Siren, CSL, and CRAM:

Building Large-scale Interactive Systems

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Overview: CREATE/MAT Sound Group

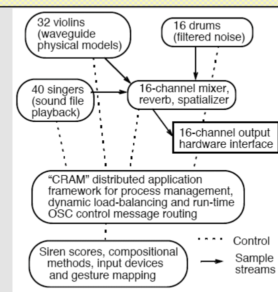
- The Context: Siren, CSL, and CRAM
- Siren: Object models, control mappings, and GUIs for composers and performers
- CSL (“Sizzle”): The CREATE Signal Library for distributed DAudioSP
- CRAM: DBs and tools for managing & monotoring distributed real-time apps
- Examples, evaluation, next steps, discussion

UCSB Labs, Programs, and Teams

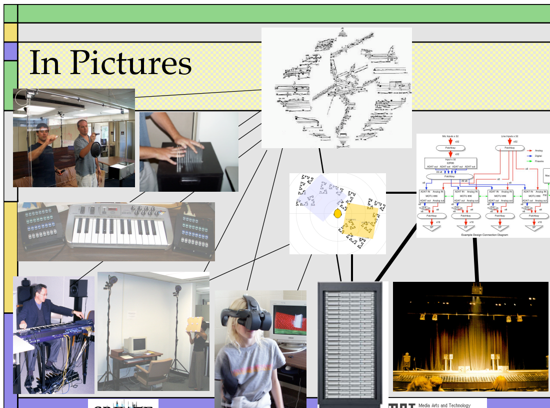
- CREATE
  - JoAnn Kuchera-Morin, Curtis Roads, Ioannis Zannos, STP, etc.
- UCSB Music Dept.
  - Comp: J. Haladyna, L. Hogan, K. Tanaka, J. Feigin
  - Piano, Winds, Perc., Voice, Theory, Ethno/musicology
- Graduate Program in MAT
  - Music, **Art Studio** (LeGrady/IA, Jevbratt/WA, Novak/VA, Peljhan/IA) , **CS** (Turk/CV, Almeroth/Net), **ECE** (Gibson/Comm, Mitra/DSP, Manjunath/ImProc)
- CNSI: California NanoSystems Inst. @ UCSB/UCLA
  - CompuChem, BioInf, MaterialsSci, MolecGenetics, MAT
- UCSB Digital Media IGERT
  - 5 Years @ 14 PhDs per year, assoc. depts

Synthesis/Performance Group Goals

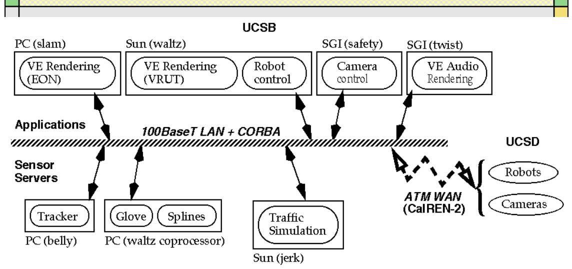
- Support reliable “orchestra-scale” sound synthesis, multi-modal gestural sensing and control, and pluriphonic projection (up to 128 channel output in the CNSI sphere)



In Pictures



Example: ATON DRIVE (1998-2000)



What's Needed?

- Representations and interfaces for composers and performers (Siren)
- Scalable DAudioSP framework (CSL)
- Management infrastructure for distributed RT OO software (CRAM)
- A really cool loud/bright/sensing space to play it in! (CNSI)

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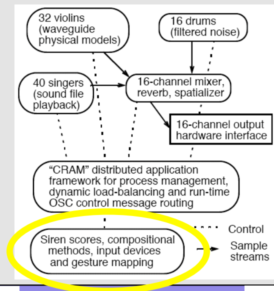
Part 1: Siren



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Siren (MODE, HSTK, DoubleTalk)

- Smalltalk-based object-oriented framework for sound/music description and processing, under development since 1984
- Focus on structure representation, control mapping, and composition, rather than on performance, DSP, or notation
- API/Platform for music representation and composition language development

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What's Siren?

[440 Hz, (1/4 beat), 44 dB]
evtList mapPItches: gamut.
evtList playOn: Voice default.

