Foundations of Hybrid and Embedded Software and Systems

University of California, Berkeley, CHESS
Vanderbilt University, ISIS
Memphis State, Mathematics

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INSTITUTE FOR SOFTWARE INTEGRATED SYSTEMS

Mathematics & Statistics

NSF-ITR Investigators

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George Necula, Alberto Sangiovanni Vincentelli, Shankar Sastry, Janos Sztipanovits, Pravin Varaiya.

ITR-Center Mission

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- **The goal of the ITR is to provide an environment for graduate research on the design issues necessary for supporting next-generation embedded software systems.**
  - The research focus is on developing model-based and tool-supported design methodologies for real-time fault-tolerant software on heterogeneous distributed platforms.
- **The Center maintains a close interaction between academic research and industrial experience.**
  - A main objective is to facilitate the creation and transfer of modern, "new economy" software technology methods and tools to "old economy" market sectors in which embedded software plays an increasingly central role, such as aerospace, automotive, and consumer electronics.

Key Properties of Hybrid & Embedded Software Systems

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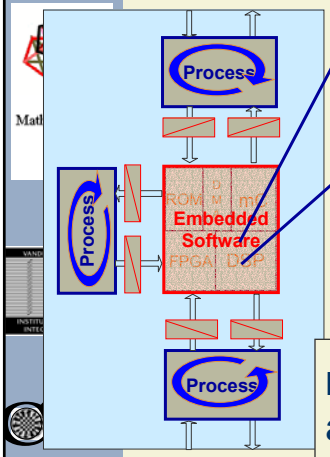
- **Computational systems**
  - but not first-and-foremost a computer
- **Integral with physical processes**
  - sensors, actuators
- **Reactive**
  - at the speed of the environment
- **Heterogeneous**
  - hardware/software, mixed architectures
- **Networked**
  - adaptive software, shared data, resource discovery

The Embedded Software Challenge



Problem indicators:
- Integration cost is too high (40-50%)
- Cost of change is too high
- Design productivity crisis

Root cause of problems is the emerging new role of embedded software systems:
- exploding integration role
- new functionalities
- expected source of flexibility in systems

PROBLEM: lack of Design Technology aligned with the new role.

Embedded Software: Today's Techniques Won't Do

Largely missing:
- Abstraction (especially time)
- Compositionality
- Inheritance & polymorphism
- Portability & reusability
- Connectivity
- Verifiability & reliability
- Robustness

Project Approach

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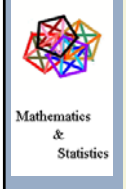
- **Model-Based Design (the view from above)**
  - principled frameworks for design
  - merging specification, modeling, and design
  - manipulable (mathematical) models
  - enabling analysis and verification
  - enabling effective synthesis of implementations
- **Platform-Based Design (the view from below)**
  - exposing key resource limitations
  - hiding inessential implementation details
- **Tools**
  - concrete realizations of design methods

Foundational Research



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- **The science of computation has systematically abstracted away the physical world. The science of physical systems has systematically ignored computational limitations.**
  Embedded software systems, however, engage the physical world in a computational manner.
- **We believe that it is time to construct an Integrated Systems Science (ISS) that is simultaneously computational and physical.**
  Time, concurrency, robustness, continuums, and resource management must be remarried to computation.
- Mathematical foundation: **Hybrid Systems Theory: Modern Integrated Systems Science.**

… and Embedded Software Research

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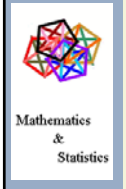
- Models and Tools:
  - Model-based design (platforms, interfaces, meta-models, virtual machines, abstract syntax and semantics, etc.)
  - Tool-supported design (simulation, verification, code generation, inter-operability, etc.)
- Applications:
  - Flight control systems
  - Automotive electronics
  - National experimental embedded software platform
- From resource-driven to requirements-driven embedded software development.

