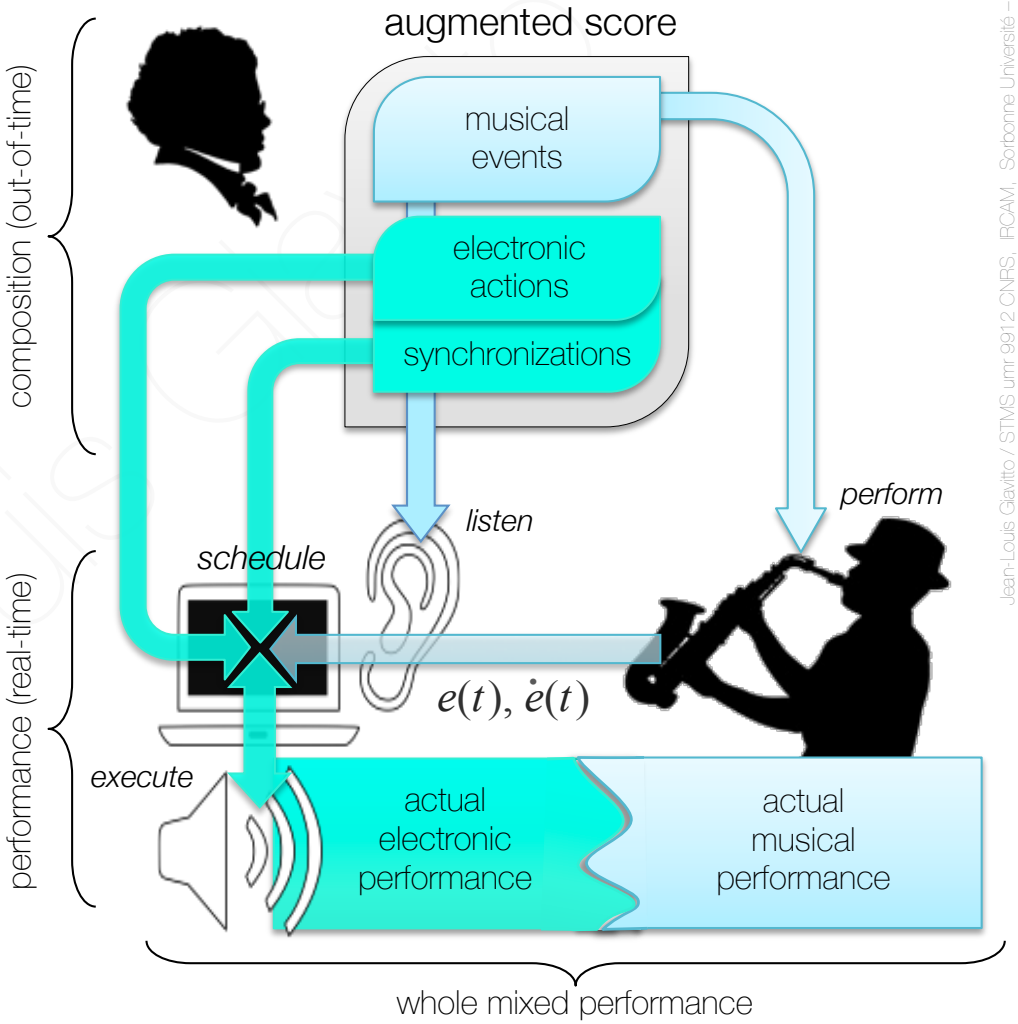
reactive, strongly timed language + score following

Antescofo





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La « solution Antescofo »

- La *partition augmentée* est un programme temps-réel
  - le compositeur est un programmeur
  - l'évaluation se fait par le <musicien | la machine>
  - le compositeur doit spécifier la concordance des deux parties
- La machine d'écoute fournit les entrées du programme côté ordinateur <musicien|écoute|programme réactif>
- Le temps est une entité de 1ère classe du langage
  - ce n'est pas une propriété opérationnelle
  - traiter événement et durée
  - chronométrique et relationnel
  - définir des repères temporels par synchronisation avec un autre repère
- Le musicien a son propre repère temporel
  - le tempo n'est pas une vitesse quand l'humain est dans la boucle

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Notion of

CYBER-TEMPORAL SYSTEMS

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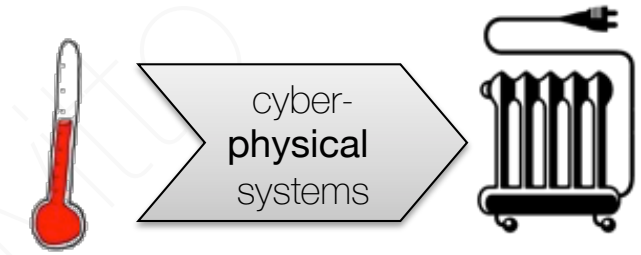
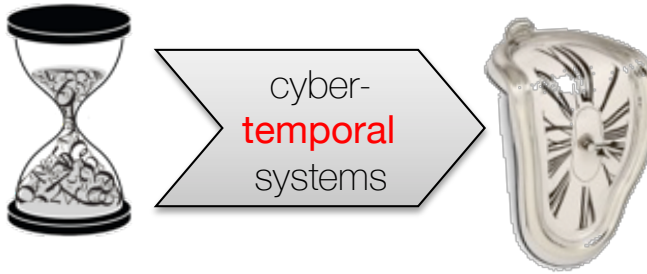
Cyber-temporal systems:

computing time in real-time

- *from:* physical entities
  monitored by algorithms
- *to:* temporal relationships
  sensed and produced by algorithms
- *example:* interactive music systems
  Antescofo





- notion**S** of TIME:
  - multiple times: deferred time, real-time
  - multiple models of time: event-driven, time-driven
  - multiple scales: from audio (0.02 *ms*) to control (*hours*)
  - time programmability: time is a denotable entity

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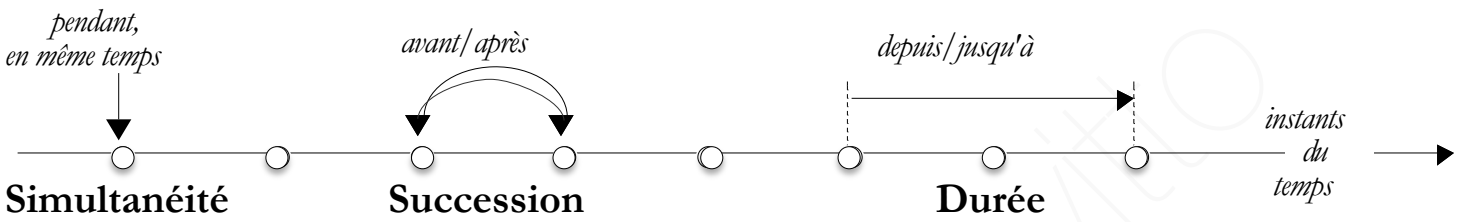
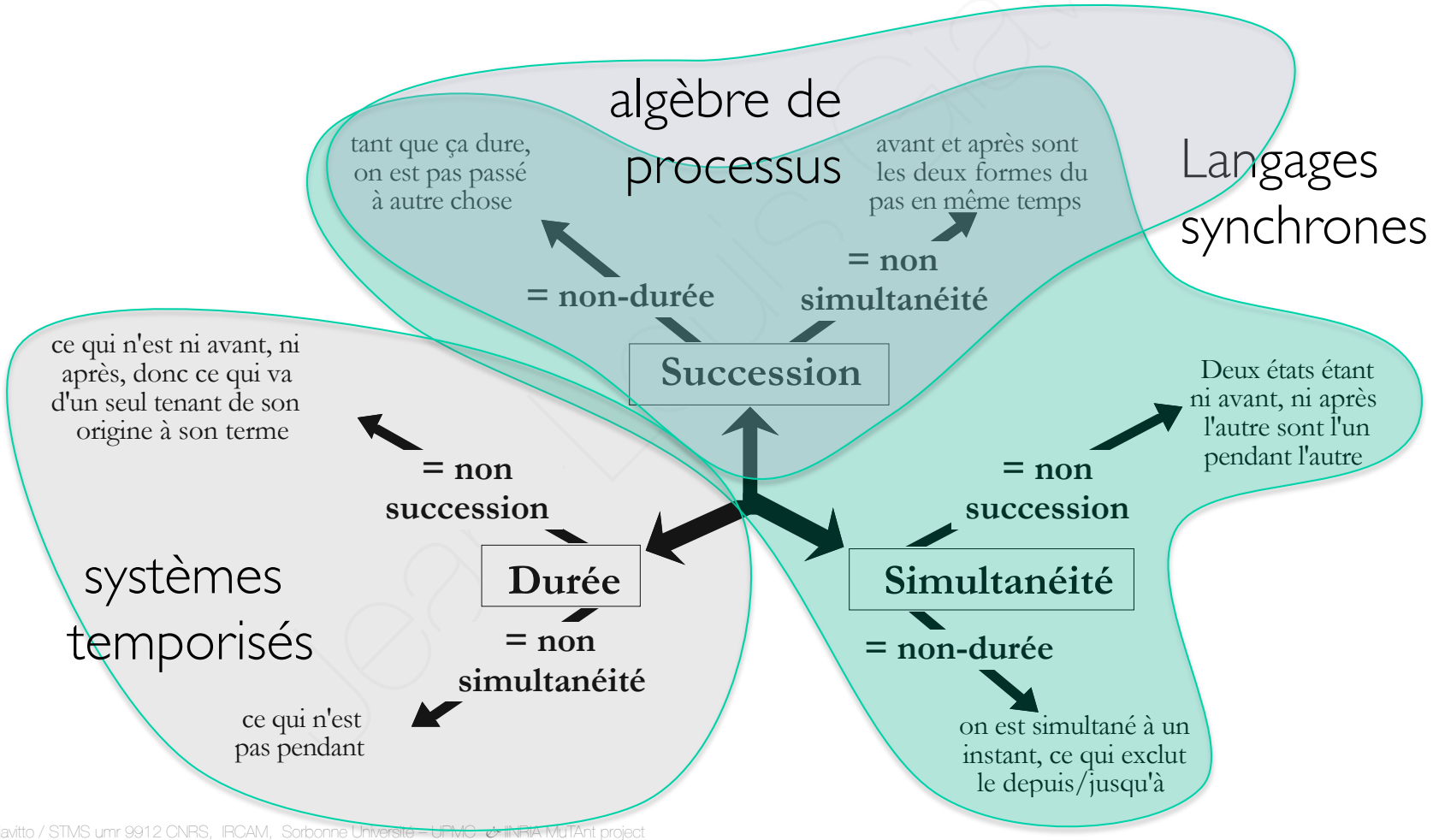
Simultanéité, succession & durée





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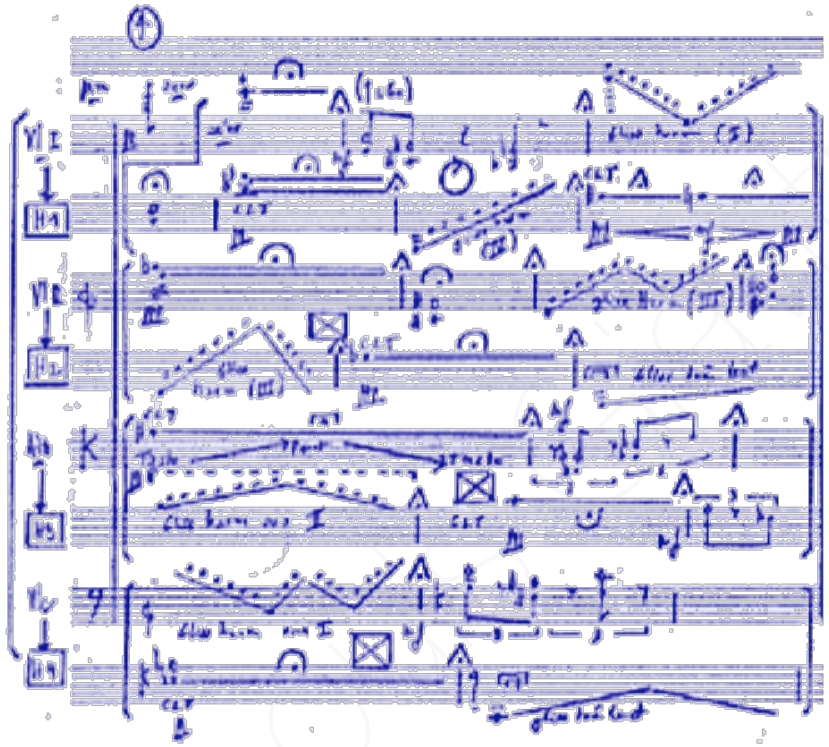

AN HYBRID TIME

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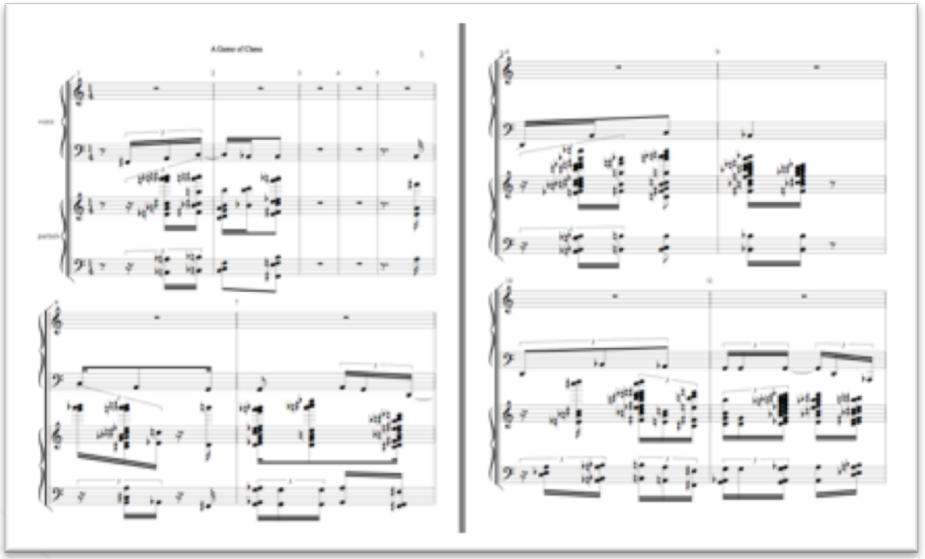
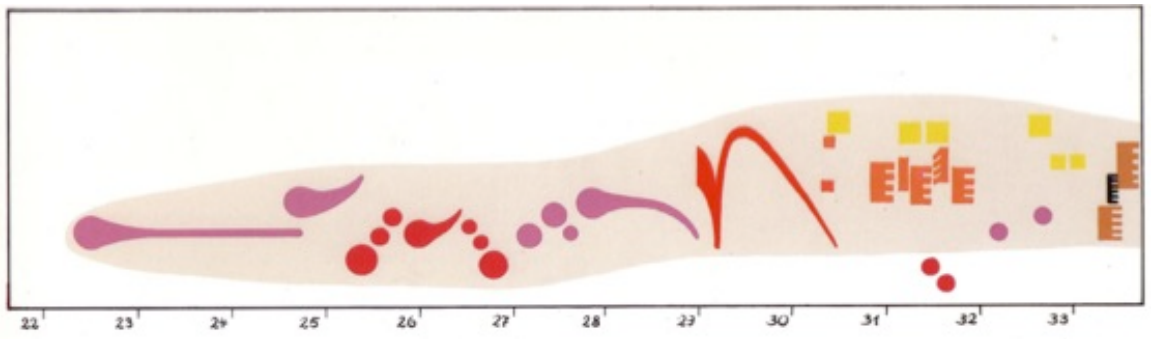
A Score

- instantaneous events
  (e.g. the onset of a note)



- events that last
  (duration of a note)

- continuous change of parameter (*movement*, *gesture*)
  - frequency
  - ambitus
  - sound localization
  - etc.