- **Smoke** music representation language
  - Music magnitudes, events, event lists, generators, modifiers, struct. algorithms, …
  - Organize timing, tuning, timbre, space, gesture, grouping, versioning
- I/O **voices** (players, property-parameter mappers) for many formats: (m11-SC3) note lists, OSC, MIDI, XML, CORBA, …
- Multi-threaded RT **scheduler**
- GUI **widgets** and apps for music
- (OO/R)DBMS interfaces for **persistency**

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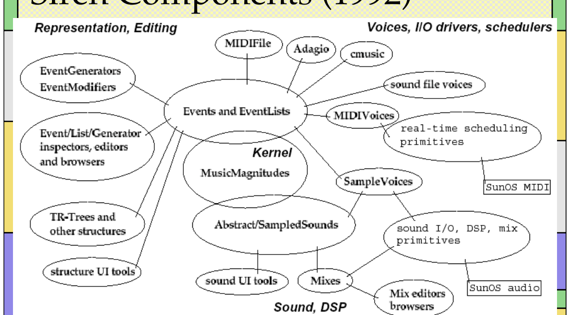
Siren Components (1992)



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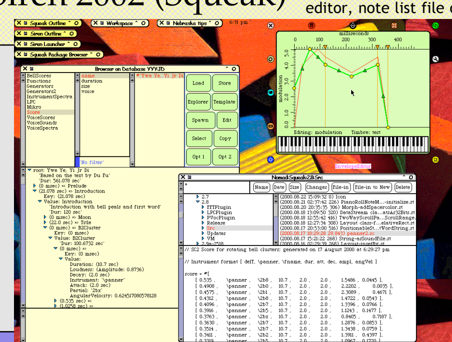
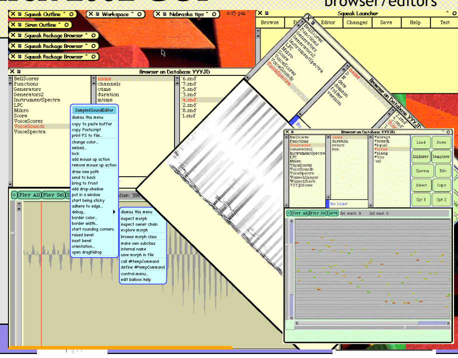
Siren 2002 (Squeak)

Score browser, function editor, note list file output



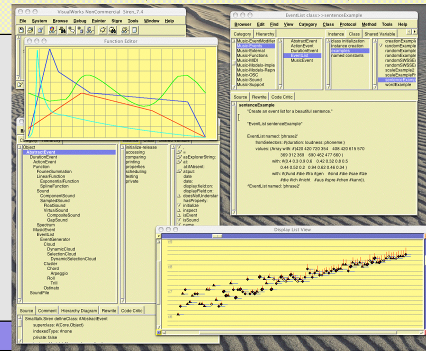
Siren 2002 GUI

Sound/spectrum/score browser/editors



Siren 2003 (VisualWorks)

Demo



Composition in Siren

```
RotatingBellCluster class methodsFor: 'HeavenEverywhere'
setup: dataSelector functions: fcnSelector
    "(RotatingBellCluster setup: #b2Data functions: #b2aFunctions) eventList explore"
    | i dat parts clust fcns |
    parts := OrderedCollection new: 16.             "Load partial data"
    dat := self perform: dataSelector.
    i := 1. [i < dat size] whileTrue:               "Create partial list"
      [parts addFirst: (BellPartial named: (dat at: i) freq: (dat at: i + 1)
                        ampl: (dat at: i + 2) dur: 10.7).   i := i + 3].
    clust := self new partials: parts.              "Load function data"
    clust name: #'rBell.b2.14c'.                    "Set your name"
    fcns := self perform: fcnSelector.              "***Get the time-function list ***"
    clust spectralFcn: (fcns at: 1).                "Spectral weighting function"
    clust densityFcn: (fcns at: 2).                 "Time/density function"
    clust velocityFcn: (fcns at: 3).                "Mapping of pitch to angular velocity"
    clust duration: 90; att: 2.0 sec; dec: 2.0 sec. "Set bll cluster parameters"
    clust pitch: 14.07 Hz.                          "= Base * 1.61803398"
    clust ampl: -7.2 dB.                            "Mezzopiano"
    clust voice: #panner2.                          "Add to panner voice"
    ^clust                                          "Answer bell cluster"
```

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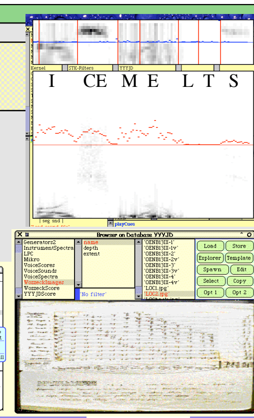
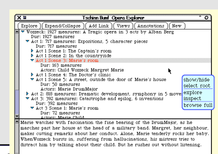
Recent Siren Apps

- 8S speech segmenter and database
- Opera Browser
- SeSpSp and EMA prototypes





Siren Evaluation

- **Medium-sized**: 250 classes, 12 kLOC core, 24 total
- **Multiplatform**: CPU, OS, GUI, RMI, control, ST-impl.
- **Flexible/Comprehensive**: models, prop. organization, group hierarchy, persistency, IO, GUI
- **Declarative/Procedural**: OO arch., msg-based agent threads, parser generators, grammars, Slang xlators
- **AI** frameworks (rules, nets, logic, CSP, genetic)
- **DB** support: VI, OO (Gemstone, SMS_DB), RDBMS
- <u>Still my favorite</u> (real-estate: productivity).
- Smalltalk's still considered obscure or esoteric.