Some Current Research Focus Areas



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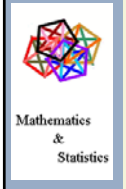
- Software architectures for actor-oriented design
- Interface theories for component-based design
- Virtual machines for embedded software
- Semantic models for time and concurrency
- Design transformation technology (code generation)
- Visual syntaxes for design
- Model checking hybrid systems
- Autonomous helicopters
- Automotive systems design

- Mobies
- SEC
- Fresco
- Ptolemy
- Metropolis
- BEAR

"Center" Organization

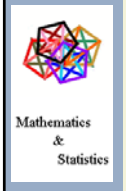
- **Funding Sources**
  - Large NSF ITR
  - Other federal (NSF, DARPA, MURI, etc.)
  - Industrial (Participating Member Companies): IT and applications (automotive, aerospace, consumer electronics)
- **Outreach**
  - Curriculum development
  - Community colleges (EECS 20)
  - SUPERB program
  - SIPHER program
- **National Experimental Platform for Hybrid and Embedded Systems and Software**

NSF ITR Organization



- **PI:** Shankar Sastry
- **coPIs:** Tom Henzinger, Edward Lee, Alberto Sangiovanni-Vincentelli, Janos Sztipanovits
- **Participating Institutions:** UCB, Vanderbilt, Memphis State
- **Five Thrusts:**
  - Hybrid Systems Theory (Henzinger)
  - Model-Based Design (Sztipanovits)
  - Tool-Supported Architectures (Lee)
  - Experimental Applications: automotive (ASV), aerospace (Sastry)
  - Education and Outreach (Karsai, Lee, Varaiya)
- **Five year project:** kick-off meeting November 14, 2002
  - Run up planning: development of cooperative agreement
  - Weekly seminar series

Thrust 1 Hybrid Systems



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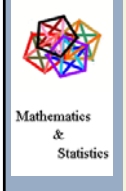
- **Deep Compositionality**
  - Assume Guarantee Reasoning for Hybrid Systems
  - Practical Hybrid System Modeling Language
  - Interface Theory for hybrid components
- **Robust Hybrid Systems**
  - Bundle Properties for hybrid systems
  - Topologies for hybrid systems
  - Stochastic hybrid systems
- **Computational hybrid systems**
  - Approximation techniques for H-J equations
  - Synthesis of safe and live controllers for hybrid systems
- **Phase Transitions**

Thrust II: Model Based Design



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- **Composition of Domain Specific Modeling Languages**
  - Meta Modeling
  - Components to manipulate meta-models
  - Integration of meta-modeling with hybrid systems
- **Modal Synthesis Using Design Patterns**
  - Pattern Based Modal Synthesis
  - Models of Computation
  - Design Constraints and Patterns for MMOC
- **Model Transformation**
  - Meta Generators
  - Scalable Models
  - Construction of Embeddable Generators

Thrust III:Advanced Tool Architectures

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- **Syntax and Synthesis**
  - Semantic Composition
  - Visual Concrete Syntaxes
  - Modal Models
- **Interface Theories**
- **Virtual Machine Architectures**
- **Components for Embedded Systems**

Thrust IV: Applications

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- **Embedded Control Systems**
  - Avionics
  - Veitronics
  - Wireless Embedded Systems
- **Embedded Systems for National/Homeland Security**
  - Air Traffic Control
  - UAVs/UGVs
- **Networks of Distributed Sensors**
- **Hybrid Models in Structural Engineering**
  - Active Noise Control
  - Vibration damping of complex structures

Thrust V: Education and Outreach

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- **Curriculum Development for MSS**
  - Lower Division
  - Upper Division
  - Graduate Courses
- **Undergrad Course Insertion and Transfer**
  - Goals and ABET requirement
  - New courses for partner institutions
  - Introduction of new courses
  - New elective courses
  - Expansion of SUPERB program
- **Summer Internship Program in Embedded Software Research (SIPHER)**

Management Plan

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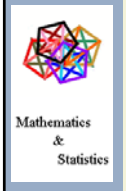
- **Executive Board (Pis and co-Pis)**
- **Thrust Leaders**
  - Hybrid Systems: Henzinger
  - Model Based Tool Design: Sztipanovits
  - Integrated Tool Architectures: Lee
  - Applications: Sangiovanni-Vincentelli
  - Education: Lee, Varaiya
  - Outreach: Karsai, Williams
- **Scientific Advisory Board**
  - Industry
  - NSF and Darpa PMs
  - Other Academia: Stanford, Penn, CMU, Artiste

Success Metrics



- Research
  - Model Based Design Methodologies
  - Open Source Tools
  - National Security
  - Homeland Security
- Education
  - Undergrad + SUPERB
  - Graduate
  - Outreach to Community Colleges
  - Outreach to Research
- Industry Outreach
  - NEPHEST
  - Avionics
  - Veitronics
  - Consumer Electronics