ICMC 1993

International Computer Music Conference 1993

Nyquist

Tutorial Text

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International Conference Center
Waseda University
September 10, 1993
Room D, 14:00~17:00

Nyquist Tutorial

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Nyquist Overview

- A sound synthesis *language*
  - gives flexibility
  - extensibility
  - tailor to your own needs
- Manages signals in *time*
  - create instances of sound computations, e.g. notes
  - logical stop times for joining sequences
  - multiple sample rates
- Composition and *structure*
  - symbolic pitch and duration possible
  - sequential and parallel combination
  - transformation operators: transpose, stretch, etc.

Tutorial Overview

- About Nyquist – some basics
- Lisp Basics – enough to make you dangerous
- Nyquist – language elements
- Examples – small programs that work
- Leftovers

Differences from Music *n*, cmusic, Csound

Music *n*	Nyquist
Separate Score and Orchestra languages	One unified language for both
Score preprocessors often needed	Powerful built-in scoring capability
No hierarchy: difficult to phrase	Naturally hierarchical
Two levels: instruments cannot invoke score language	Fully recursive, multi-level
Synthesis-oriented	Analysis and Synthesis support
Difficult to extend efficiently	Instrument compiler simplifies extension writing

Installing Nyquist

- ftp unix tar file from `g.gp.cs.cmu.edu`, directory `/usr/rbd/pub/nyquist`
- install the source:
  `zcat nyquist.tar.Z | tar xf -`
- print the manual:
  `lpr nyquist.ps`
- compile nyquist:
  `make`
- run it:
  `ny`

Quick Examples

- `(play (osc C4))`
- `(mult (osc C4)`
  `(env .05 0.1 .5 1.0 .5 .4))`
- `(seq (note c4) (note c5))`
- `(seq (phrase) (trans 2 (phrase)))`
- `(snd-lp 400.0`
  `(snd-load "mysound.snd"))`

Quick Examples (Behind the Curtains)

- ```
  (defun note (pitch)
      (mult (osc pitch) (env ...)))
  ```

- ```
  (defun phrase ()
      (seqrep (i 12)
          (stretch 0.15
              (note (+ C4 i)))))
  ```


Introduction to Lisp

- Lisp is interactive: read - eval - print loop

```
> 2
2
> (+ 1 2)
3
```

Lisp (cont'd): Applying a Function to an Argument

```
(osc C5)
```

Function

Argument (Parameter)

```
(play (osc C5 ) )
```

```
(play (osc C5 ) )
```


Lisp (cont'd): Multiple Function Arguments

```
(s-add a b)
```

Function

Arguments (Parameters)

```
(stretch 0.3 (osc C4))
```

```
(stretch 0.3 (osc C4 ) )
```

Function

Lisp (cont'd): Invoking a Function with No Arguments

```
(gc)
```

Function | No Arguments

```
(print (room))

(print room)
```


Lisp (cont'd): Defining a Function

```
(defun incr (n) (+ n 1) )
```

Function Name | Parameter List | Function Body

```
(defun note (pitch)
  (mult (env)
        (osc pitch)))
```

```
(defun note (pitch)
  (mult (env)
        (osc pitch)) )
```

Lisp (cont'd): Assigning Values to Variables

```
> (setf v 2)
2
> v
2
> (setf s (osc C4))
<sound: #2006a074>
> (play s)
nil
```


Lisp (cont'd): Introducing Local Variables

```
(let (x y)
  (setf x (osc C5))
  (setf y (osc G5))
  (sim x y))
```

adds sounds

```
(let ((x (osc C5))
      (y (osc G5)))
  (sim x y))
```

Lisp (cont'd): Arrays

```
> (vector 0.1 0.2 0.3)
#(0.1 0.2 0.3)
> (setf x (vector 0.1 0.2 0.3))
#(0.1 0.2 0.3)
> (aref x 0)
0.1
> (aref x 3)
error: array index out of bounds - 3
> (setf (aref x 2) 0.4)
0.4
> x
#(0.1 0.2 0.4)
```


Lisp (cont'd): Immutable Values

- Data is rarely modified
- New data is often allocated or generated
- Never use parameters to return values