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Evaluating Smalltalk as a Platform

- **Language**: uniform, reflective, malleable, stable/std
- **Run-time**: Run-time types and polymorphism; Compiler available at run time; GC works; persistent run-time state in VI, LWP, thinks it's the OS
- **IDE Tools**: Browsers, refactoring, classes rather than files; awesome debugger and change manager, best GUI painter
- **Delivery Environment**: Change/Config Mgmnt with Envy or Store (parcels/projects); Shared desktops (RemEvts, SHARK, Kansas, DST); External calls: RMI/CORBA/DST

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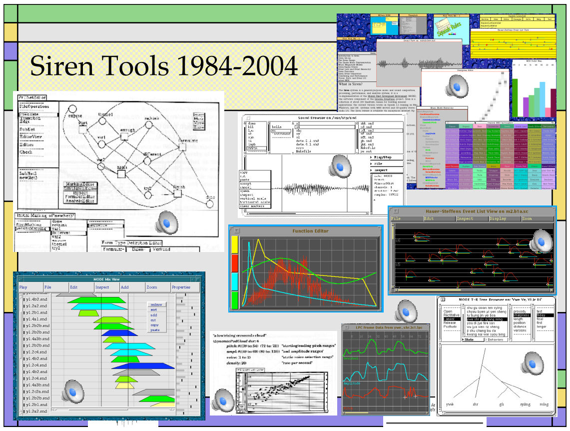
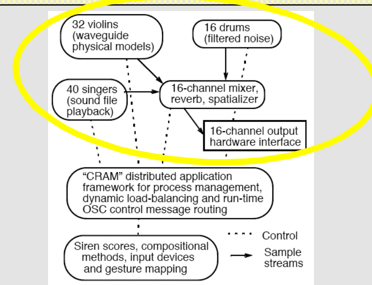
Siren Tools 1984-2004



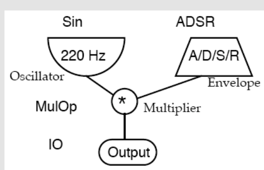
Part 2: CSL (1998-2004)



The CREATE Signal Library (CSL, "sizzle") ("chill?")

Demo

- General-purpose, portable C++ framework for distributed, real-time digital audio synthesis and processing
- Used for stand-alone applications, plug-ins, OSC servers, etc.



CSL Relatives

- Like Cmix, STK, Siren, JSyn, MxV, or CLM
  - Delivered as a library in a general-purpose programming language
- Unlike SuperCollider, Csound, Max
  - Not its own language
  - No scheduler
  - Uses C++ development environment

Why on Earth another one???

- Cmix -- old, flaky
- SuperCollider -- different question, complex
- Csound, Music-N -- not languages, source clarity
- Jsyn -- closed DSP kernel
- STK -- PM-centric, tick model
- CLAM -- way complex
- CLM -- who knows LISP?
- Siren/Squeak -- who knows Smalltalk?

Our Requirements

- Simple, easy to learn
- Flexible, multi-purpose
- Portable
- Scalable
- Embeddable
- Distributable
- Network-oriented
- Debuggable

CSL Background

- "CREATE Oscillator" -- 1998, CORBA_A/V
- MAT 240D course (digital audio synthesis techniques, Spring '01, '03)
  - CO1 (minimal), 2 (full-featured)
  - CSL_lean (redesign from scratch by one person)
  - CSL3
- Designs driven by immediate needs for concrete applications (pieces, theses, etc.)

CSL3 Basics

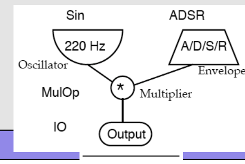
- **Buffer** objects (1-4 classes)
  - Multichannel non-interleaved sample storage
  - "Smart" object, not just a (float **), ptr. mgmnt.
  - Handle malloc/free, filling statistics, etc.
- **FrameStream** classes (Ugens) (many)
  - Respond to the message next_buffer(input, output)
  - Processors have a FrameStream as input
- **Mix-in** classes (vs. wrapper classes)
  - Phased, Positionable, Writeable, Cacheable, etc.