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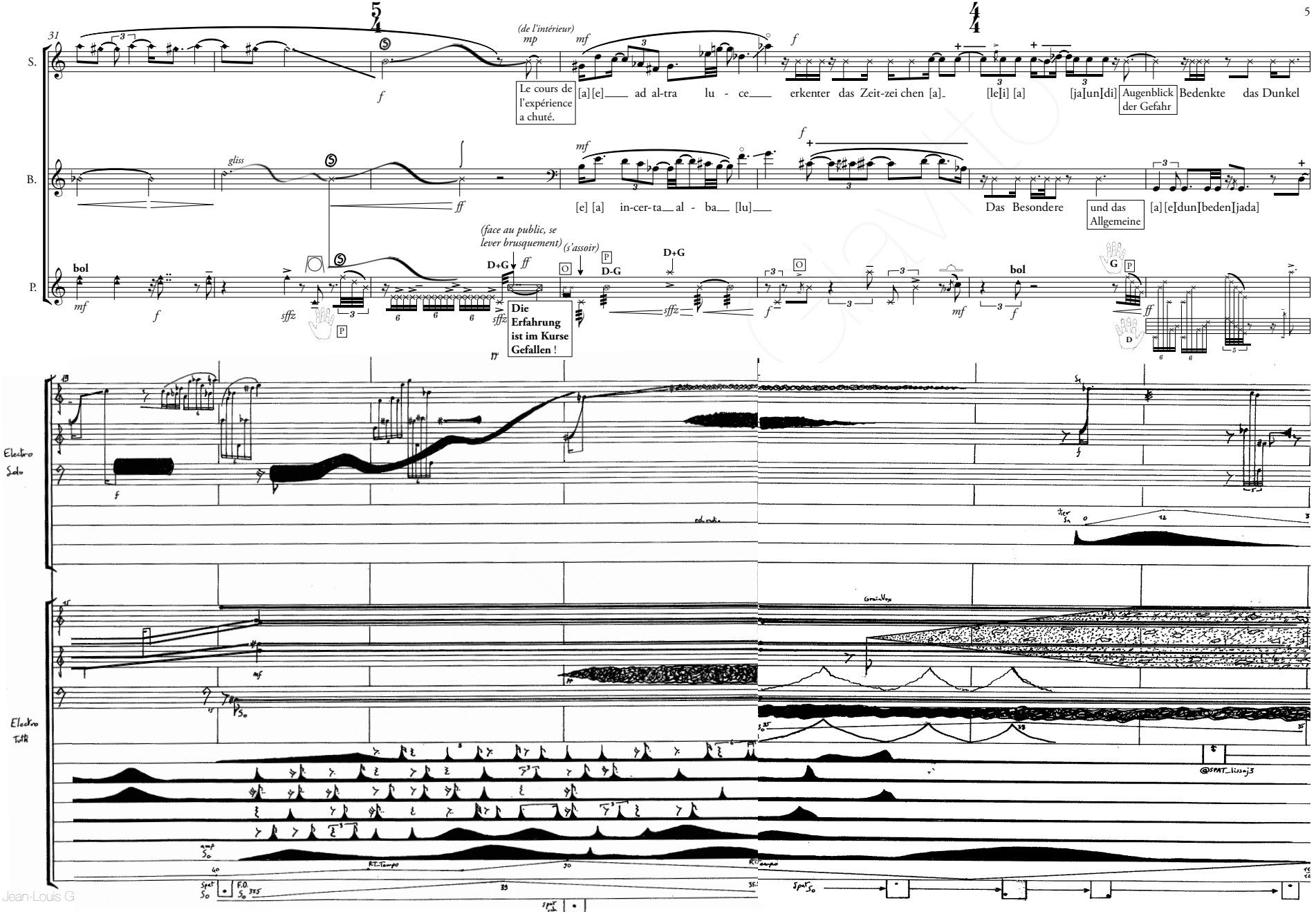
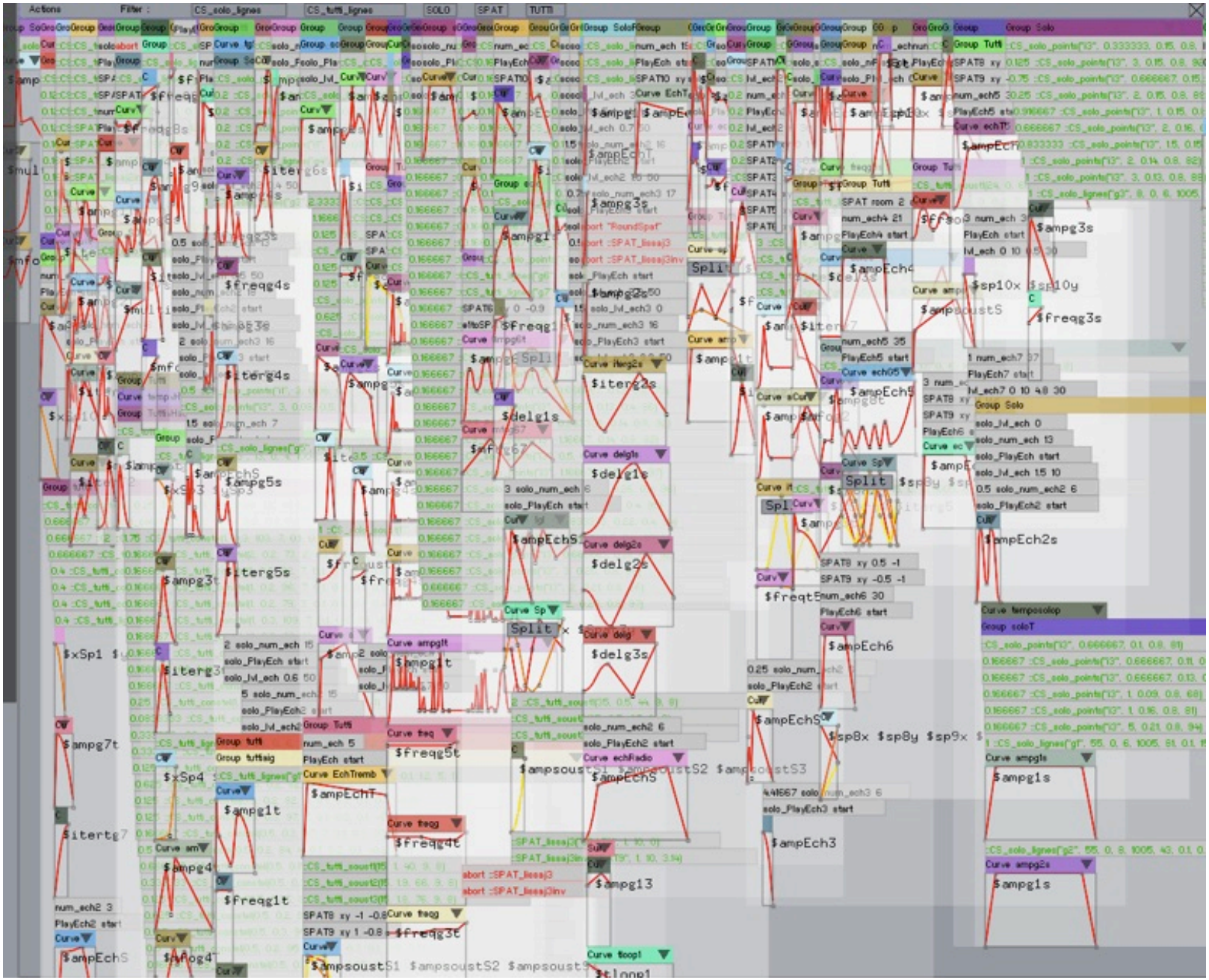
Nachleben Julia Blondeau (2014)



Nachleben, Julia Blondeau (8'30)



Des objets et des relations temporelles

- instant, durée
- succession, simultanéité, duration (se dérouler)
- différents temps
  - événementiel / chronométrique
  - absolu / relatif
  - continu / discret
  - contrôle / audio
- différentes échelles
  - audio (1/44 ms)
  - contrôle (2 ms -> 1 h)
  - simultanéité sonore ~ 20ms

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Peux t'on réduire les durées aux instants ?

- evenemential-time

versus

- the fluxion: continuous passage of time
  - going twice faster
  - finishing together
  - accelerando
  - rubato
  - tempo
  - etc…

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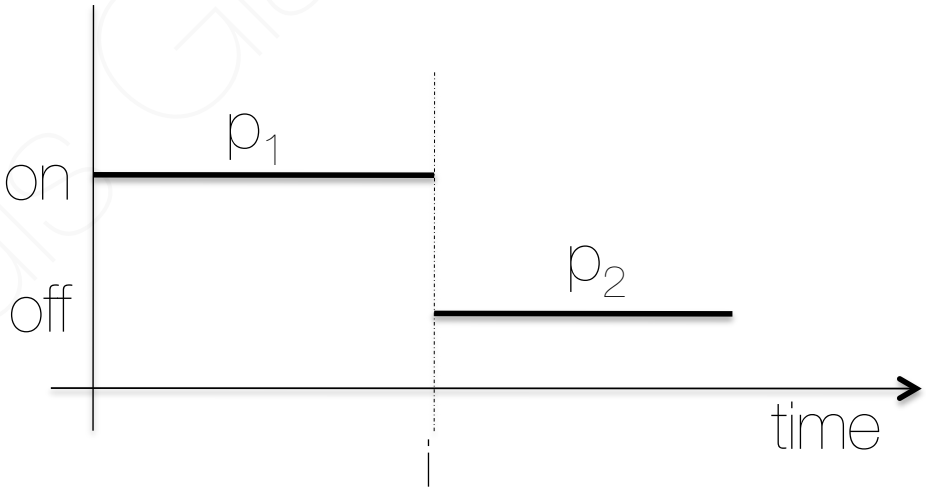
Can duration be reduced to instant? (in temporal logic)



doing real analysis and topology

or

making instant and duration primitive notions

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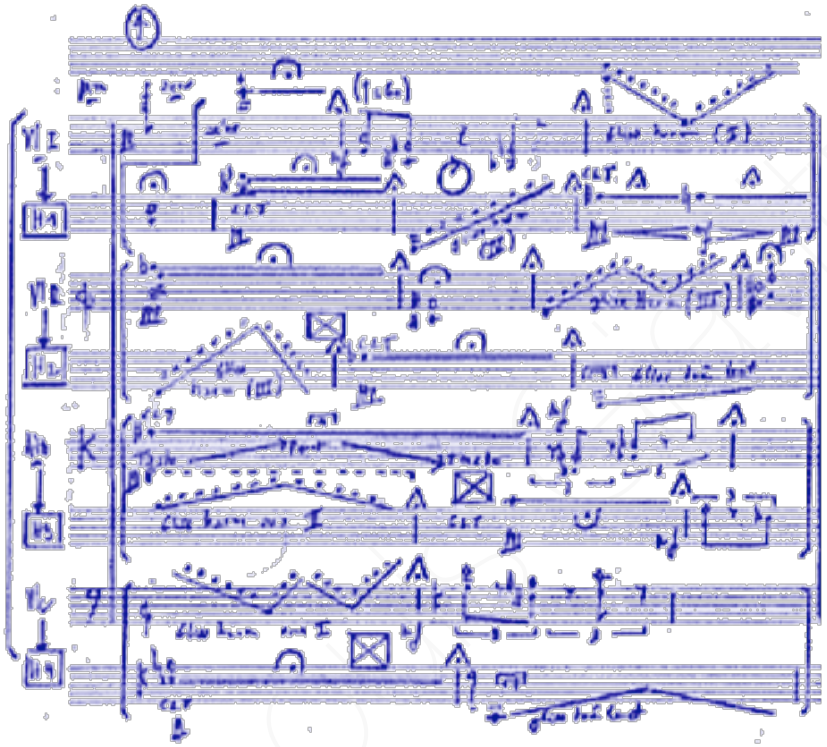

MULTIPLE TIMES

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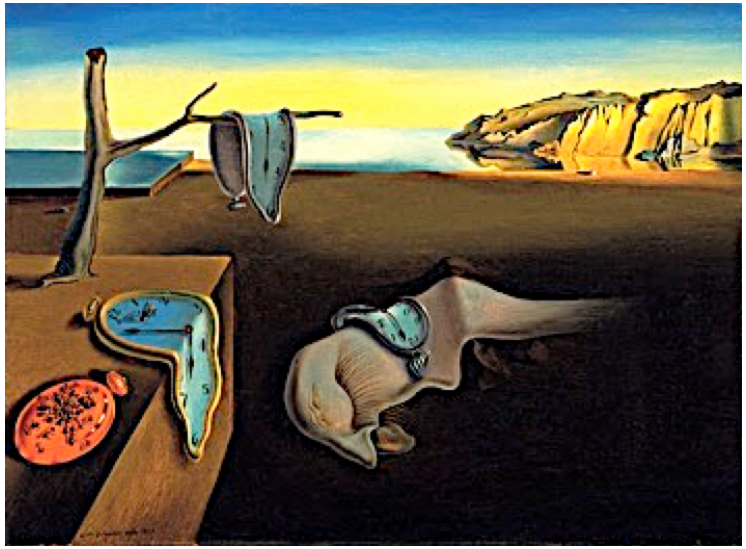
Du temps unique aux temps multiples

- temps unique : *une horloge externe objective*
  - les événements arrivent *dans* le temps
  - temps newtonien, unités temporelles *fongibles*
  - un temps partagé prescriptif
    (qui n'est éventuellement que partiellement connu)

- temps multiples : *pluralités co-dépendantes*
  - les événements définissent le temps
    (Bluedorn: epochal time is defined by events)
  - Temps leibnizien, relationnel
  - Exemples :
    - partition : couches temporelles
    - relation partition / performance
    - co-construction lors de la performance



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Un temps relationnel
Les heures du jour d'été et les heures du jour d'hiver