Lisp (cont'd): Syntax Review

- (*function arg1 arg2 arg3 ...*)
- `(defun` *function* (*arg1 arg2 ...*)
  expression1
  expression2
  ...)
- `(defun` *function* (*arg1 arg2 ...*)
  `(let` (*var1 var2 ...*(*var3 expression*)*...*)
  expression1
  expression2
  ...))
- `(setf` *variable expression*)

Lisp (cont'd): Debugging

- `(trace` *function*) - adds *function* to trace list
- `(untrace` [*function*]) - removes *function*
- `(setf *tracenable* t)` - backtrace on error
- `(setf *breakenable* t)` - break on error
- `(clean-up)` - pop back to previous error
- `(top-level)` - pop up to top level
- `(baktrace` *n*) - print n-level backtrace
- `(continue)` - retry restartable error

Lisp (cont'd): Debugging Example

```
> (defun add-n (i) (+ i n))
ADD-N
> (add-n 3)
error: unbound variable - N
if continued: try evaluating symbol again
Function: #<Closure-ADD-N: #20058e48>
Arguments:
 3
1> (setf n 3)
3
1> (continue)
[ continue from break loop ]
6
```


Lisp (cont'd): More Debugging

```
> (trace add-n)
(ADD-N)
> (add-n (add-n 5))
Entering: ADD-N, Argument list: (5)
Exiting: ADD-N, Value: 8
Entering: ADD-N, Argument list: (8)
Exiting: ADD-N, Value: 11
11
>
```

The Sound Type

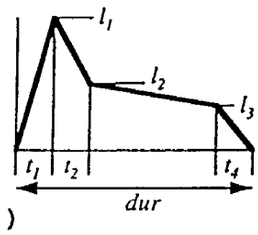
- A stream of samples, with
- a (fixed) sample rate
- a scale factor
- a time offset
- a logical stop time
- A genuine Lisp data type:
  `(type-of` *sound* `)` ⇨ `SOUND`

Naming Conventions

- `s-`*fn* – low-level sound function (avoid)
- `snd-`*fn* – common sound function
- no prefix – operation on behaviors

Sound Generation Functions

- (env t_1 t_2 t_4 l_1 l_2 l_3 [*dur*])



- (pwl t_1 l_1 t_2 l_2 t_3 l_3 ... t_n)
- (lfo *freq* [*dur table phase*])
- (mult *beh1 beh2* ...)
- (rest [*dur*])
- (noise [*dur*])

Sound Generation (Cont'd)

- (osc *pitch* [*dur table phase*])
- (osc-note *pitch* [*dur env volume table*])
- (amosc *pitch mod* [*table phase*])
- (fmosc *pitch mod* [*table phase*])
- (snd-lp *sound cutoff*)
- (snd-hp *sound cutoff*)
- (snd-reson *sound center bandwidth*)

Instruments

Defined by Lisp functions:

```
(defun fm-inst (pitch mod-index)
    (mult (my-env) (fmosc ...)))

(defun add-inst (pitch)
    (sim (partial-1 pitch)
         (partial-2 pitch)
         (partial-3 pitch)
         (partial-4 pitch)))
```


Scores

- using seq:
  ```
  (seq (note C4) (fm-inst D4 2.5))
  ```
- using sim:
  ```
  (sim (note C4) (fm-inst D4 2.5))
  ```
- using defun:
  ```
  (defun myscore ()
      (seq (note C4) (fm-inst D4 2.5)))
  ```

Linear Scores

```
(sim
  (at 0.0 (flute 1.2 C5 ...))
  (at 0.5 (bass  0.7 Ef3 ...))
  (at 0.9 (bass  1.3 E3 ...))
  (at 1.1 (clar  1.1 Ef4 ...))
  ...)
```


Hierarchical Scores

```
(defun phrase-1 ()
  (sim (at 0.0 (flute 1.2 C5 ...))
       (at 0.5 (bass  0.7 Ef3 ...))))

(defun phrase-2 ()
  (sim (at 0.0 (bass  1.3 E3 ...))
       (at 0.2 (clar  1.1 Ef4 ...))))

(sim
  (at 0.0 (phrase-1))
  (at 0.9 (phrase-2))
  ...)
```