"Hello world" in CSL

Demo

Sine wave with envelope

```
// Create a sine oscillator -- this is a comment
        Sine osc(220.0);
// Create an ADSR envelope -- args are (dur, a, d, s, r)
        ADSR env(3.0, 0.06, 0.2, 0.2, 1.5);
// Create a multiplier
        MulOp mul(osc, env);
// Plug it into the output driver
        globalIO.set_root(mul);
```



Sine Osc Alternatives

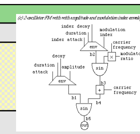
Processor::set_input()
Ugen::set_scale()
Ugen::set_offset()

```
// Use the envelope object as a generator and processor
    SumOfSines osc(220.0, 1, 5, 0.7...);   // make a sum-of-sines
    Triangle env(3.0);                     // triangle envelope
    env.set_input(osc);                    // send osc as input to env
    gIO.set_root(env);                     // env is root

// Use the osc's scale (volume control or AM) input
    SquareBL osc(220.0);                   // make a band-lim square
    Gaussian env(3.0, 0.2);                // envelope with bell width
    osc.set_scale(env);                    // set osc scale to env
    gIO.set_root(osc);                     // osc is root
```

Reverb'd Panning Dual-Env. FM

(7 Ugens, minimal, procedural)



```
        //// FM instrument with stereo panning and reverb ////
    ADSR a_env(1, 0.01, 0.1, 0.1, 0.6);    // create ampl. env., ADSR(dur, a, d, s, r)
    ADSR i_env(1, 0.001, 0.1, 0.5, 0.5);   // create FM mod. index env.
    i_env.set_scale(110);                  // scale i_env by base freq.
    Sine car, mod(110);                    // create 2 sine oscs: carrier & modulator
    mod.set_scale(i_env);                  // scale the modulator by the i_env
    mod.set_offset(220);                   // add in the base freq.
    car.set_frequency(mod);                // set the carrier's freq. to the modulator
    a_env.set_input(car)                   // plug the carrier into the a_env's input
    Sine pos(0.25);                        // create an LFO for panning
    Panner pan(a_env, pos);                // plug the a_env into a stereo panner
    Stereoverb verb(pan);                  // plug the panner into a stereo reverb
    gIO->set_root(verb);                   // plug the reverb into the output
//  gMixer->add_input(verb);               // or add it to a global mixer
```

Demo

CSL FrameStream Details

- Core FrameStream methods
  - next_buffer(in, out) - fill in a buffer's worth of frames
  - next_sample(in, out) - answer 1 sample; adjust phases…
  - is_fixed_over(in) - is the receiver's value fixed over range?
  - is_active() - are a graph's envelopes on?
- Policies for handling next_buffer() with multi-channel I/O buffers: call mono_next_buffer() and iterate (vs. copy - FanOut, Splitter)

CSL Sources, Controls, and Processors

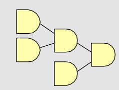
- **Sources**
  - Oscillators (perfect, BL), SumOfSines, Noise, SoundFiles, Chaotic/IteratedFS, IFFT, Physical Models, Granulators, Signal windows
- **Control**
  - Envelopes, LFOs, LFNoise, ProbDists, DynamicVariables, OSC, MIDI, GUI, CORBA, XML, note lists, Feature extractors, Input followers
- **Processors**
  - Operators, Mixers, Filters/banks, Reverbs, (N-M)Panners, DelayLines, FDN, WaveShape, Lo-latency Convolution, FFT/IFFT, LPC/FIR
- **Support**
  - RingBuffer, ThreadedFrameStream, BlockResizer, RateConvertor, Splitter/Joiner, FanOut (needed), Interleaver/Deint., Test main()s
  - Tools: FIR/Reverb IR Design, Spectrum DBs, Control-mapping

CSL I/O - The Pull Model

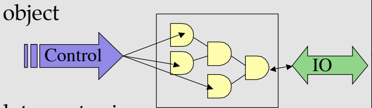
- The IO object
  - Holds onto a DSP graph (root node, may be mixer)
  - Receives periodic call-backs from somewhere (driver such as PortAudio, CoreAudio, UDP, TCP, file I/O scheduler, etc.)
  - Sends next_buffer() to the root of its graph with IO buffer pointers filled in (timing base freq.); may interleave
- Subclasses for PortAudio, CoreAudio, UDP/TCP RemoteIO, FileIO, streaming, etc.

