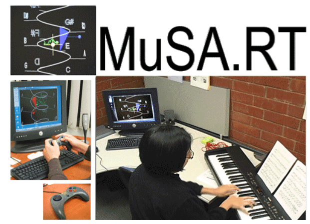
MuSA.RT and SAI

Data Stream Processing for Music and More

Alexandre R.J. François
afrancoi@usc.edu
http://iris.usc.edu/~afrancoi

Prelude

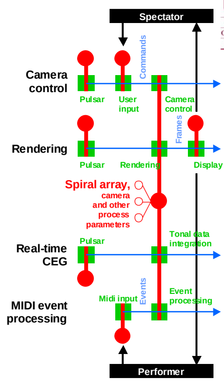
A system for real-time analysis and interactive visualization of tonal patterns in music



[MM2003]

From Algorithms to System

- Tonal analysis
  - Spiral Array model
  - CEG algorithms
- Input devices
  - MIDI keyboard
  - Gamepad
- Rendering
  - 3D graphics (OpenGL)
  - MIDI synthesizer



System Requirements

- Efficiency
  - Real-time processing: analysis, rendering, etc.
- High throughput
  - Interactive rendering
- Low latency
  - Immediate (perceived) reactivity
- Synchronization
  - Graphics and sound

Roadmap

- SAI
  - Software Architecture
  - The SAI style
  - Architectural properties
  - Architectural Middleware
  - Example designs
- MuSA.RT
  - Background and context
  - System design
  - Algorithms and implementation
  - System performance

SAI

Software Architecture for Immersipresence

Introduction

SAI is a software architecture model for designing, analyzing and implementing applications performing distributed, asynchronous parallel processing of generic data streams

Software Architecture

- The road from equations to software product
  - From algorithm to implementation-proof of concept
  - From proof of concept-test code to integrated systems
- Explicit system structure
  - Technical basis for design
  - Blue-prints for implementation
- Project management
  - Planning: cost estimation, resource allocation
  - Separation of concerns
- Question #1: what architectural style(s)?

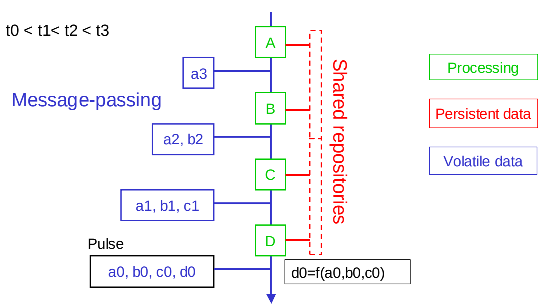
SAI Goal and Scope

- Framework for the design, analysis and implementation of complex software systems
- Hard performance constraints (throughput and latency)
- Distributed asynchronous parallel processing of generic data streams

Key Concepts in SAI

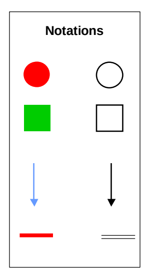
- Time
  - All data can be considered a data stream in time
  - Perceptual constraints: precedence and simultaneity
  - Explicit attribute of all data
- Data classes
  - Volatile: stream samples
  - Persistent: process parameters, dynamic structures
- Asynchronous parallelism

A Hybrid Model



The SAI Style

- Components
  - Sources: system states (shared memory)
  - Cells: processing (no state)
- Connectors
  - Cell-cell: volatile data samples (stream)
    - At most one upstream cell
    - Any number of downstream cells
  - Cell-source: persistent data access
    - A cell is connected to exactly one source
    - A source is connected to any number of cells
- Topological constraints
  - Active (stream): process dependency
  - Passive: concurrent access



[ICSE2003]

Data Model

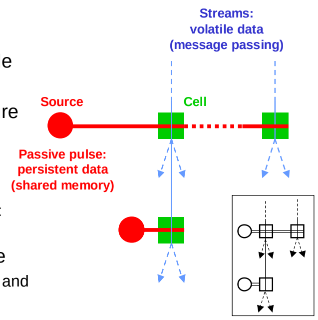
- Pulses
  - Synchronization structure (time stamp, duration)
  - Active: volatile, flow down stream connections
  - Passive: persistent (dynamic), held in sources
- Pulse is organized as a hierarchy of nodes
  - Nodes are atomic data units
  - Encode state and methods
- Extensible set of nodes
  - Specialized into data structures
  - Encapsulate existing ones (APIs and libraries)