Computed Scores

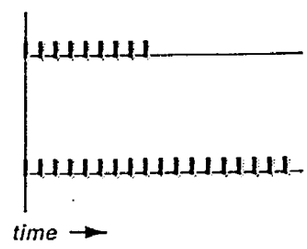
```
(defun roll (dur)
   (let ((n (/ dur stroke-len)))
     (seqrep (i n) (stroke))))

(defun random-melody (n)
   (seqrep (i n)
     (let ((pitch (+ c4 (random 30))))
       (note pitch))))
```


Computed Scores (cont'd)

```
(defun roll ()
  (let ((n (/ *stretch* stroke-len)))
    (stretch-abs 1.0
      (seqrep (i n) (stroke)))))
```

(roll)

(stretch 2.0 (roll))



Transformations

- `(stretch 0.5 (note C4))`
- `(transpose 2`
  `(stretch 0.5 (myscore)))`
- Transformation Operators are:
  - `abs-env`
  - `at, at-abs` — `*time*`
  - `control-srate-abs` — `*control-srate*`
  - `sound-srate-abs` — `*sound-srate*`
  - `extract, extract-abs` — `*start*, *stop*`
  - `loud, loud-abs` — `*volume*`
  - `stretch, stretch-abs` — `*stretch*`
  - `trans, trans-abs` — `*transpose*`

Combination & Structure

- `(seq` *beh*$_1$ [*beh*$_2$ ...] `)`
- `(seqrep (`*var limit*`)` *beh* `)`
- `(sim` *beh*$_1$ [*beh*$_2$ ...] `)`
- `(simrep (`*var limit*`)` *beh* `)`
- `(set-logical-stop` *beh time* `)`

Behavioral Abstraction

- "instrument" defines whole class of sounds
- parameters allow you to specify some details
- transformations support "implicit" parameterization:

```
(defun note (p)
    (mult (env ...) (osc p)))
```

```
(stretch 2.0 (note GS4))
(loud 4.0 (note GS4))
(trans 12.0 (note GS4))
```


Example 1 - Wavetable

```
(defun mkwave ()
  (let ((table
         (s-add (s-scale (build-harmonic 1.0) 1.0)
          (s-add (s-scale (build-harmonic 2.0) 0.5)
           (s-add (s-scale (build-harmonic 3.0) .25)
            (s-scale (build-harmonic 4.0) 0.12))))))
     (setf *wave*
      (list table
            (hz-to-step
             (/ *SOUND-SRATE* 2048.0))
            t)) ))

(if (not (boundp '*wave*)) (mkwave))
```

Example 2 - Table-lookup osc

```
(defun note (pitch dur)
  (osc pitch dur 0 *wave*))
```

phase

table

Example 3 - Note Sequence

```
(play (seq (note c4 i)
           (note d4 i)
           (note f4 i)
           (note g4 i)
           (note d4 q)))
```

note: `i` = 0.3 (eighth note at MM=100),
`q` = 0.6 (quarter note)

Example 4 - Envelope & Duration

```
(defun env-note (p)
   (mult (note p 1.0)
         (env .05 0.1 0.5 1.0 0.5 .4)))

; try it out
(play (env-note c4))

; use it with stretch to change duration
(play (seq (stretch 0.25
                    (seq (env-note c4)
                         (env-note d4)))
           (stretch 0.5
                    (seq (env-note f4)
                         (env-note g4)))
           (env-note c4)))
```


Example 5 - Sounds vs. Behavior

```
; load a sound
(setf a-snd
      (sf-load "demo-snd.nh" 22050.0))

; play it
(play a-snd)

; two sounds in sequence:
(seq a-snd a-snd) ; WRONG!

(seq (cue a-snd) (cue a-snd)) ; RIGHT!
```

Example 4 - Envelope & Duration

```
(defun env-note (p)
   (mult (note p 1.0)
         (env .05 0.1 0.5 1.0 0.5 .4)))

; try it out
(play (env-note c4))

; use it with stretch to change duration
(play (seq (stretch 0.25
                    (seq (env-note c4)
                         (env-note d4)))
           (stretch 0.5
                    (seq (env-note f4)
                         (env-note g4)))
           (env-note c4)))
```