The Big Picture of CSL

- Basic DSP graph



- Connected to control input (OSC, MIDI, GUI, CORBA, XML), and IO object



- Buffering and latency tuning

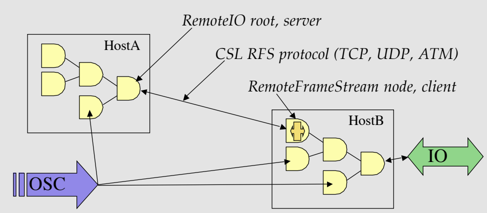
CSL DSP Graph Flexibility

- Sub-graphs can run at different:
  - Sample rates (for control),
  - Buffer sizes (for transforms),
  - Numbers of channels (for efficiency),
  - Buffer formats (interleaved or not),
  - In different threads, etc.
- These can be changed (within reason) at run-time (e.g., for load- or traffic-balancing)

Multi-host CSL Graphs

Demo

- Distributed sub-graph processing with RemoteIO and RemoteFrameStream, RFS protocol, buffering



RemoteFrameStream Details

- Uses simple protocol, LAN/WAN-oriented (we use switched 1000BaseT & TCP)
- Relatively careful (packet header/trailer, sequence numbers, format packets)
- Double-send optional with UDP/ATM
- RFS uses ThreadedFrameStream with variable-sized (zero-possible) RingBuffer

Control, Latency, Scheduling

- All CSL processing is triggered by output requests (pull model, buffer size = control rate)
- Slow computations should use ThreadedFrame-Stream or transform/convolver threads
- Control may change asynchronously; query is_processing() optional (semantics of control)
- Latency determined by buffer size, amount of cacheing in graphs, remote links (few msec for small buffers, <1 msec doable [?])
- Dynamic graphs are rare; no time or event models

Instruments and OSC/MIDI/XML

- Instrument object
  - Holds onto a DSP graph; adds "reflective" accessors
  - Generates OSC address spaces, MIDI maps, etc.
  - Server `main()` function loads an instrument library and publishes an address space on a listener socket
  - Example: // C++ accessor decl.

```
list[0] = new Accessor("du", set_duration_f, CSL_FLOAT_TYPE);
list[1] = new Accessor("am", set_amplitude_f, CSL_FLOAT_TYPE);

-->         /i1/        instrument 1's OSC address space
             /i1/du:  set-duration command
             /i1/am: set-amplitude command
```

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CSL Portability

- MacOSX, *nix, Linux, MS-Windows (gcc relatives)
- Cross-platform APIs
  - PortAudio for RT sound IO†
  - LibSndFile for sound file IO
  - PortMIDI for MIDI†
  - LibNewRan for probability distributions
  - FFTW for FFT†
  - CyberX3D for VRML, OpenGL†
- Issues
  - C++ compiler, socket/thread code, GUI
  - Base sample data type (float vs int)

† = may use platform-specific APIs (CoreAudio, DSP_FFT, etc.)

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Using CSL

- As a library
  - Link a graph and IO into your application, game, GUI, etc.
- For plug-ins
  - AudioUnits or VST with GUIs; call-back to `next_buffer()`
- For OSC, MIDI, CORBA, XML-RPC, etc. servers
  - Stand-alone instrument groups as soft-synths; RemoteIO
- With CRAM
  - Multi-host control/server/output configurations
- The `main()` function creates graph or mixer, may spawn threads, then registers an IO call-back object

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CSL "beep" main (all of it!)

Demo

```
//   Beep_main.cpp -- the simplest CSL "main" program -- a 3-second beep
#include "CSL_All.h"                  // CSL "kitchen sink" include
using namespace csl;                  // Use C++ CSL namespace
                                      // MAIN -- plays a 3-second beep
int main (int argc, const char * argv[]) {
    PAIO gIO;                         // PortAudio IO object
//  FileIO gIO("csl_test.aiff");      // File IO object
    Sine osc(220);                    // create a sine oscillator at 220 Hz
    gIO.set_root(osc);                // plug it in to the IO
    gIO.open(); gIO.start();          // open/start the IO
    sleep_sec(3);                     // sleep 3 seconds (CSL blt-in fcn)
    gIO.stop(); gIO.close();          // stop/close the IO
    return(0);                        // exit
}
```

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CSL Example: Se/Sp_Sp (2002)

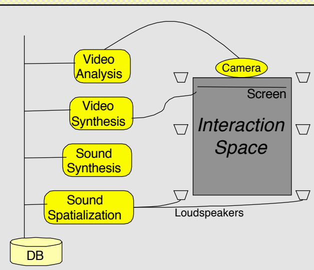
Sensing, computation, (m-) presentation (MVC)

Camera-based multi-user sensing (aware space)

Computer vision SW follows mvmnt & grouping among attendees; sends OSC msgs to 3 servers