Underlying Processing Model

- A cell processes incoming active pulses in separate threads (asynchronous model)
- Active pulse
  - Cell process may read and add to an active pulse
  - Concurrent read access
  - Strict message passing communication
- Passive pulse
  - Cell process may read and modify a passive pulse
  - Concurrent shared memory access (read/write)

Notation for Architectural Designs

- Levels of detail provide different views
- Conceptual architecture
  - Data streams
  - Cell functionalities
- Logical architecture
  - Component interfaces: nodes, cells
- Execution architecture
  - Explicit cell processes and data structures

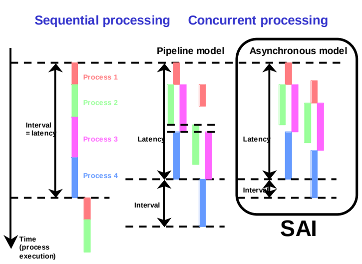


Architectural Properties

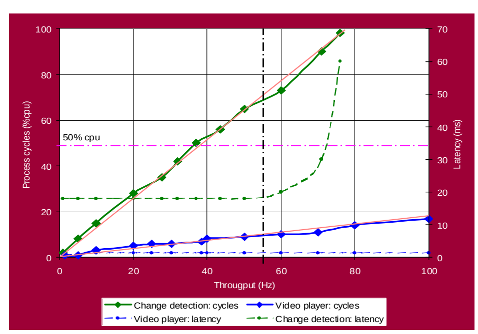
- Facilitates system design
  - Intuitive architectural style, preserve natural flow of data
  - Unified processing model and unified data model
  - Achievable optimality and scalability
- Facilitates distributed development, fast integration, code reusability
- Facilitates system maintenance, modification and evolution (change in algorithm and in function)
- Naturally support concurrent execution and distributed processing

Achievable Optimality

- Asynchronous parallel processing: decouple latency and throughput
- Optimal design (actual performance depends on implementation)



Scalability

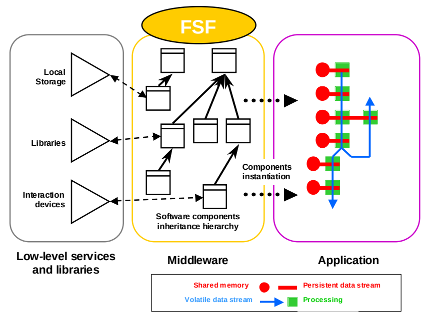


Architectural Middleware: MFSM

- Open source project
  - mfsm.SourceForge.net
  - C++(STL) / Windows
  - Multithreaded (assume fair scheduling)
- FSF Library: extensible set of classes that implement
  - All SAI style elements: source and cells* (connectors do not have an active role)
  - Related elements: nodes*, filters, handles; system, factories; node and cell specializations

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004   Alexandre R.J. Francois

Architecture Model Overview



ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004   Alexandre R.J. Francois

MFSM Pluses

- Modules: specializations that implement specific algorithms or functionalities
  - Video, MIDI, sound, graphics
  - Encapsulate existing libraries: Windows API, OpenGL, OpenCV, etc.
- Documentation and tutorials
  - User guide
  - Reference guide
  - Tutorials (Image, Video, etc.)