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Programming

② TEMPORAL SCENARIOS

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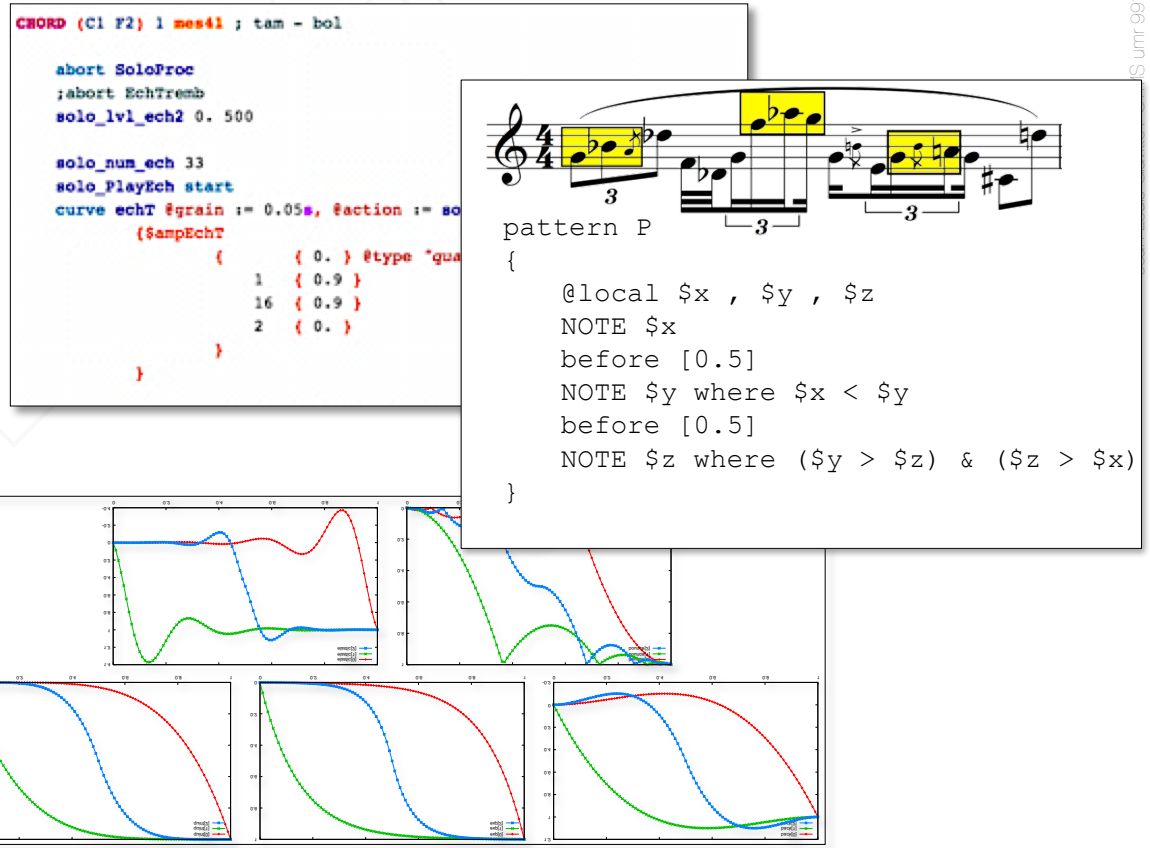
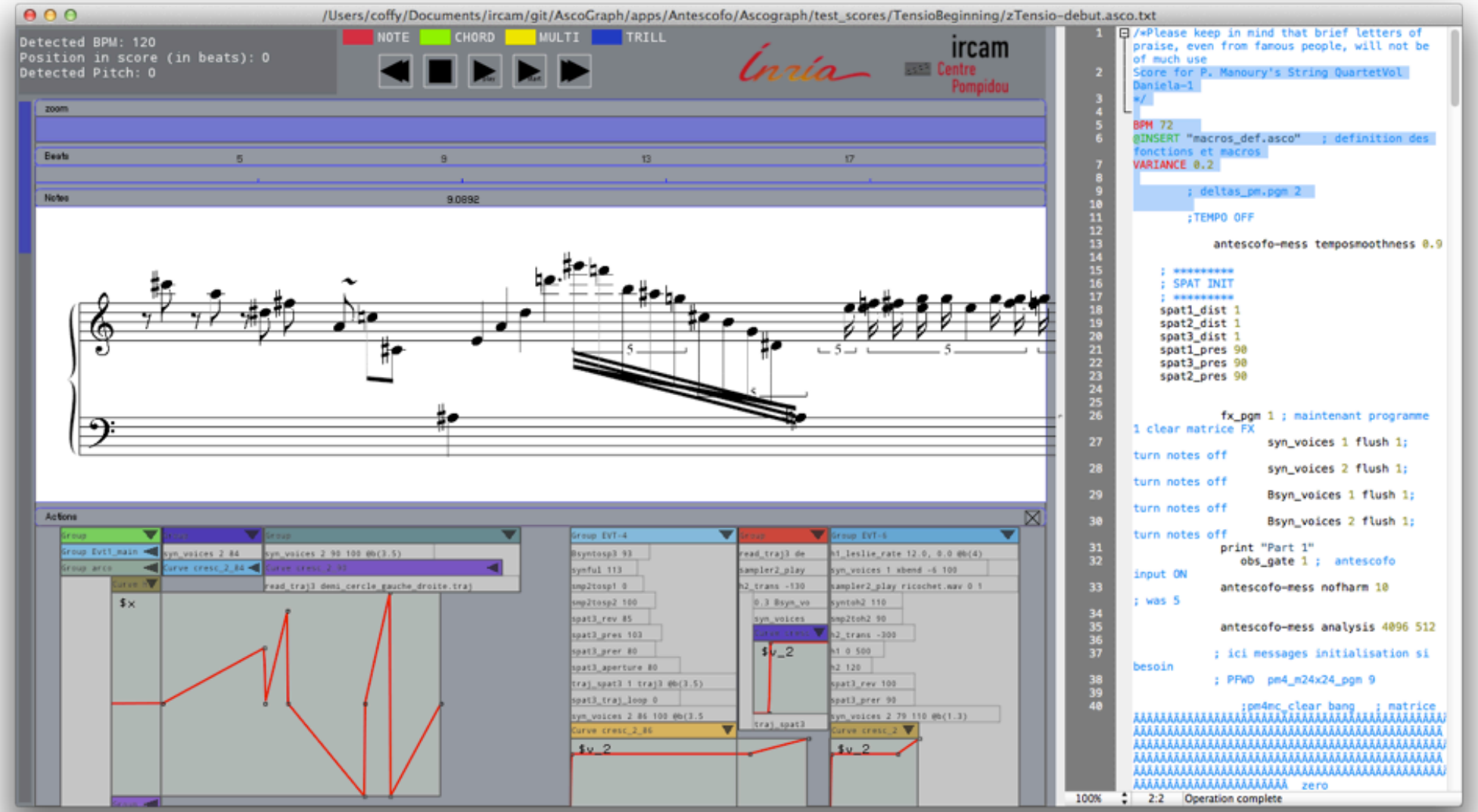
The Antescofo approach

- The mixed music score is a real-time program
  - composer is a programmer
  - joint evaluation/performance of augmented score by <musician | computer>
  - the composer specifies the synchronization constraints between the two parts
- The listening module gives the program inputs
- Program constructions
  - group, forall, loop, if, whenever, curve
  - process, actors
  - pattern, track, …
  - continuations
- Data Structures
  - int, float, string…
  - vector, map, nim
  - function, process, actor, coroutine




/Users/coffy/Documents/ircam/git/AscoGraph/apps/Antescofo/Ascograph/test_scores/TensioBeginning/zTensio-debut.asco.txt
Detected BPM: 120
Position in score (in beats): 0
Detected Pitch: 0
NOTE
CHORD
MULTI
TRILL
zoom
Beats
Notes
Actions
/*Please keep in mind that brief letters of praise, even from famous people, will not be of much use
Score for P. Manoury's String QuartetVol Daniela-1
*/
BPM 72
@INSERT "macros_def.asco" ; definition des fonctions et macros
VARIANCE 0.2
; deltas_pm.pgm 2
;TEMPO OFF
antescofo-mess temposmoothness 0.9
; *********
; SPAT INIT
; *********
spat1_dist 1
spat2_dist 1
spat3_dist 1
spat1_pres 90
spat3_pres 90
spat2_pres 90
fx_pgm 1 ; maintenant programme 1 clear matrice FX
syn_voices 1 flush 1; turn notes off
syn_voices 2 flush 1; turn notes off
Bsyn_voices 1 flush 1; turn notes off
Bsyn_voices 2 flush 1; turn notes off
print "Part 1"
obs_gate 1 ; antescofo input ON
antescofo-mess nofharm 10
; was 5
antescofo-mess analysis 4096 512
; ici messages initialisation si besoin
; PFWD pm4_m24x24_pgm 9
;pm4mc_clear bang ; matrice
zero
100%
2:2
Operation complete

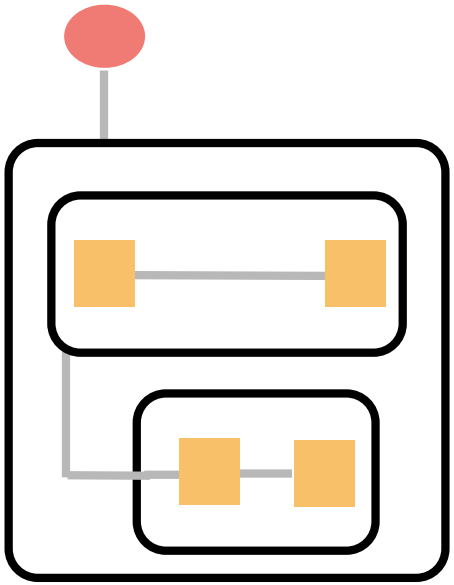
Syntax

events: `NOTE 60 2.0`

atomic actions:

```
$v := @sin($x)
superVP ($v+3)
```

compound actions:



```
group
{
        print hello
        print beautiful
    2.0 print world
}
```

```
loop  3.0
{
   print "loop"
} during [6#]
```

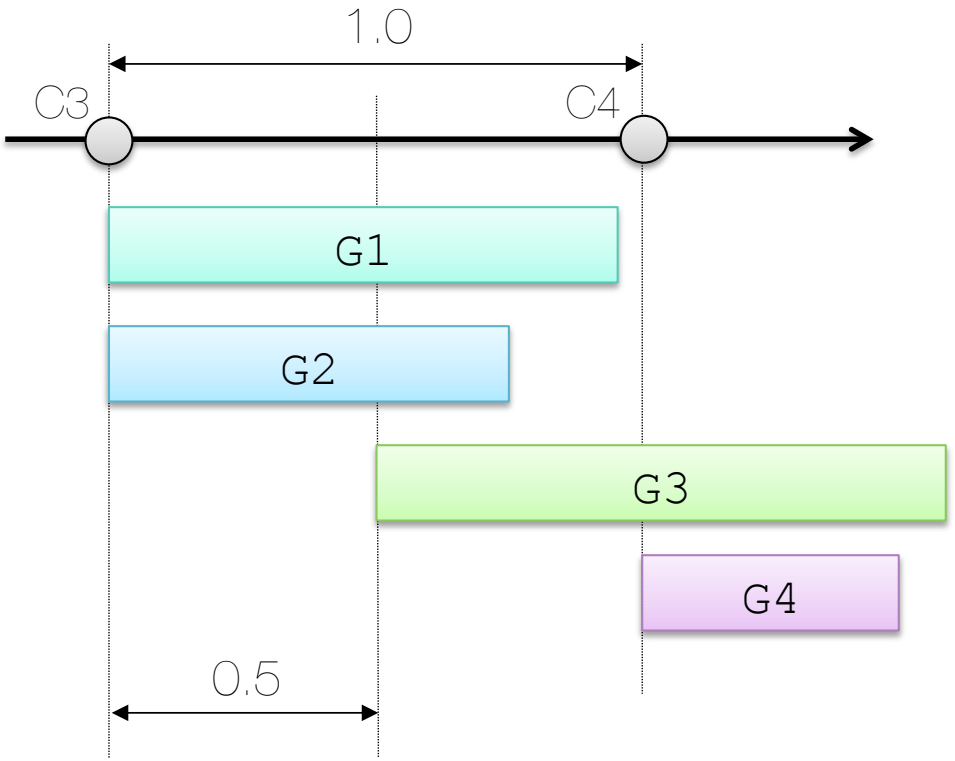
```
whenever ( $y > 3.0 )
{
   print $y "greather than 3"
}
```

```
curve @grain 0.1s
      @action draw $x $y
{
 $x,$y {    { 0.3,  1.2 }
          4s { 0.9,  2.4 }
        }
}
```

Group

Note C3 1.0

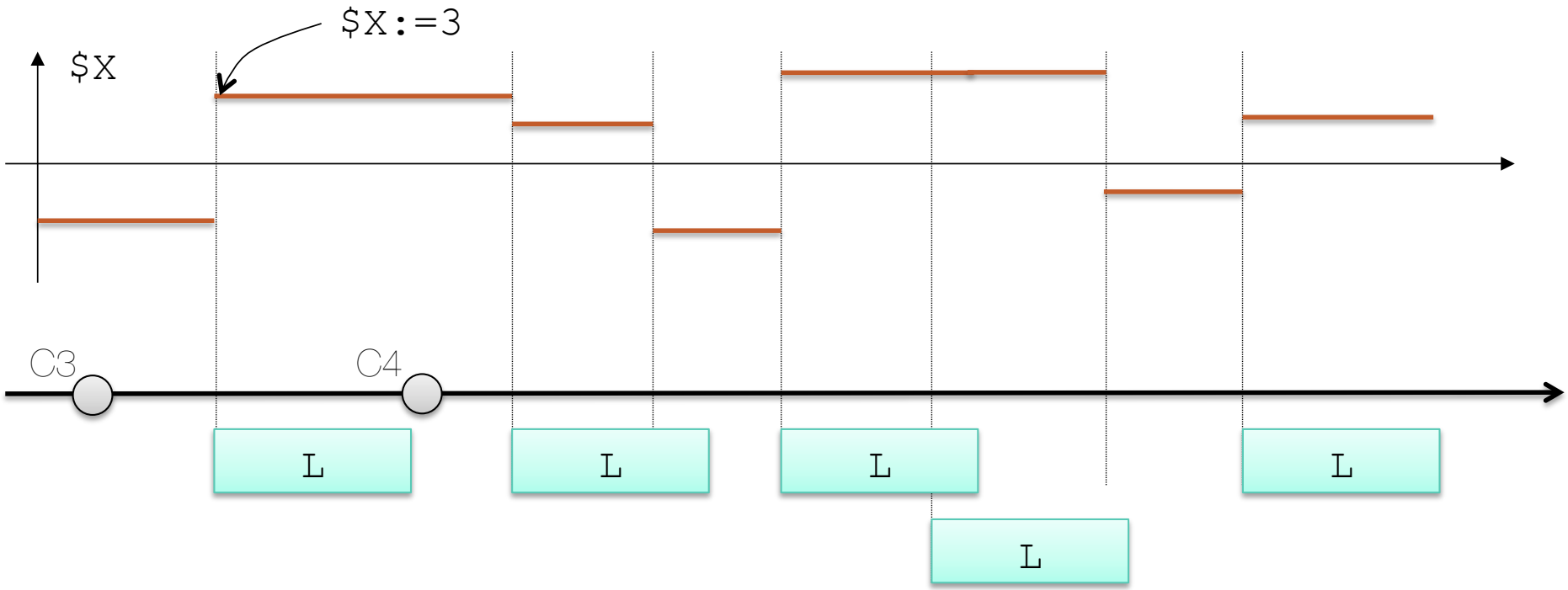
```
Group G1
{
}
Group G2
{
}
0.5 Group G3
{
}
0.5 Group G4
{
}
```



Note C4 1.5

…

Whenever




```
Note C3  2/3
    Whenever ($X > 0)
    {
        L
    }
Note C4 1.5
…
```

Expressions

- **Values**

  `int, float, bool, string, symbol…`
  `tab, map, continuous symbolic curve…`
  `functions, processes… (first-order values)`

- **Operators and predefined functions**

  `@sin(), @exp(), (…? … : …), @random(), @score()…`

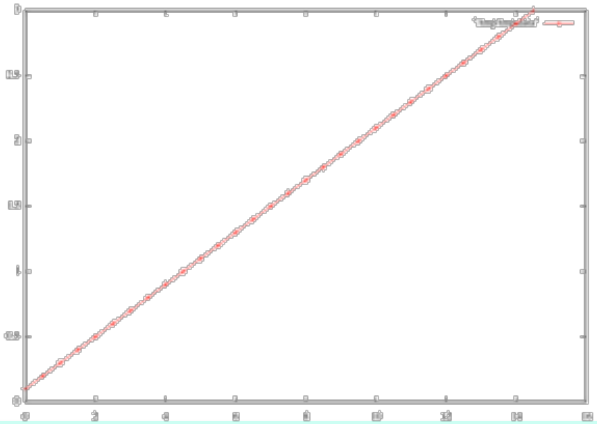
- **Imperative Variables**
  - system variables: `$RT_TEMPO $NOW $RNOW $TEMPO $PITCH,` *etc.*
  - history

    `[3#]:$x`
    `[3]:$x`
    `[3s]:$x`

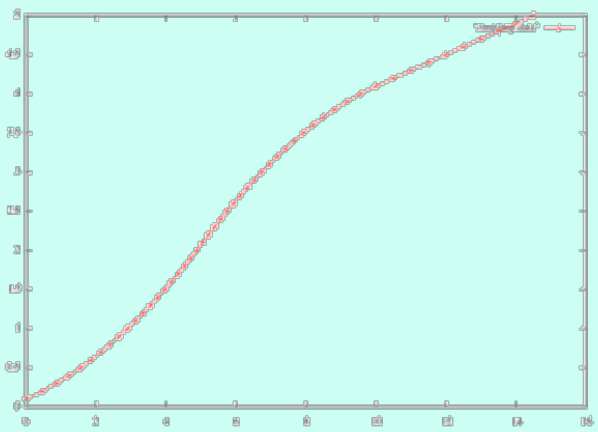
$v	*undef*	43	52	53	49
timestamps in beats	0.0	1.0	2.5	4.0	5.5
timestamps in sec	0.0	2.3	4.2	5.9	7.5