Synchronized multi-camera projection and 6-ch. surround sound

Port from SC2 to CSL2



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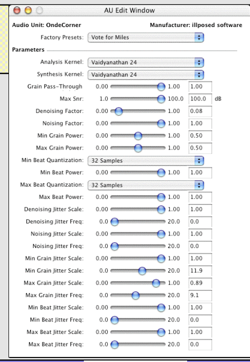
Sensing/Speaking Space @ SFMOMA Feb. '02

Example: OnDeCorner

- CR's AudioUnit plug-in for experimenting with wavelet transforms
- Pluggable FWT code
- Play to DAC or file



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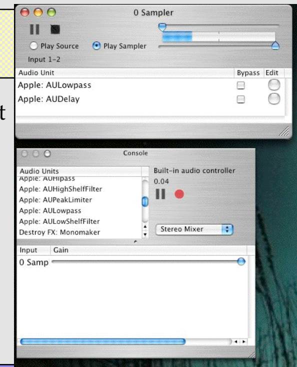
Example: Ouroboros



- CR's AudioUnit host application for processing sound files and live input
- Extensions planned for remote AudioUnits

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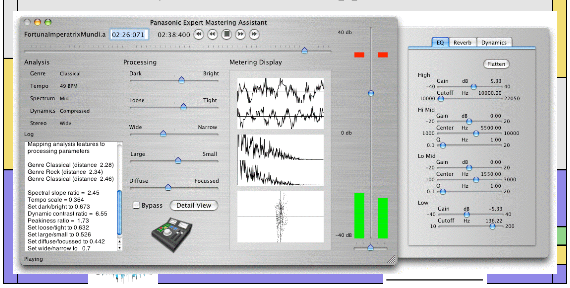
Example: Expert Mastering Assistant

Demo

Process: Analysis, GenreDB, Mapper, DSP, Interact



Generating CSL Graphs/Events

- Using scripting languages
- Smalltalk Slang translator
- From XML
- DragNDrop "patcher" GUIs
- Storing signals and graphs in an OODB
- Instrument libraries and event stores
- Auto-gen of flat namespace for C RMI

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Example: LUA Patcher (worked, but failed)

CSL as a library for a scripting language

```
-- Lua program for a panning chaotic oscillator
panning_chaos = function {}
     lorenz = Lorenz{};
     envargs = {0.5, 0.0, 0.0, 0.003, 0.5, 0.5, 0.0};
     envelope = Envelope{envargs};
     panner = Panner2{lorenz, envelope};
     audio_out{panner};
end
```

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So we know it all, right?

- NOT!
- Many open architecture, design, modeling, implementation, deployment, issues
- Some basic choices we're still debating
- Some real dilemmas, limitations, principles
- Tensions between our design bias towards simplicity and "creeping featurism"

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Open CSL Design Issues

- Basic models: buffer-based, event-based, signal-based
  - Current pull-model driven by PortAudio and CoreAudi APIs; granularity of events
  - Need a unification of types (semantics) of buffers (samples, FFT frames, FWT frames, IRs, etc,)
  - Signal semantics: operators on buffers vs. procedural ugens?
- How to support dynamic graphs in a simple system (punt)
- That latency thing, polynomial ctrl interpolation, clock sync.

Speed Hacks & Optimizations

- User-visible optimizations
  - is_fixed_over(), is_active() -- used
  - is_linear_over(), is_polynomial_over() -- ?
- Several kinds of buffers (cache optim.)
- Control interpolation?
- DSP graph-to-SMP allocation
- Managed sample-rate conversion
- Better C++ compiler (IBM or Intel/AMD)
- Many interesting optimizations would greatly complicate the system (our guess)

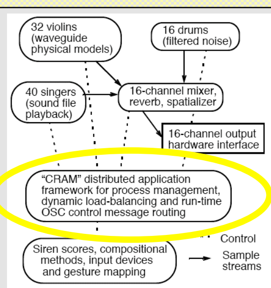
CSL Wish List

- Better IDE/CVS/GUI (Smalltalk)
- Better base libraries (Smalltalk)
- Better MM libraries (Java, CommonLISP)
- Untyped language (SuperCollider)
  - ST Slang + operators?
  - Scripting language bindings?
  - Java with OO RMI?
- Language with GC (SC3, Smalltalk)?
- Otherwise, just like CSL3!

Next Steps for CSL

- Unified buffer class (cache usage)
- New synthesis techniques: MAT 240D '03: design issues raised
- Tighter integration with CRAM planner, monitoring, IO/DB managers
- Siren OSC routing in CSL server farms
- MAT 240F going on now!