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004   Alexandre R.J. Francois

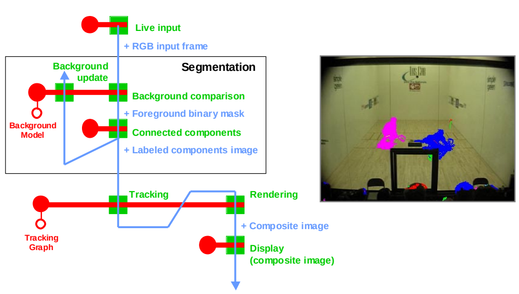
Example Designs

- From real-time computer vision to integrated, distributed interactive systems…
  - Real-time video segmentation and tracking (IRIS)
  - Video Painting (IRIS)
  - Handheld mirror simulation (IMSC)
  - Live video in animated 3-D graphics (IMSC)
  - IMSC Communicator (IMSC)
  - Distributed collaborative game (CS 599 – IMS)

[ETCV]
[IMSC-03-001]

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004   Alexandre R.J. Francois

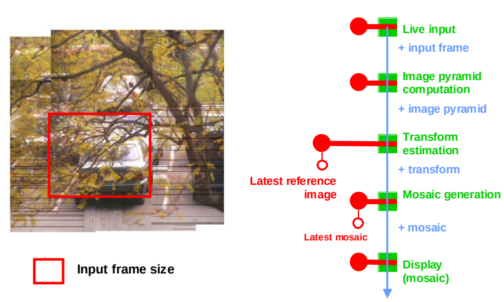
Real-Time Video Segmentation and Tracking



[ICVS2001]

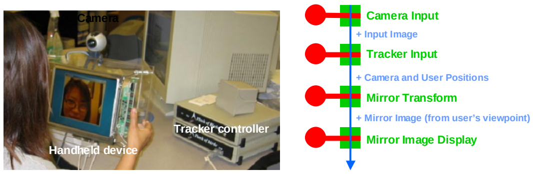
ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004   Alexandre R.J. Francois

Video Painting



ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004   Alexandre R.J. Francois

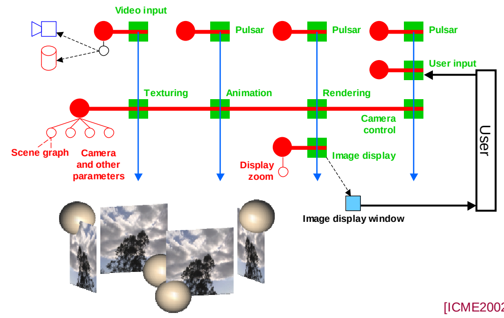
Handheld Mirror Simulation



[ICME2003]
[SIGGRAPH2002]

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

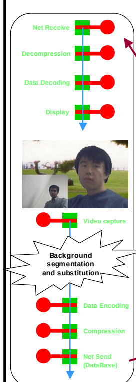
Live Video in Animated 3D Graphics



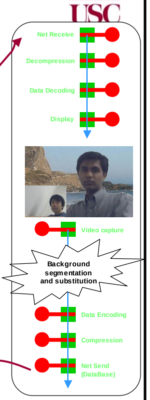
[ICME2002]

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

IMSC Communicator

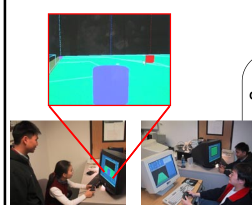


- Real-time 2-way video + voice communication
  - Encoding/Decoding
  - Compression/ Decompression
  - Synchronization
- Background substitution technology integrated
  - Fixed camera
- Beyond voice and image…

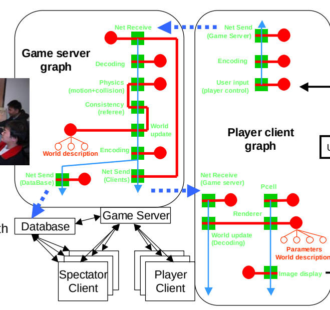


ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

Distributed Collaborative Game (class project)



- 25 students, 2 months
- Distributed development
- Real-time multiplayer gaming with database recording/replay



Course co-taught with R.Zimmermann

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

Summary

- SAI: software architecture for distributed parallel processing of data streams
  - Subsumes pipes and filters and shared repositories
  - Interaction, efficiency, scalability
- MFSM: open source architectural middleware
  - C++ / Windows
  - Use with existing libraries: OpenCV, DirectX, etc.
- Applications: Integrated Multimedia Systems
  - Cross-Disciplinary
  - Interactive