  - `@date([3#]:$x)`
    `@rdate([3#]:$x)`

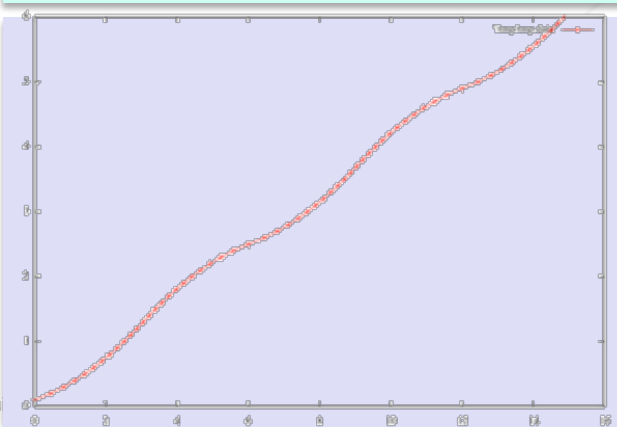
Tempo inheritance



```
@proc_def ::Trace()   {
        @local $x
        $x := 0
        Loop L 0.1 {
                $x := $x + 0.1
                plot $NOW " " $x "\n"
        }
}
$trace1 := ::Trace()
```



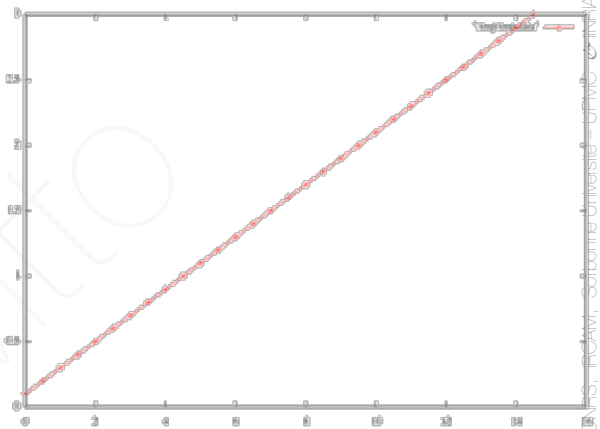
```
Curve C1 @grain 0.05s
{  $t1 { {60} 5 {180} 5 {60} } }

Group G1 @tempo := $t1
{
        $trace2 := ::Trace()

        Curve C2 @grain 0.05s
        { $t2 {  {60} 3 {180} 3 {60} 3 {180}
           3     {60} 3 {180} 3 {60} }
    }
```

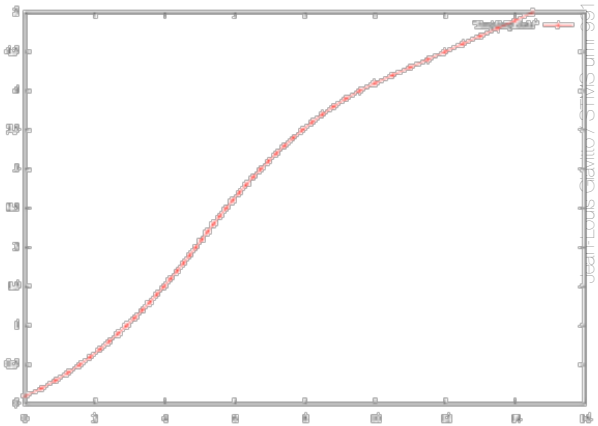


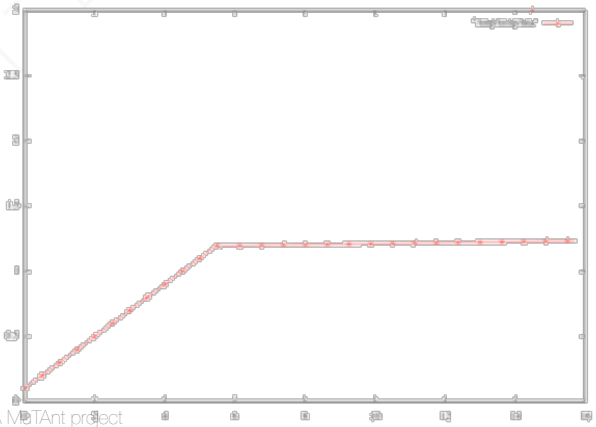
```
        Group G3 @tempo := $t2
        {
                $trace3 := ::Trace()
        }
}
```

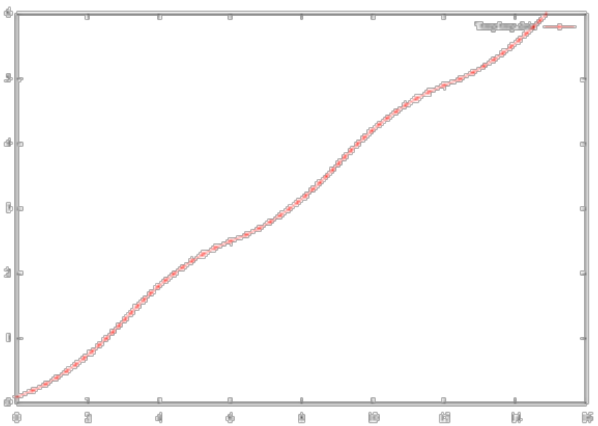
Strongly timed

- **event-driven system**
  - events from the listening machine
  - logical events
    - predicates on variables
    - begining or end of a computation (continuation)
  - introspective events
- **time-driven: computing with duration**
  - delay
  - continuous actions
  - relative time (dynamic) tempo
  - synchronization: tempo + event
- **time-controled concurrency**
  - all actions are *in parallel*
  - **no** lock/mutex/threads…

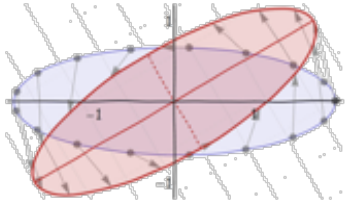








Strongly timed



- time transformations are for Antescofo
  what changes of coordinates are for postscript…
- BUT
  - time is only spent in real-time
  - time is causal
    (I don't know the transformation in the future)
  - the transformation comes from the environment
    (synchronization)
  - transformations are not necessarily *newtonian*
    (when human is in-the-loop position ≠ ∫ tempo)

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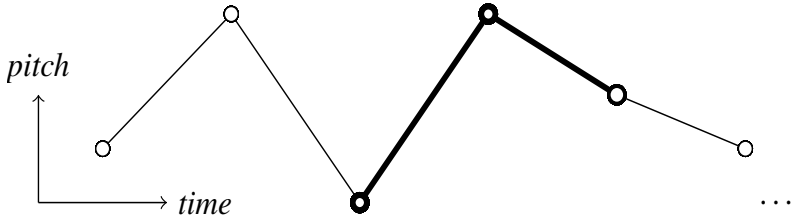
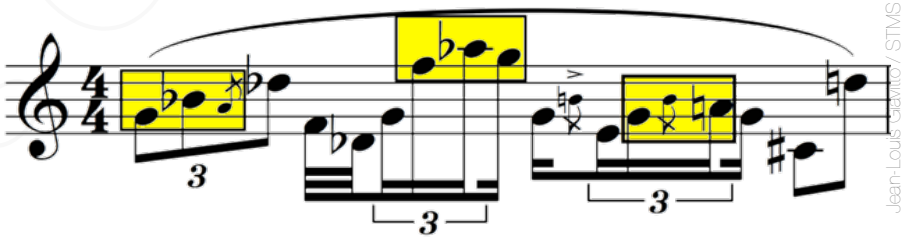
Real-Time Matching a Temporal Pattern

Real-Time Matching of Antescofo Temporal Patterns,
J.-L. Giavitto, J. Echeveste,
ACM PPDP 2014, 2014.

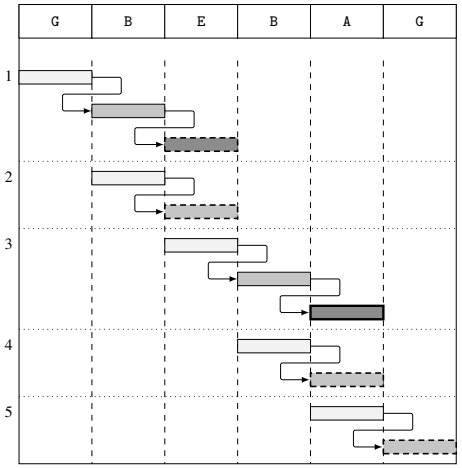



```
pattern P
{
   @local $x , $y , $z
   NOTE $x
   before [0.5]
   NOTE $y where $x < $y
   before [0.5]
   NOTE $z where ($y>$z) & ($z>$x)
}
```

compilation & on-the-fly matching

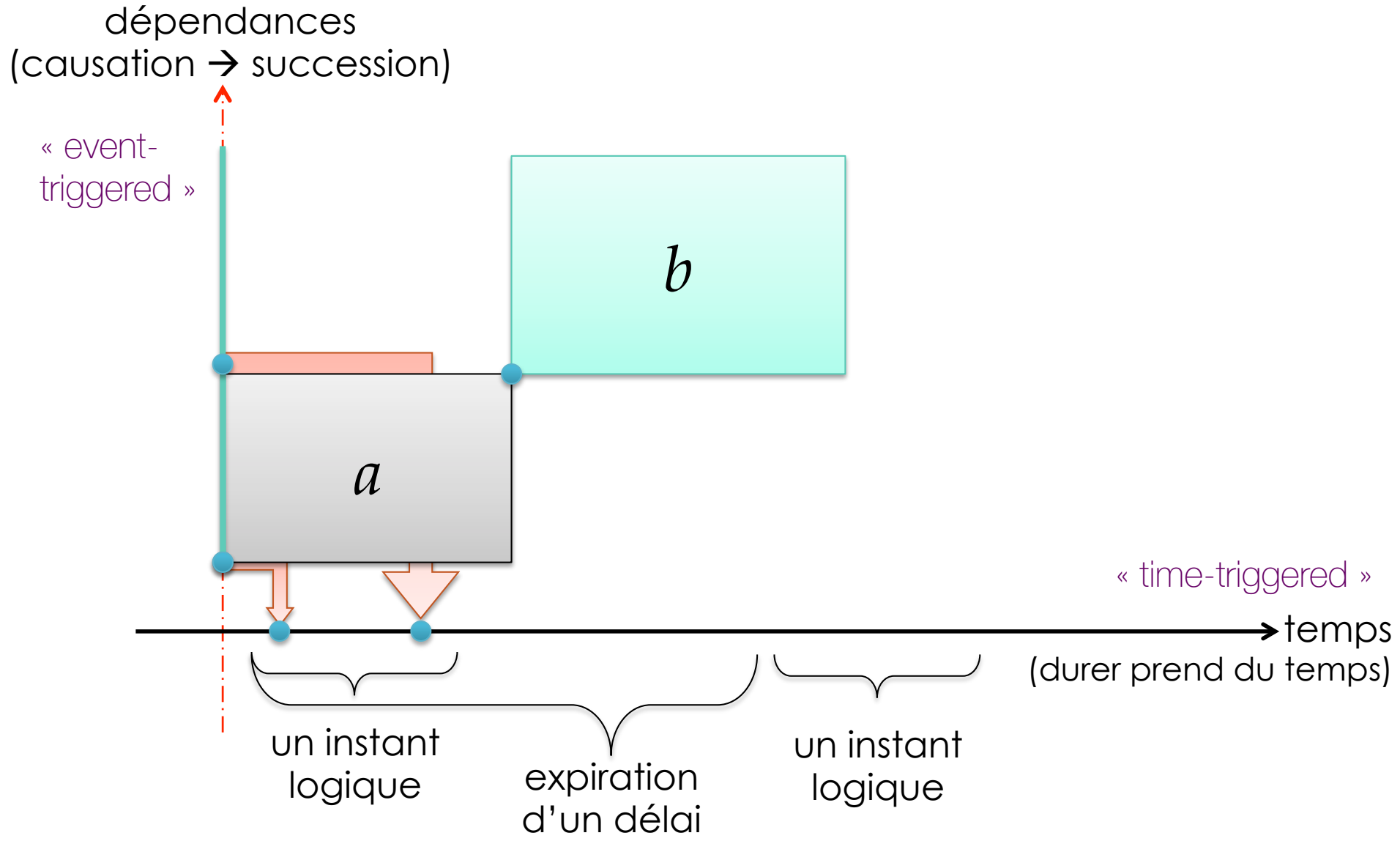



```
1  whenever ($PITCH) {
2    @local $x
3    $x := $PITCH
4    whenever ($PITCH > $x) {
5      @local $y
6      $y := $PITCH
7      whenever ($PITCH<$y & $PITCH>$x) {
8        @local $z
9        $z := $PITCH
10       a
11     } during [1#]
12   } during[1#]
13 }
```