Part 3: The CRAM DPE



Managing Siren and CSL: CRAM

- CRAM: Yet another **Distributed Processing Environment** (DPE, Cluster Mgmnt. literature)
- Framework to deploy, start/stop, and monitor multi-host distributed real-time OO applications
- Provides fault-tolerance and load-balancing*
- CRAM is 3rd-gen. DPE implementation at CREATE (1996-2004) (HPDM/TAO, Yellow/CORBA_AV)
- Designed for robustness, simplicity, and low overhead; limited services and scalability/replication

CRAM DPE Operation Model

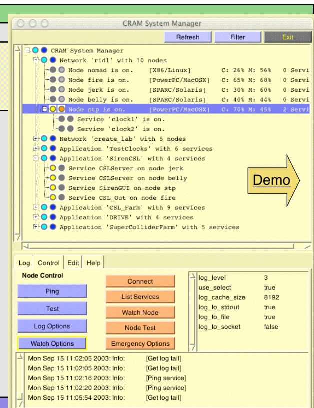
- **Applications** are composed of services
  - which probably talk among themselves apart from the management system
- Any program can be a service (lightweight wrapper)
- **Nodes** (HW) can run services
  - and monitor their hardware and services
- The **system manager** talks to a node and its services
  - Start/stop, load-balance, monitoring, fault-detection/restart, etc.

Components of a DPE

- Node manager program (Node)
  - Daemon that provides "remote exec" functionality and status/performance monitoring; runs on all machines
- Service interface (Service)
  - Wrapper code that is added to all application server programs managed by the DPE
  - Adds socket listener threads for mgr messages
  - May add init/restart functions between server obj. & app.
  - May integrate logging, status monitoring into app. code
- System manager (Manager)
  - Talks to nodes to administer services for distr. apps
  - Uses DBs for network, services, and app. configurations
  - May offer an expert/constrained configuration planner

CRAM Manager

- Network/Node
- Node/Service
- Application/Service
- Log/Control pane
  - Run-time monitor
  - Planning
  - DB play-back



Using CRAM

- Write a Service class for the app
- It handles main() (creates the service object) and start/stop messages (start/stop the base app)
- (Optional) add run-time option-setting, logging, app. status monitoring (handle CRAM msgs)
- Create a service type record in the DB
- Add applications to the DB
- Go!

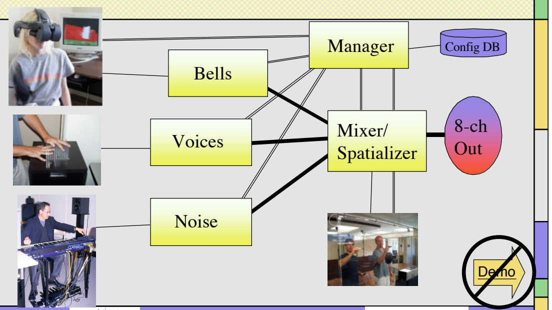
CRAM Databases (Simple RDBMS)

- Networks
  - Nodes and their properties
    - HW, OS, MIPS/MFLOPS, LAN, special I/O
- ServiceTypes
  - Name, arguments, options
  - HW/OS/IO requirements (for configuration)
- Services
  - Type and actual run-time arguments (net IO)
- Applications & History
  - Lists of services (& their options) on nodes

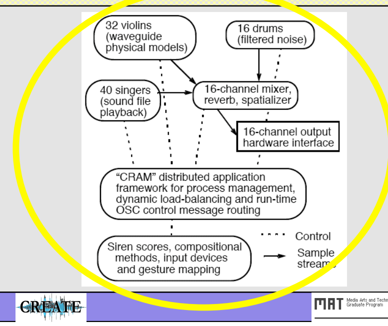
CRAM Implementation Details

- Node/Service source = 4kLOC C++, 2.5 kLOC Java, 0.8 kLOC ST80 (w. DB-IO)
- Manager & DB source = 4kLOC Smalltalk [~50% auto-gen]
- Uses low-level UDP/TCP protocols
- Several levels of failure recovery, node-service-discovery, heart-beat monitors
- Logging and monitoring to DB, replay