Example 5 - Sounds vs. Behavior

```
; load a sound
(setf a-snd
      (sf-load "demo-snd.nh" 22050.0))

; play it
(play a-snd)

; two sounds in sequence:
(seq a-snd a-snd) ; WRONG!

(seq (cue a-snd) (cue a-snd)) ; RIGHT!
```

Example 6 - Sim and At

```
(play (sim (at 0.0 (cue a-snd))
           (at 0.7 (cue a-snd))
           (at 1.0 (cue a-snd))
           (at 1.2 (cue a-snd))))
```


Example 7 - Nested Transformations

```
(sim (cue a-snd)
     (loud 2.0 (at 3.0 (cue a-snd))))

(loud 2.0 (sim (at 0.0 (cue a-snd))
               (at 0.7 (cue a-snd))))
```

Example 8 - Defining Behaviors

```
(defun snds (dly)
  (sim (at 0.0 (cue a-snd))
       (at 0.7 (cue a-snd))
       (at 1.0 (cue a-snd))
       (at (+ 1.2 dly) (cue a-snd))))

(play (snds 0.1))

(play (loud 2.5
        (stretch 0.9 (snds 0.3))))
```


Example 9 - Stretching Sounds

```
(play (stretch 3.0 (sound a-snd)))

(defun down ()
  (seq (stretch 0.2 (sound a-snd))
       (stretch 0.3 (sound a-snd))
       (stretch 0.4 (sound a-snd))
       (stretch 0.5 (sound a-snd))
       (stretch 0.6 (sound a-snd))))

(play (down))

(play (seq (down) (up) (down)))
```

Example 10 - Saving Sounds

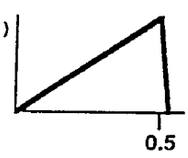
```
; save sound to a file
(sf-save a-snd "a-snd-file.snd")

; execute Unix command to play file
(system "play a-snd-file.snd")

; simple string manipulation
(setf snd-file-name "a-snd-file.snd")
(system
   (strcat "play " snd-file-name))
```


Example 11 - FM Sound

(fmosc *pitch mod table phase*)

```
(play (fmosc c4 (pwl 0.1)))
; one octave frequency sweep:
(play (fmosc c4
   (pwl 0.5 (step-to-hz C4) 0.501)))
```

```
(fmosc c4
       (pwl 0.5 (step-to-hz Cs4) 0.501)
       *fm-voice* 0.0)

; vibrato:
(fmosc Cs2 (s-scale (lfo 6.0) 10.0)
       *fm-voice* 0.0)
```

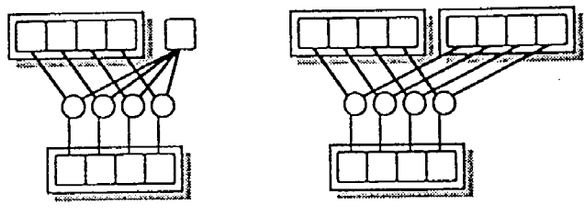


Multichannel Sound

- An array of sounds is a multichannel sound:

```
(vector sound1 sound2 ...)
(mult (env) multi-sound)
(s-lp multi-sound 400.0)
```

- Sample rates need not match
- Functions generalize to multichannel operands:



Extending Nyquist

```
(mult
 (arguments ("sound_type" "s1")
            ("sound_type" "s2"))
 (inner-loop "output = s1 * s2")
 (commutative ("s1" "s2"))
 (linear "s1" "s2")
 (start (max "s1" "s2"))
 (logical-stop (min "s1" "s2"))
 (terminate (min "s1" "s2")))
```

- translate.lsp: mult.alg ⇨ mult.c

Future Plans

- MIDI file interface
- Pitch analysis
- Synthesis techniques:
  - FOF synthesis
  - Reverberation
  - Spacial Location
  - Sampling (with looping)
- Analysis/Synthesis techniques:
  - LPC
  - Phase Vocoder
  - Spectral Interpolation
  - Wavelet transform
- Instrument libraries

Conclusion

- Thank you for you attention!
- Please share your comments on this tutorial
- ... and on **Nyquist.**