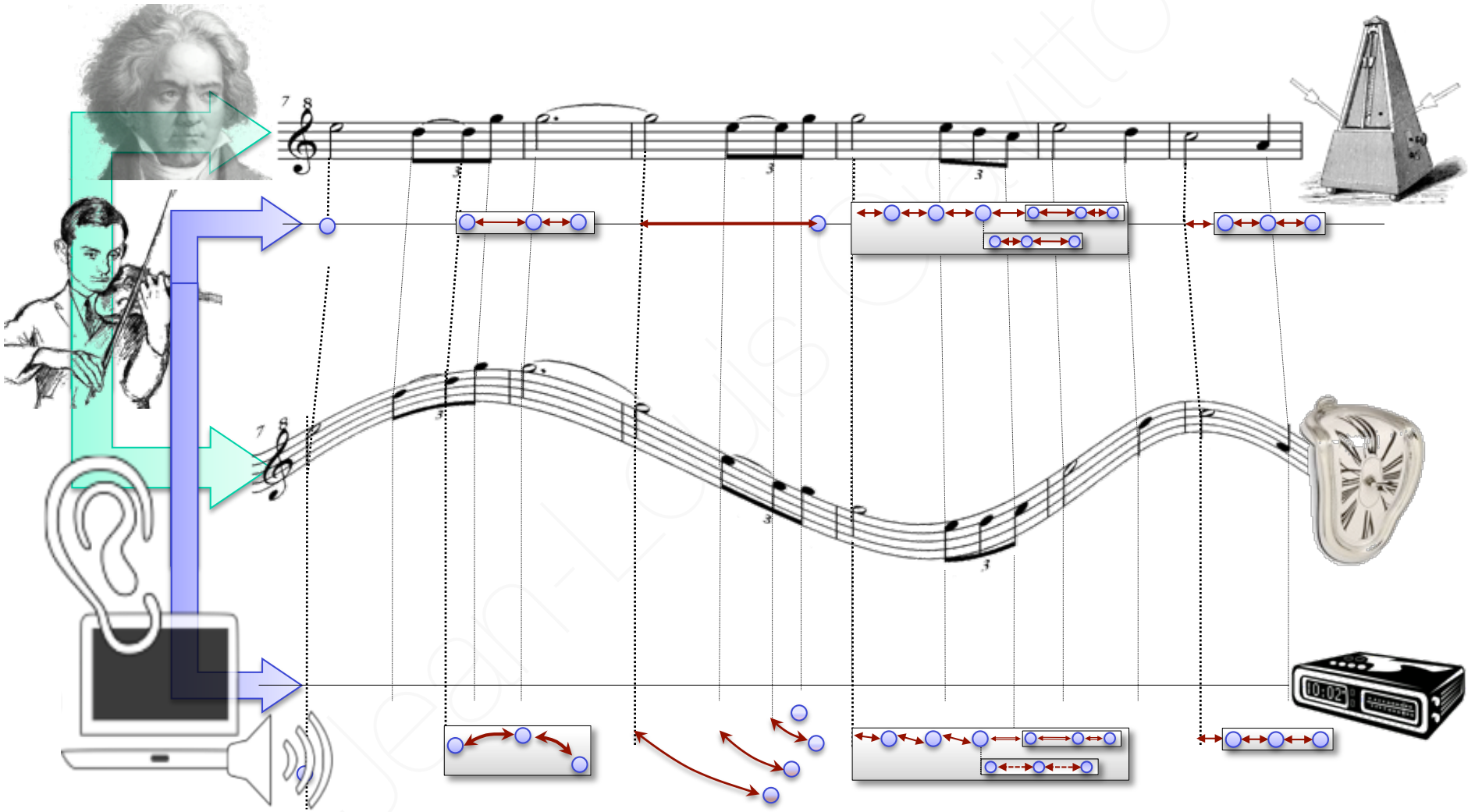
temporal patterns

Les sources de passage du temps :
Causalité & Durée



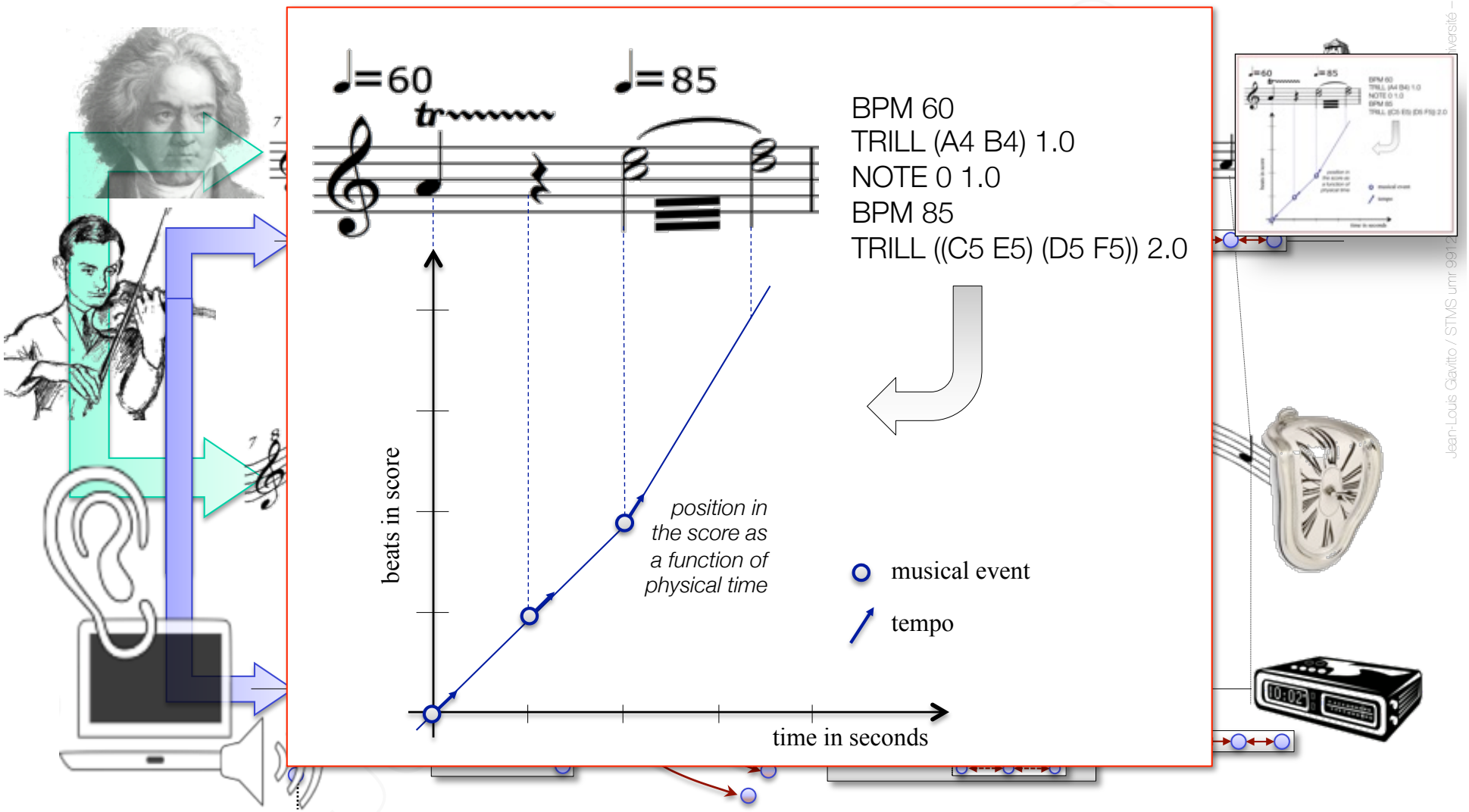
Un temps construit à plusieurs

The Multiples Times of Temporal Scenarios

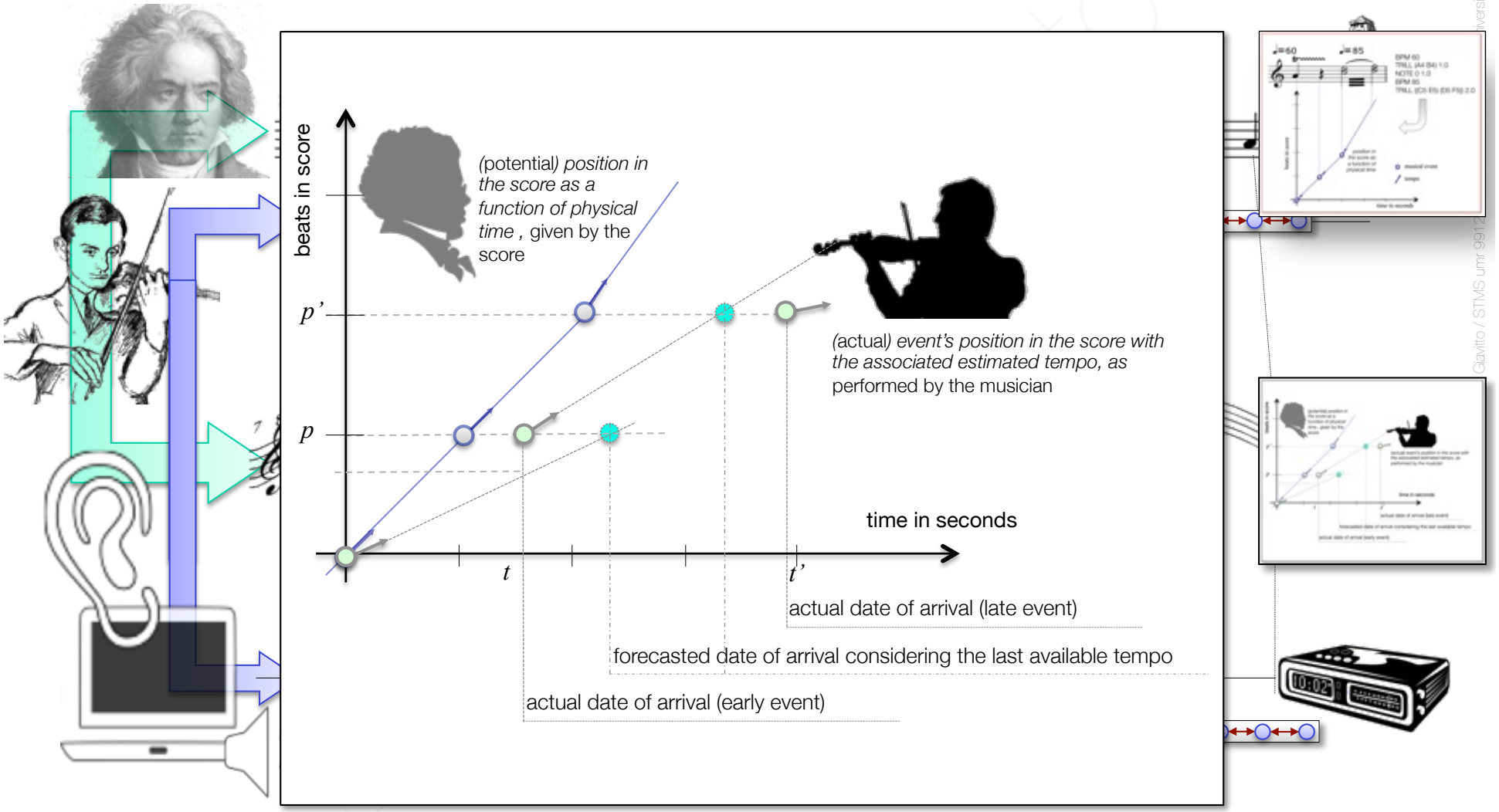


Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ☞ INRIA MuTAnt project

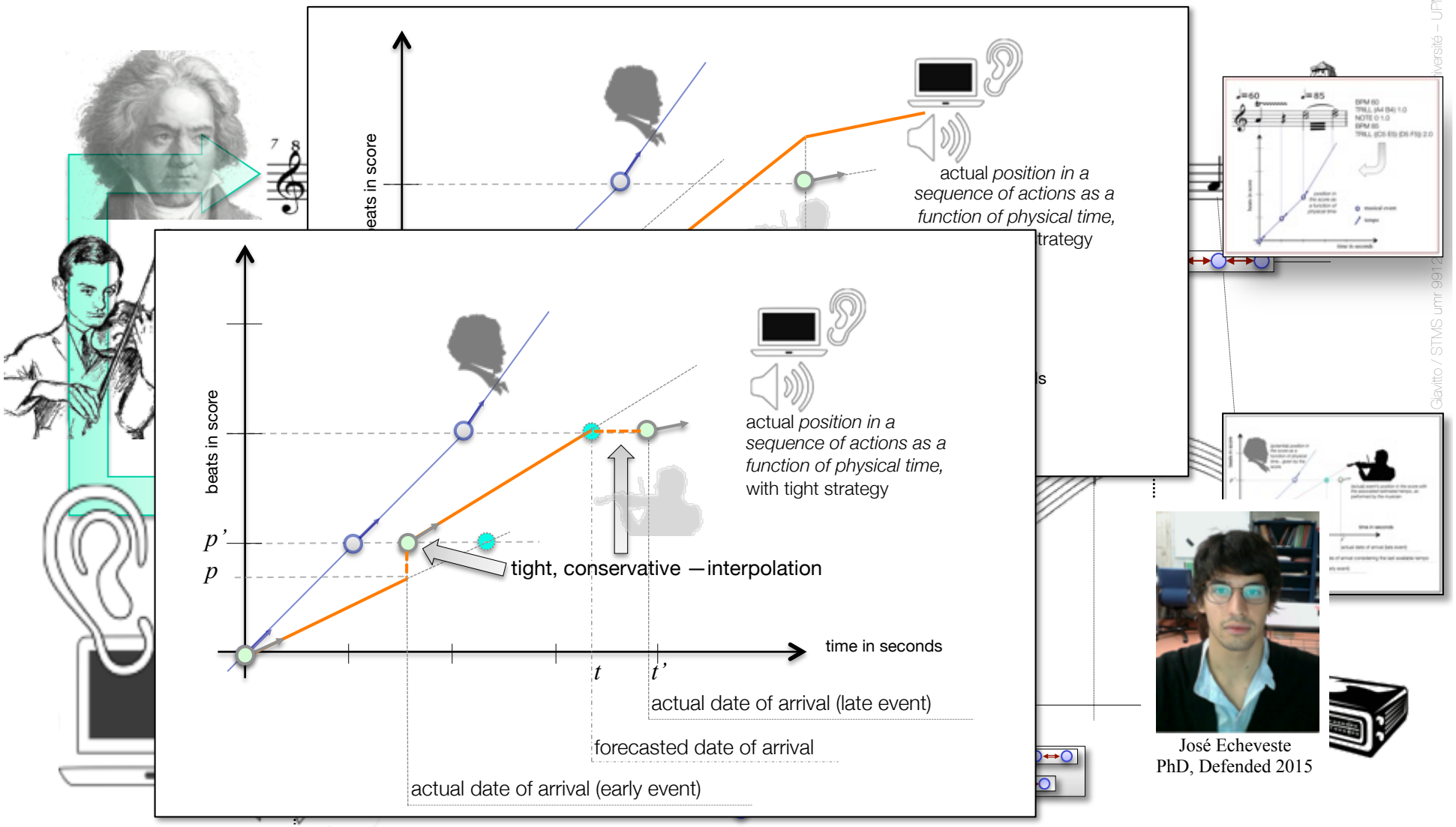
Time-time diagrams



Time-time diagrams



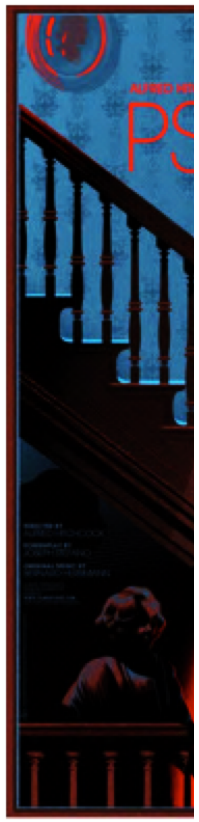
Time-time diagrams



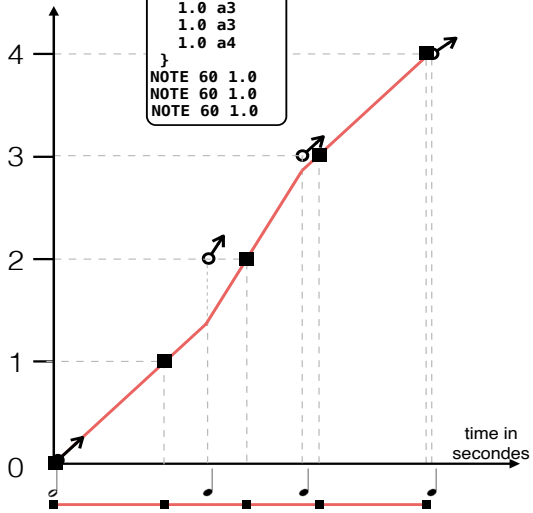
José Echeveste
PhD, Defended 2015

Temps strié et temps lisse

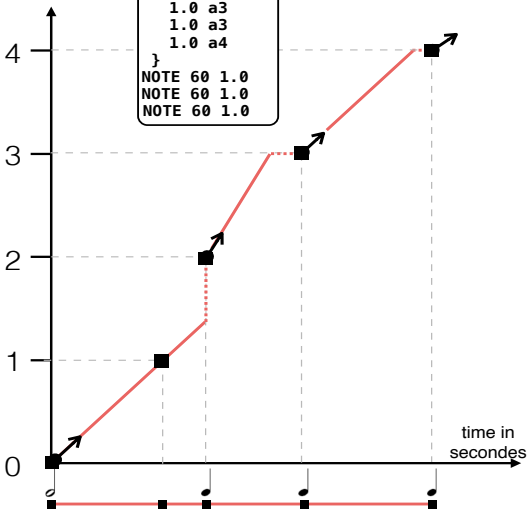
Bernard Herr



```
NOTE 60 2.0
 group @loose
 {
   a1
   1.0 a2
   1.0 a3
   1.0 a3
   1.0 a4
 }
NOTE 60 1.0
NOTE 60 1.0
NOTE 60 1.0
```

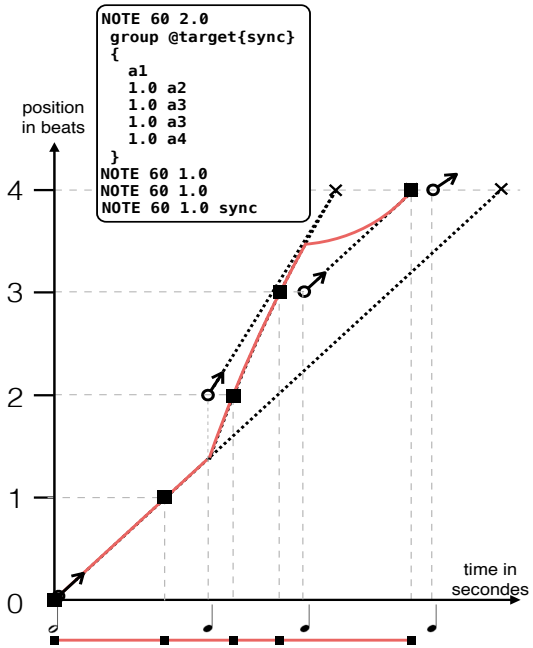



```
NOTE 60 2.0
 group @tight
 {
   a1
   1.0 a2
   1.0 a3
   1.0 a3
   1.0 a4
 }
NOTE 60 1.0
NOTE 60 1.0
NOTE 60 1.0
```