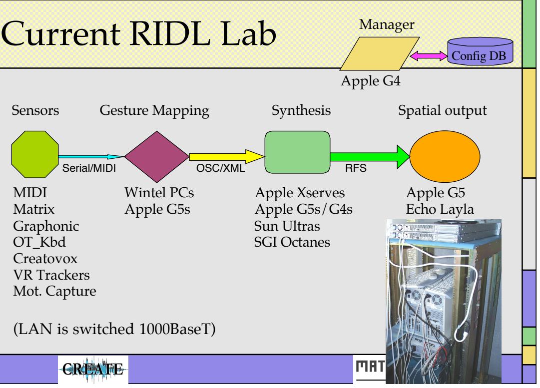
CRAM Configuration for CSL



Part 4: Putting it All Together



Current RIDL Lab

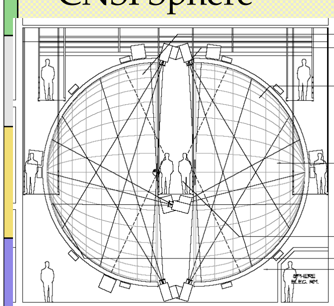


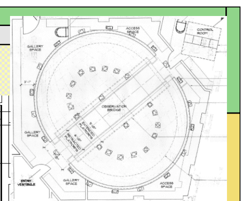
(LAN is switched 1000BaseT)

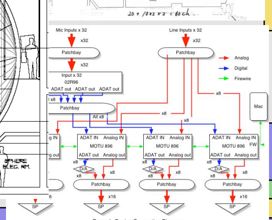
Next Gen Lab: CNSI

- MAT in CNSI: labs, studios, workshops, sphere
- CNSI compute infrastructure
  - Traditional vector supercomputer
  - 1024-node Linux cluster
  - Multimedia processing cluster (TBD)
- Sphere (3-story) I/O space
  - 12-channel overlapping video output
  - 128-channel sound output
  - Camera-based and (multi) other input sensing

CNSI Sphere







How? DSCP!

Distributed Sensing, Computation, and Projection = *MVC on steroids*

Back-end application models are scientific/numerical/simulation

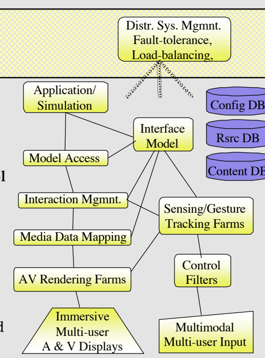
Multimodal multiuser **sensing/control** and tracking/mapping farms

Application = sensing/tracking policies + output data mappings

Presentation/interaction via CNSI Sphere, LAN/WAN streaming

Infrastructure uses CRAM mgmnt

DBs for configurations, resources, and media content (renderers)



Challenges to CRAM & DSCP

- True fault tolerance with off-the-shelf HW/OS
  - Robust node manager (emergency thread monitor/restart), TAO, SqVM
  - Debugging (LAN) network problems
- The plethora of protocols, IPv6, ATM, FireWire
- Performance and scalability issues
  - Node monitoring (<u>top</u>-ing)
  - Logging (capture)
  - Service creation, sync, init, restart

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Conclusions: Siren, CSL, and CRAM for DSCP

- For our requirements, we really had to start from scratch for most of the components.
- The KISS principle (or XP) paid off in simplicity, flexibility, and ease of use.
- There are many things we could have done other ways (we're still debating; that's the whole fun of it!).
- <u>We'll be installing DSCP in CNSI in 2005/6!</u>
- See create.ucsb.edu/{Siren, CSL, CRAM}

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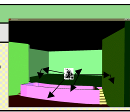
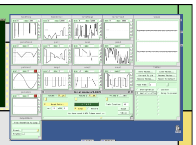
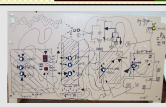
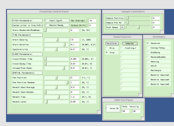
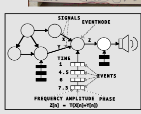
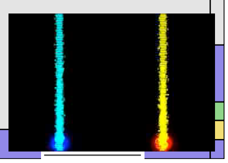
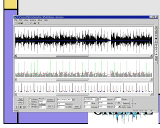
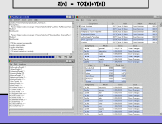
Related Projects at CREATE

- Auralizer & VRML
- Pulsar Generator
- Creatovox
- MusicVisualization
- FMAK DB
- TimeMachine
- InteractEMGroup
- Creatophone
- Time-DDecomp
- SC_3 Work

Recent Compositions (2000-03)

- *— Sensing/Speaking Space (pt. 2)*
  Interactivity, speech DB, spatialization
- *— Four Magic Sentences*
- *— Gates Still Open (2nd development)*
  Phrase grammars, DSP
- *— Eternal Dream (finale)*
  Large-scale form, speech DB, DSP
- *— Leur Songe de la Paix (1st/2nd mvmnt.)*
  DSP, structure-extraction, speech DB

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Demonstrations

- **Siren** models, GUI, sound tools, browsers, music representation, composition code
- **CSL** examples: instruments, client/server
- **EMA** mastering application, DB/DSP
- **CRAM** DPE manager and tools

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Thank You ! (Q & A)