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

MuSA.RT

Music on the Spiral Array . Real-Time

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

Introduction

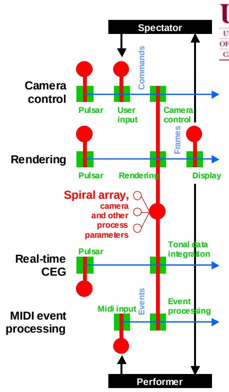
- Real-time analysis and interactive visualization of tonal patterns in music
- Analysis with the Spiral Array
  - MIDI input mapped to Spiral Array: pitch spelling
  - CE tracking: linear filter for memory decay
  - Chord and key tracking: nearest neighbor search
- Interactive visualization
  - Real-time rendering (OpenGL)
  - Camera control
  - Autopilot

Related Work

- MuSA.RT is the first system combining real-time music analysis and content-based, interactive 3D visualization of tonal structures
- Visualization:
  - Rubato (Garber,): off-line music analysis and performance rendering
  - Tonal Landscapes (Sapp,): off-line analysis and 2D color maps of tonal patterns
- Real-time system:
  - Continuator (Pachet,): music generation system, not multimedia (only sound)

System Design

- Main data repository
  - Spiral Array structure
  - Process parameters
- MIDI event processing
- Real-time CEG
- Rendering (+autopilot)
- Camera control
- 4 distinct streams

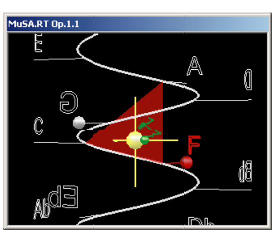


Tonal Analysis

- Use existing MIDI modules (data structures, input/output)
- Spiral Array structure
  - New custom node
- Pitch spelling
  - New custom cell
  - Map MIDI numbers to pitch classes on the pitch spiral
  - Use tonal context
- Real-time CE computation
  - New custom cell
  - Linear filter (low pass)
  - Track two distinct CEs with different memory decay to track chords and keys

Rendering

- Use existing OpenGL rendering module
  - White-box module: requires customization
- Visualization:
  - Spiral Array
  - Active triad
  - Chord CE trajectory
  - Active key
  - (Key CE trajectory)



Camera Control and Autopilot

- Camera control
  - Use existing game device module
  - Constrain camera position and view angle
- Autopilot
  - Camera position and orientation automatically computed
  - Smooth trajectory (linear filter)

Software Metrics

- Project size estimate: Software Line Of Code (SLOC)
- MuSA.RT specifics:
  - User interface (MFC) 691 (P) / 487 (L)
  - Custom cells and nodes
  - Exclude general purpose modules
- Only actual coding concerns algorithms and interface
  - FSF is non trivial to design and code!

SLOC	Physical	Logical
MuSA.RT Op.2	4784	3469
FSF	2817	2100
Total 1	7601	5569
MuSA.RT specific	3164	2380
Rendering adj.	441	397
Total 2	2723	1983
Gain (% Total 1)	4878 64%	3586 64%

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

System Performance

- Live demo on dual P4 2.8 GHz
- Throughput
  - Rendering: 640x480 @ 25-30Hz
  - Analysis: 30Hz
  - Gamepad sampling 30Hz
- Latency
  - "Looks" immediate
  - Actual measurements: work in progress…
- Possible bottlenecks: MIDI event density, graphics subsystem

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

Chord and Key Tracking Performance

- Live demo…

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

Summary

- First system combining real-time music analysis and content-based, interactive 3D visualization of tonal structures
- Collaborative cross-disciplinary project
  - Integration challenge
  - Hard performance constraints (interaction)
- Designed with SAI, implemented with MFSM
  - Clear, well-defined modular design
  - Reduced coding volume and time (and difficulty!)
  - System performance constraints satisfied
  - Easy maintenance and evolution

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois

Perspectives

- Key and chord tracking methods
- Audio input

- Visualization
- Interaction modalities

- Use as model for larger scale integration experiments

ISE599 Engineering Approaches to Music Perception and Cognition – Spring 2004 Alexandre R.J. Francois