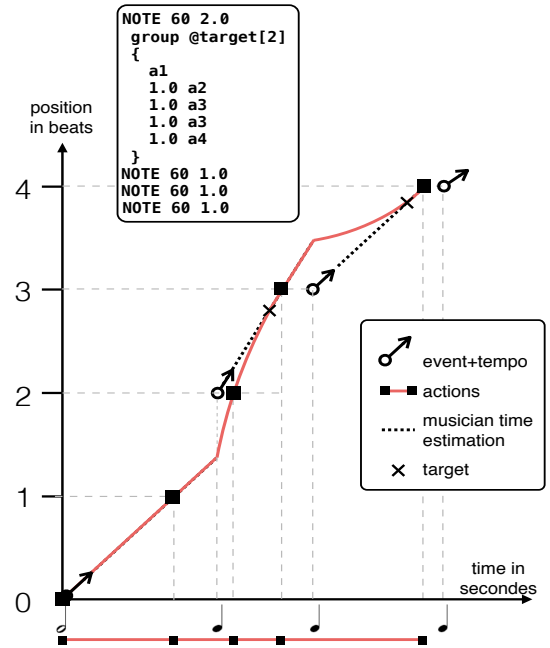


'ano (1967)


```
NOTE 60 2.0
 group @target{sync}
 {
   a1
   1.0 a2
   1.0 a3
   1.0 a3
   1.0 a4
 }
NOTE 60 1.0
NOTE 60 1.0
NOTE 60 1.0 sync
```




```
NOTE 60 2.0
 group @target[2]
 {
   a1
   1.0 a2
   1.0 a3
   1.0 a3
   1.0 a4
 }
NOTE 60 1.0
NOTE 60 1.0
NOTE 60 1.0
```



Dynamic Target

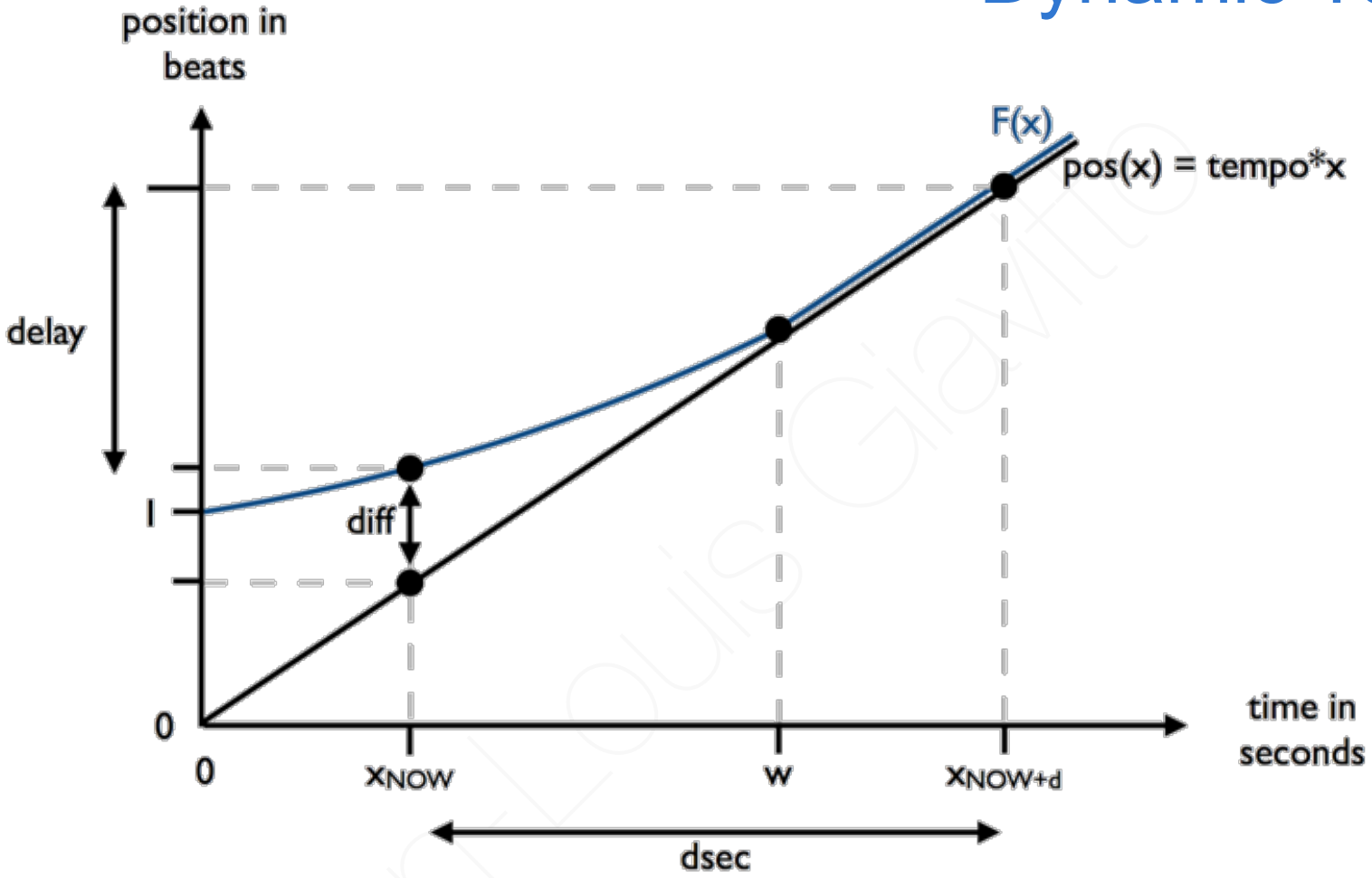
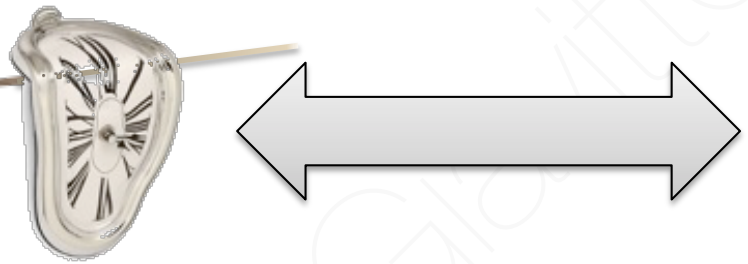


Fig. 10. Method used to compute a duration $dsec$ in seconds corresponding to a delay $delay$ in beats with a dynamic target $[w]$ and with a initial difference of position $diff = \tau.beatPos - position$. Function F represents the position in τ as a function of time x. It is made of two parts: a part G where the $\tau.tempo$ changes linearly until it becomes equal to $tempo$. From this time, F evolve as pos, with $\tau.tempo = tempo$ (a constant). Function G is the part of the parabola that goes from $x = 0$ to $x = w$. Because the origin is translated w.r.t. the origin of the physical time, the date x_{NOW} of the current instant is localized on the X axis by looking at the point which achieve the current difference $diff$.

Aligner les ligne de temps de chacun



Un repère temporel :

- des événements partagés
- une estimation du temps qui passe chez l'autre

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

Construire un temps partagé

tribu de la grande clepsydre

tribu du sable qui coule

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ☞ INRIA MuTAnt project

Construire un temps partagé

J'émettrai
un nuage rose
2 litres
après le nuage rouge

1

2 litres

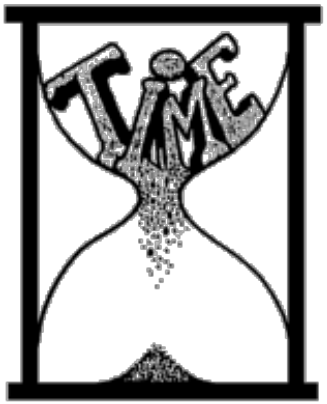
2

3

750 grammes

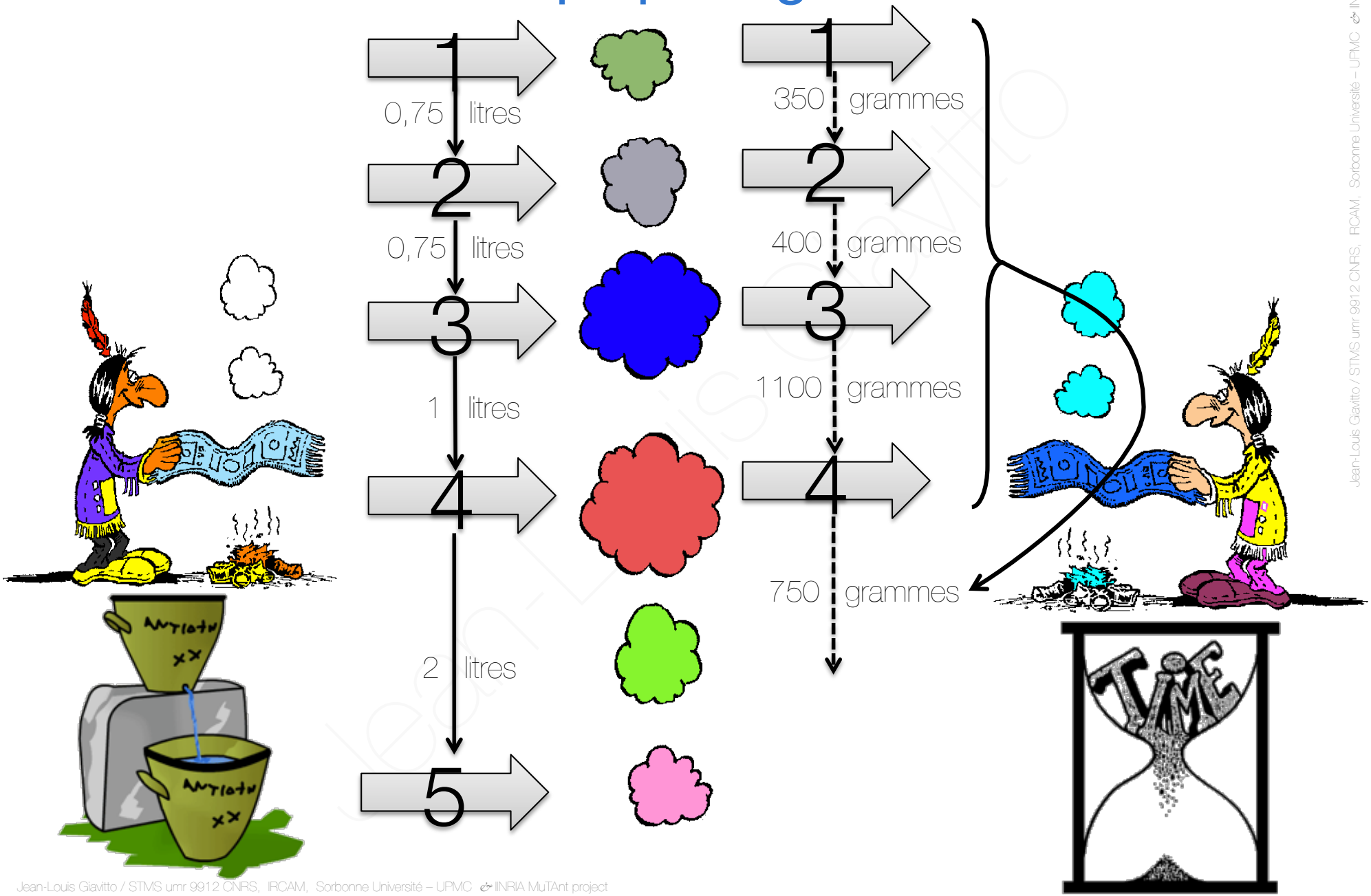
3'

J'émettrai
un nuage vert
750 grammes
avant le nuage rose



Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

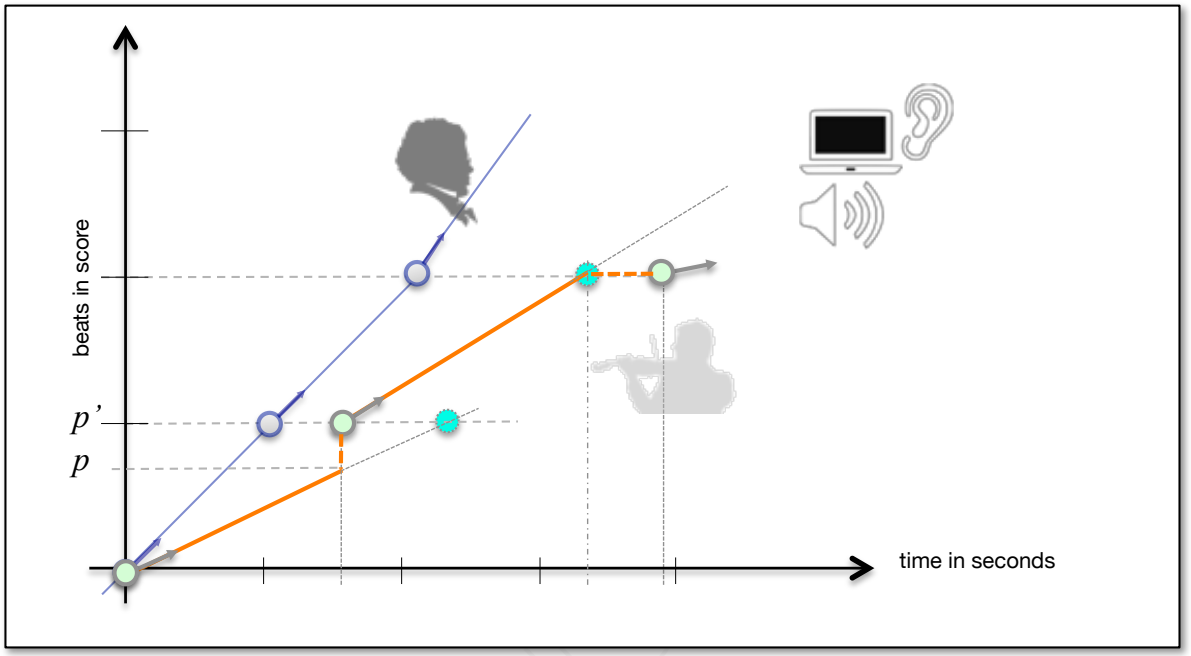
Construire un temps partagé



Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC INRIA MuTAnt project

Extraction du tempo et sympathie des horloges

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC & INRIA MuTAnt project



temps fongibles

ou

temps incommensurables ?

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ☞ INRIA MuTAnt project

Une seconde par seconde

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

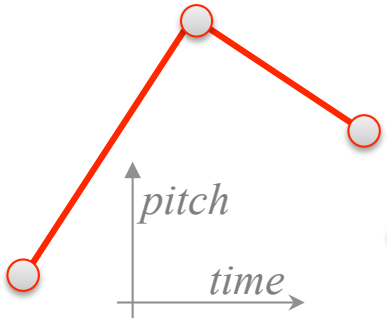
Subordonner le temps objectif au temps subjectif *au lieu du contraire*

- Les événements partagés ne suffisent pas :
  la durée n'est pas réductible aux instants
  - diviser une durée par deux
  - accelerando
  - le phrasé musical (ex. rubato)
- Le "taux de change" varie dans le temps et n'est connu qu'après.
  Il se construit avec le temps lui-même.
  - A-series et B-series,
  - temps compositionnel hors-temps et temps performatif temps réel
- Le temps subjectif est utile : la partition est écrite / tempo, pas au temps physique
- *In fine*, parce que c'est une approche effective : elle permet une interaction musicale entre instrumentistes et machine

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ☞ INRIA MuTAnt project

Open Score in Antescofo

- real-time matching of temporal pattern

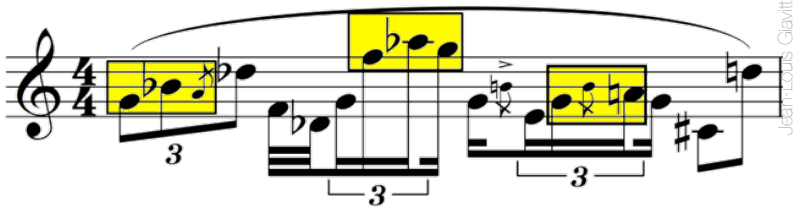


specification
(including durational properties)

```
pattern P
{
   @local $x , $y , $z
   NOTE $x
   before [0.5]
   NOTE $y where $x < $y
   before [0.5]
   NOTE $z where ($y>$z) & ($z>$x)
}
```

Real-Time Matching of Antescofo Temporal Patterns, Jean-Louis Giavitto, José Echeveste, ACM PPDP 2014, 2014.

compilation
&
on-the-fly matching



- dynamic non-deterministic score

Jason Freeman (GeorgiaTech) *Shadows,* 2015.

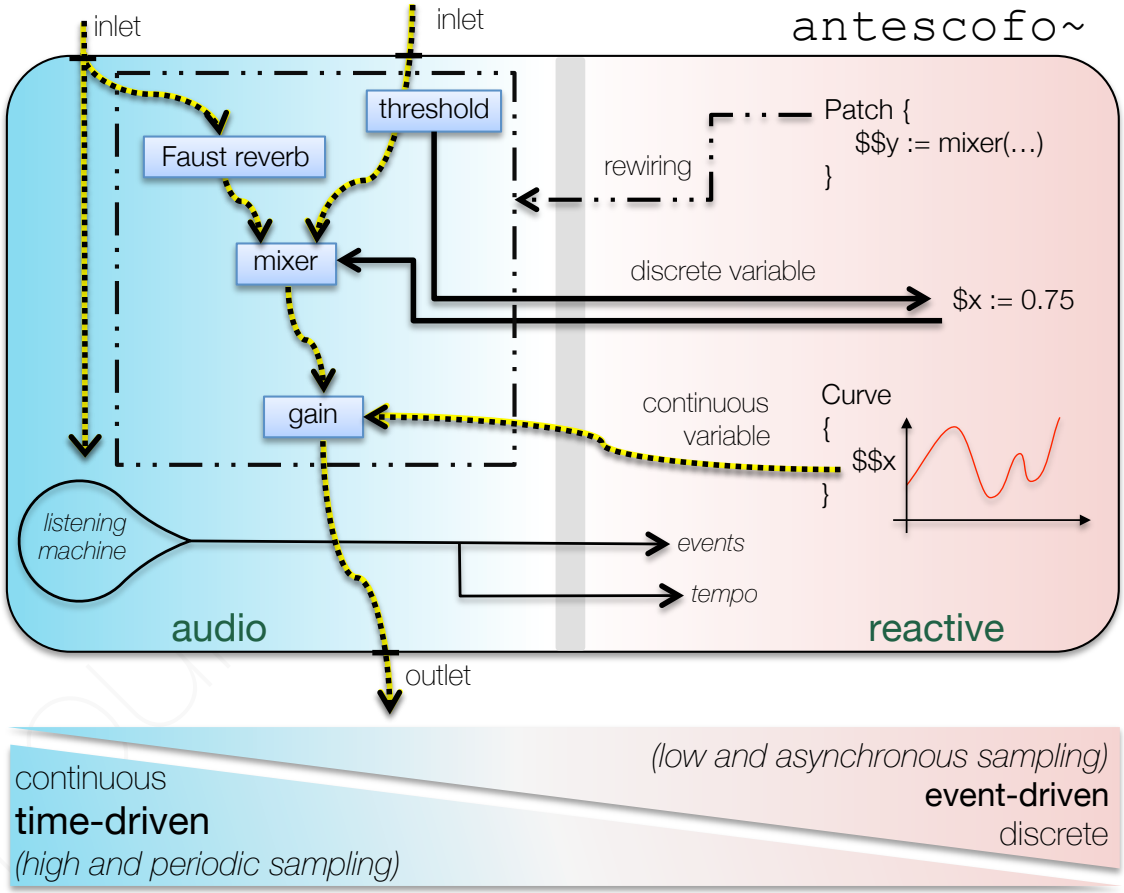
Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

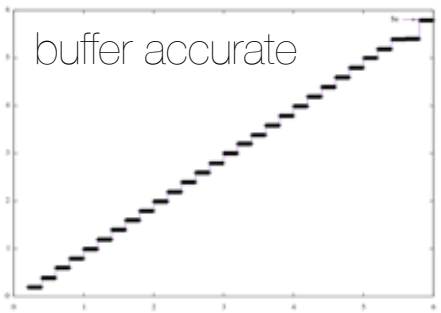
③ REAL-TIME SCHEDULING

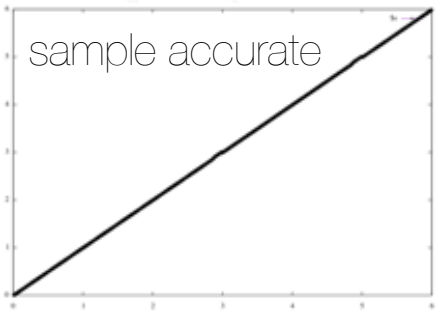
Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

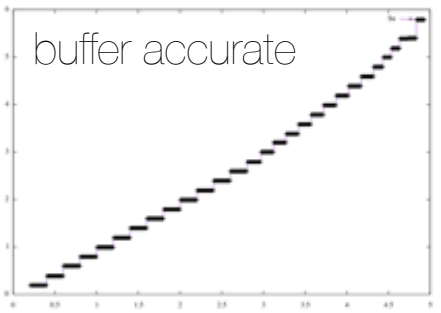
Embedding audio in Antescofo

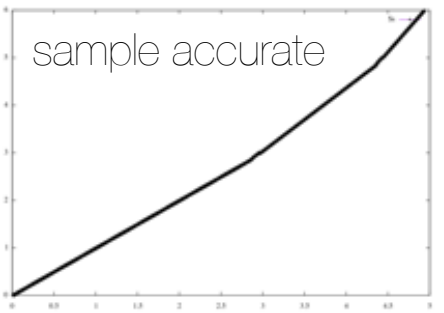
- audio effects written in FAUST + specifics (FFT)
- compiled on-the-fly
- 40% cpu improvement on the remake of *Antheme2*
- new hybrid scheduling
- sample accurate for curve → audio
- sample accurate for audio → control
- buffer accurate elsewhere











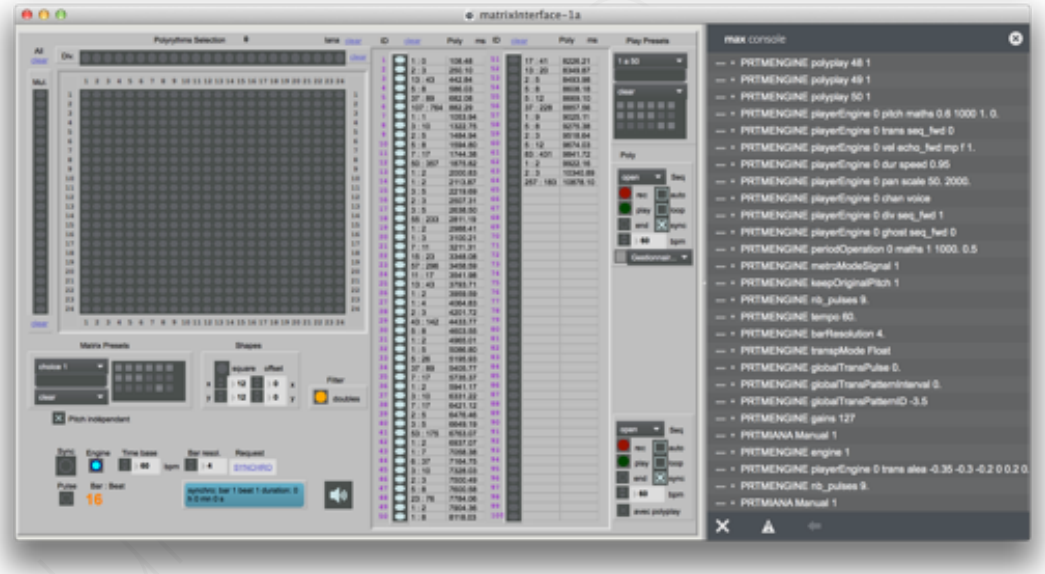
relative time

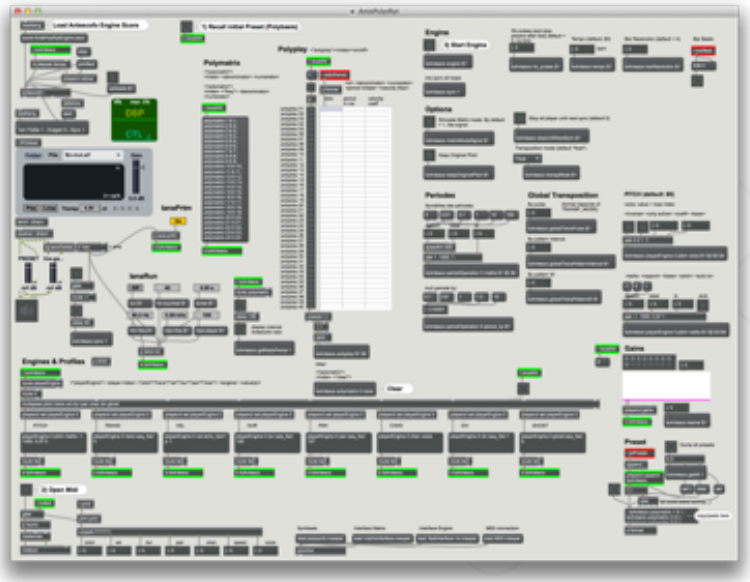
physical time

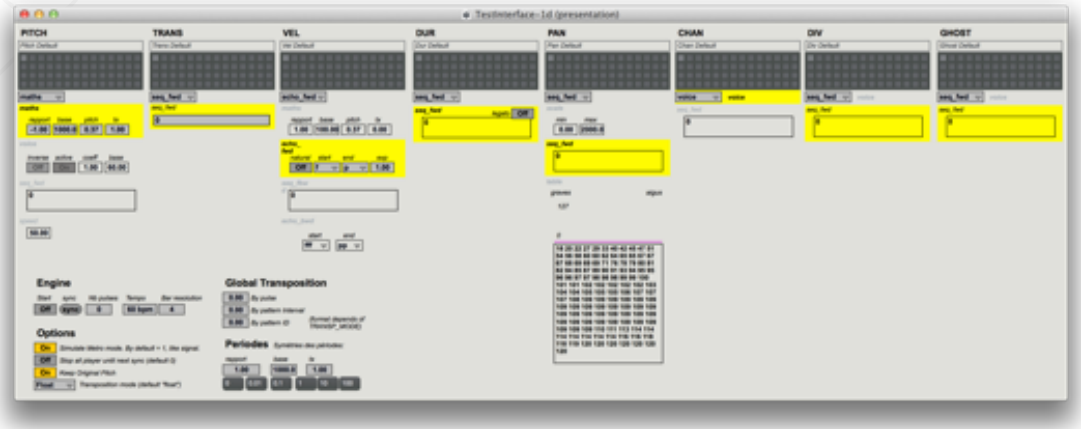
④ ARTISTIC APPLICATIONS

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

Yan Maresz *Polyrythmic machine* in Antescofo



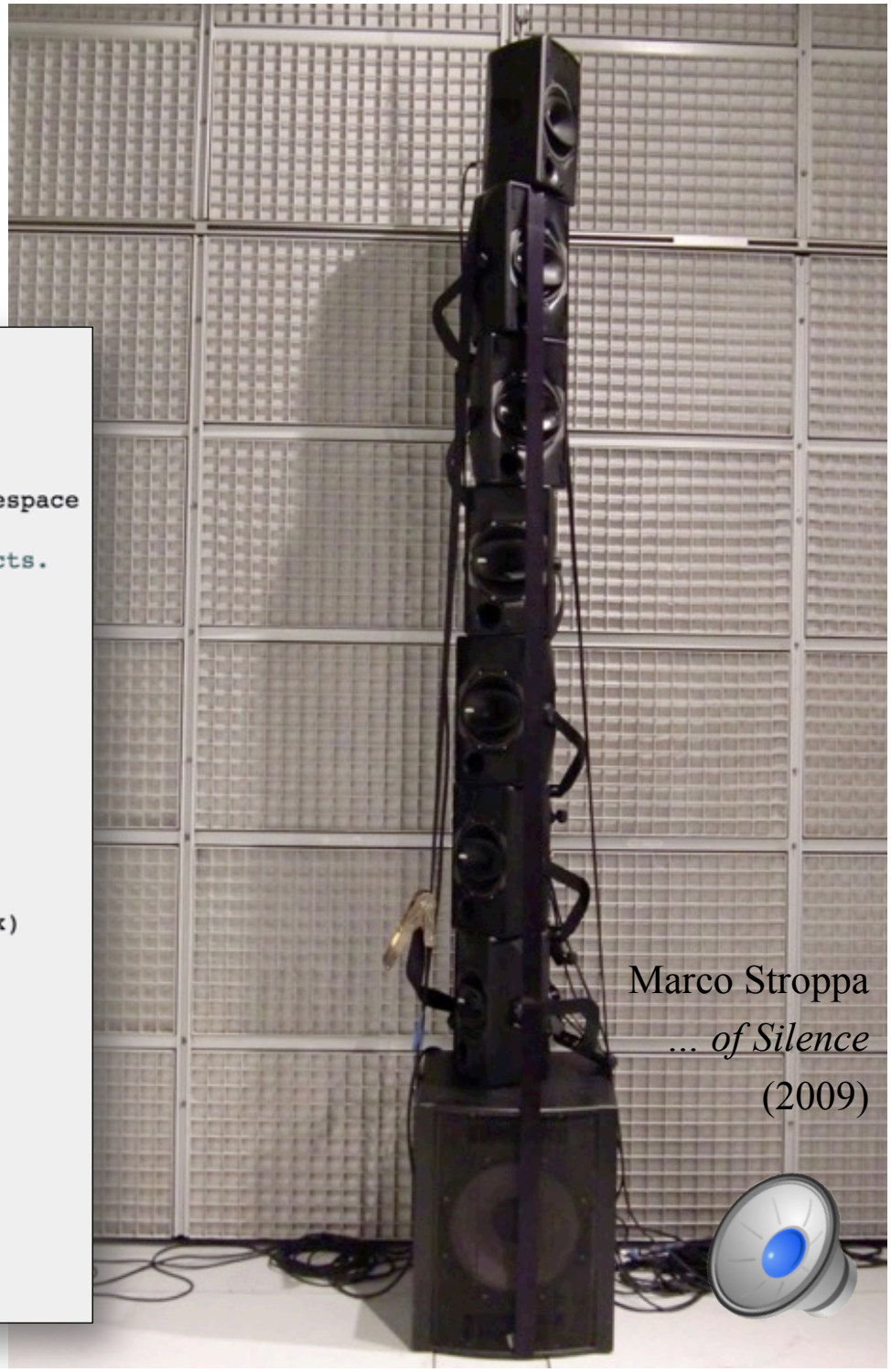




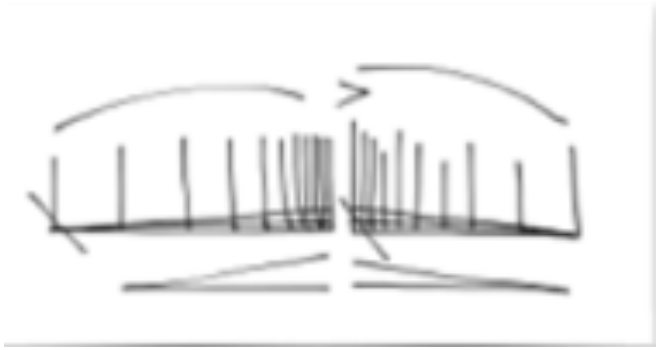
Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC INRIA MuTAnt project

Marco Stroppa
Antescofo library for totem control

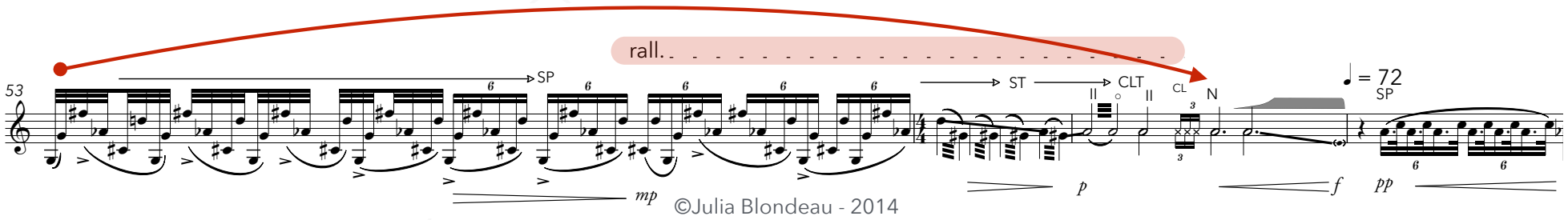
```
; SOURCE Object Definition

@obj_def source($idn, $npoints, $namespace)
{
    ; local state
    @local $coordinates, $idnum, $last_action, $prefix_namespace

    ; A broadcasted signal to all instances of source objects.
    @broadcast reset()  { abort $last_action }

    // …

    ; igoto method will create a curve that goes
    ; from $coordinates to $destination in $dur time
    @proc_def igoto($destination, $dur, $itp)
    {
        curve FlyingEngine   @Grain := 0.05s,
          @Action := {
             $coordinates := $x
             @command($prefix_namespace+$idnum+"-spat") ($x)
          }
        {
            $x
            {
                        { ($coordinates) } @type $itp
                $dur    { ($initlevels($destination)) }
            }
        }
    }

    // …
}
```



Julia Blondeau
Phrasé

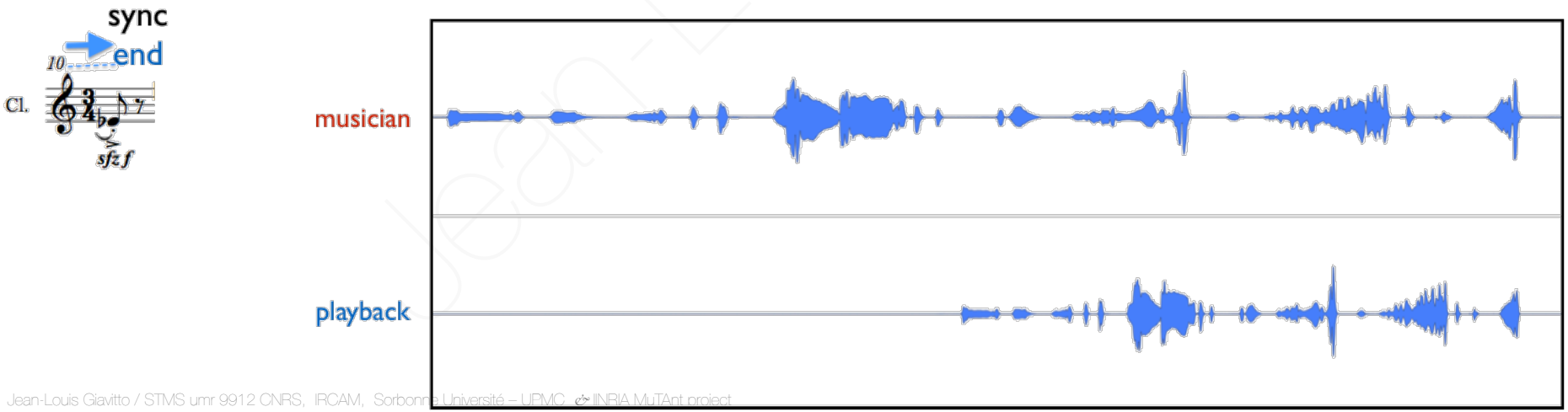


```
NOTE D4 1/6 mes52

Curve tempCouchT3 @grain := 1/12
    { $tempCouchT3
        {       { ($RT_TEMPO-5) } @type "cubic"
            2   { ($RT_TEMPO+40) }
            1/3 { ($RT_TEMPO-40) }
            1/2 { ($RT_TEMPO+30) }
            1/2 { ($RT_TEMPO-15) }
            1/2 { ($RT_TEMPO+20) }
            1/2 { ($RT_TEMPO-15) }
            3/2 { ($RT_TEMPO+20) } @type "cubic"
            7/3 { ($RT_TEMPO+60) }
        }
    }

GROUP CoucheT3 @target {mes53,sync53,mes54,sync54_1,sync54_2,sync54_3,mes57}
    @tempo := $tempCouchT3
    {
        ::SPAT_lissaj3("SPAT7",1.5,12,0)
        curve ampexplo @grain := 0.05s
            {$ampexplo
                {       { 0.08 } @type "cubic"
                    2   { 0.19 } @type "cubic_out"
                    2   { 0.09 }
                    2   { 0.23 }
                    2   { 0.09 }
                    3   { 0.05 }
                }
            }

        ::ASCOtoCS_points("i33",1/8,$ampexplo,0.9,62)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.6,87)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.6,91)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.6,67)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.6,73)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.6,98)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.6,92)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.6,103)

        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.9,102)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.9,84)
        1/8 ::ASCOtoCS_points("i11",1/8,$ampexplo,0.9,73)
```



Christopher Trapani

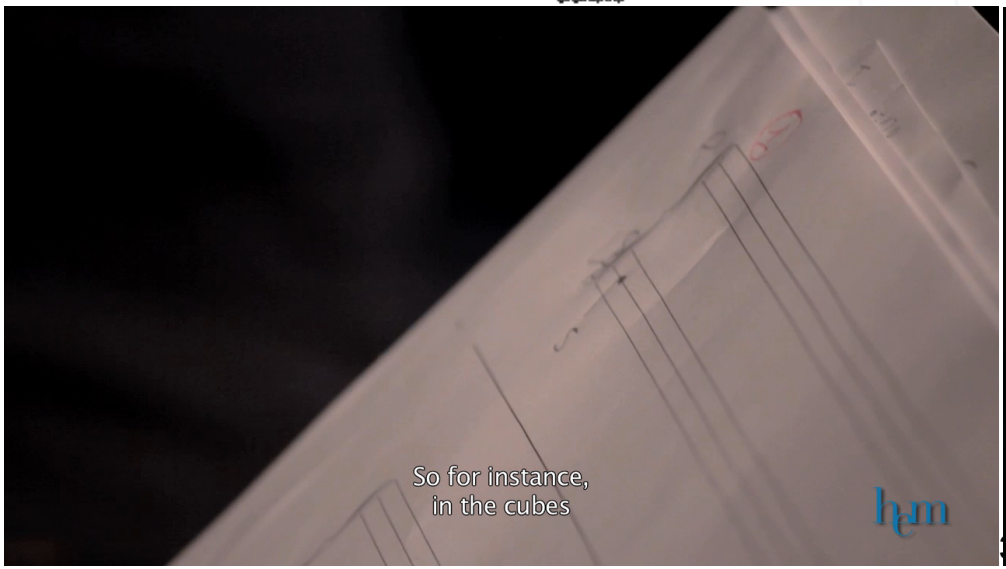
real-time rythmic canon à la Nancarow



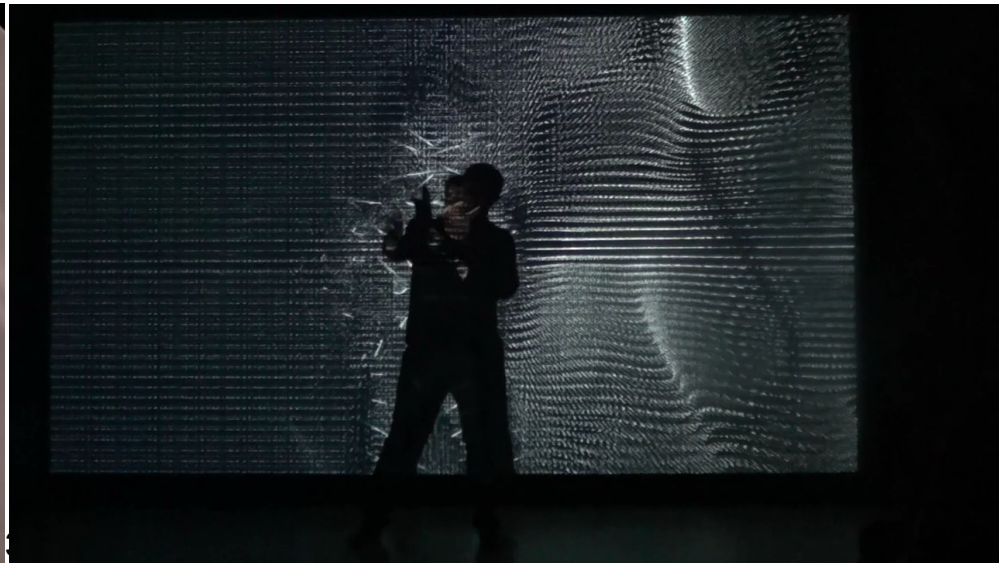
José-Miguel Fernandez
gesture-driven synthesis

OSC *or* setvar

GeKiPe (Gest Kinect Percussion),
Philippe Spiesser (percu),
Alexander Vert (composition),
Jose Miguel Fernandez (RIM)



Hypersphère, Jose Miguel Fernandez,
séance de travail IRCAM 26/2/16



FINAL REMARKS

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC INRIA MuTAnt project

José Echeveste, Arshia Cont, Julia Blondeau, José-Miguel Fernandez, Philippe Manoury, Marco Stroppa, Gilbert Nouno, …

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇝ INRIA MuTAnt project

Fundings, Collaborations, Awards, Community

PhD students… thanks !

J. Blondeau, P. Cuvillier, J. Echeveste, C. Poncelet, …

José Echeveste
PhD, Defended 2015

Philippe Cuvillier
(UPMC, Since 2012)

Clément Poncelet
(DGA/Inria, Since 2012)

Julia Blondeau
(UPMC, Since 2014)

Grants

- ANR INEDIT (2012-2015) with Grame (Lyon), LABRI (Bordeaux)
- PERSU Sorbonnes-University (2015)
- PHC LETITBE (2015-16) Exchange Program with Ch. Kirsch (U. Salzburg)

Industrial

- Contract with Qwant (2012)
- Collaborations with MakeMusic (US), Weezic (FR), AllegroIQ (China)
- **Start-up** creation by A. Cont based on Antescofo technology
  March 2016. Target: Music Entertainment and Education Industries

http://www.antescofo.com/

Scientific Collaborations

- SIERRA & PARKAS (ENS), FLOWERS & POSET (Bordeaux), Inria Chile,
- GRAME (Lyon) ... and many more
- International: UC Berkeley, UCSD, Tokyo U., Nagoya U. Salzburg U., Twente U., …

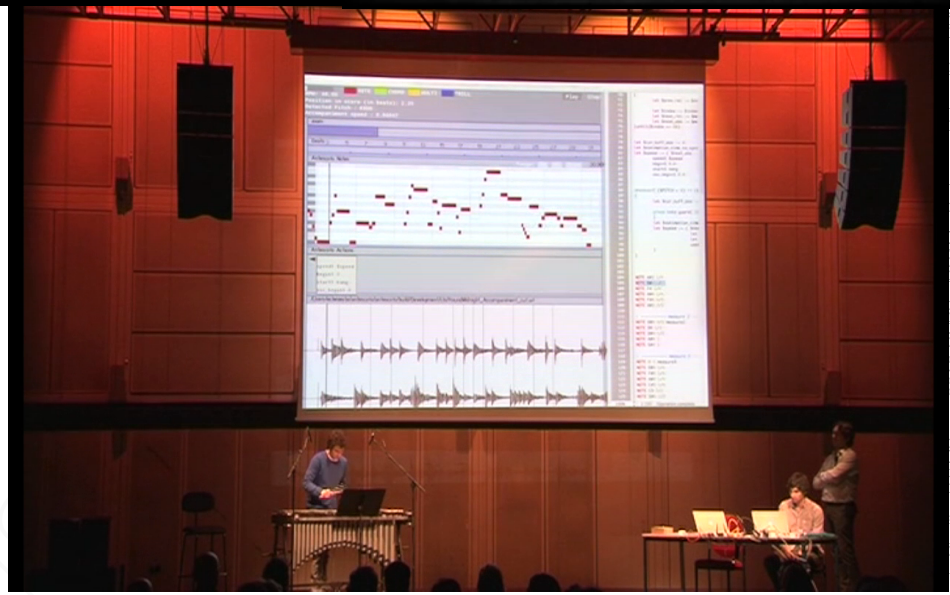
Community

- Antescofo: ~5K downloads since 2013
- of 150+ users from around the globe

Awards

IEEE ICASSP Best Student Paper Award in MLSP, 2015; CMR, Best Student Paper Award 2015; Acoustical Society of America Best Paper Award 2014; ICMC, Best Presentation Award 2014; French Minister of Industry's prize for Antescofo, 2013 (ONFI)

Towards Greater Public



Videos accessible on **http://repmus.ircam.fr/antescofo/videos**

Community

Antescofo is also:

- 100+ performances with ensembles around the world
- Community of 150+ users with contributions from around the globe
- ~5K downloads since 2013
- Subject to teaching for musicians in Brasil, Seoul, Japan, Montreal, USA, Europe… .
- Subject to massive media coverage thanks to its users:

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

Perspectives

The Augmented Score

- temporal scope as denotable value
- musical gesture
- embedding composer specific languages (idiosyncrasy)
- abstraction
- durative *vs* continuous computations

Next Generation of IMS

- offline and online score analysis
- offline and online score scheduling
- real-time score execution at sample accuracy
- extensible-, distributed-architectures for interactive music systems (ex.: VST, RTAS, audio plugins)

Digital Preservation

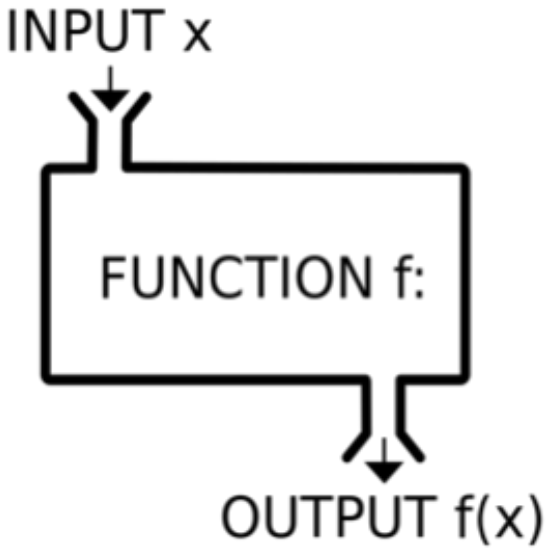
- compilation

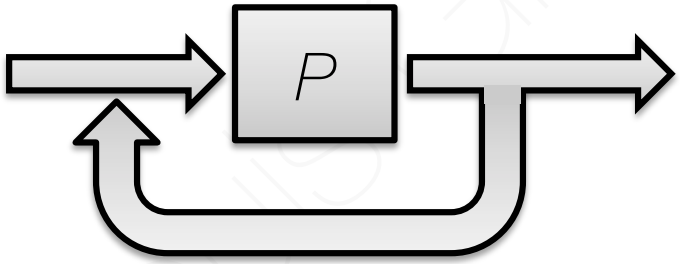
Beyond Music

- cyber-temporal systems: exploring other highly timed interactive scenarios (**Robotics**, Domotics)
- Programming with Perceptual Concepts
- other sensing devices/listening machines

Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC INRIA MuTAnt project

Le calcul : fonction, processus, *interaction*





Jean-Louis Giavitto / STMS umr 9912 CNRS, IRCAM, Sorbonne Université – UPMC ⇗ INRIA MuTAnt project

All Watched Over By Machines of Loving Grace

by Richard Brautigan

I like to think (and
the sooner the better!)
of a cybernetic meadow
where mammals and computers
live together in mutually
programming harmony
like pure water
touching clear sky.

I like to think
(right now, please!)
of a cybernetic forest
filled with pines and electronics
where deer stroll peacefully
past computors
as if they were flowers
with spinning blossoms.

I like to think
(it has to be!)
of a cybernetic ecology
where we are free of our labors
and joined back to nature,
returned to our mammal
brothers and sisters,
and all watched over
by machines of loving grace.

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