Embedded Software: Opportunities and Challenges

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Approved for public release.
Evolution of Avionics Systems:

**1958**
- Independent Avionics
  - Functionally Integrated Data Processing
  - Aircraft-Centric Operation
  - Crew-Dominated Operation

**1950’s - 60’s**
- DEDICATED SUBSYSTEMS
  - Digital Fire Control/NAV
  - PT-PT Wiring
  - Mechanically Controlled Sensors/FLT Controls/Displays
  - Crew-Dominated Operation
  - Radar
  - Comm
  - EW

**1970’s - 80’s**
- FEDERATED SUBSYSTEMS
  - Functionally Integrated Data Processing
  - Flight Control
  - Beam Steering Sensors
  - Fly By Wire
  - Dedicated Digital Processing
  - Crew-Assisted Operations
  - Weapon Delivery
    - Weapon Delivery
    - Automated TF/TA
    - EW Response

**1990’s - 00’s**
- INTEGRATED SYSTEMS
  - Aircraft-Wide Information Integration
    - Sensors/Stores/Vehicle/Propulsion
    - Modular Electronics
    - Massive Data Bases
      - Terrain, Threat
    - Digital Sensor Processing
      - Sensor Fusion
      - Hyperspectral Imaging
    - Integrated Diagnostics/
      - System Fault Tolerance
    - System Data Security
    - Limited UAV Autonomy

**2000**
- Advanced Avionics
  - SYSTEM of SYSTEMS
    - Platform Exploitation of Global Information
    - Information Mining
    - At-A-Distance Reconfiguration
    - Autonomous Vehicle Emphasis
    - Air & Space
    - Air Crew/ Ground Crew Monitoring & Management
    - Automated Functions
      - ATR (Multi-Sensor)
      - Failure Prognostics
      - Route/ Sensor/ Weapon/ Vehicle Coordination
      - Bistatic Sensing
        (Air/ Space)
      - Threat Evasion

Embedded Software: Depth of Impact

Source: AFRL
Embedded Software: Breadth of Impact

- **DoD (from avionics to micro-robots)**
  - Essential source of new capabilities
  - Largest, most complex systems

- **Automotive (drive-by-wire)**
  - Key competitive element in the future
  - Increasing interest but low risk taking

- **Consumer Electronics (from mobile phones to TVs)**
  - Problem is generally simpler
  - US industry is strongly challenged

- **Plant Automation Systems**
  - Limited market growth, conservative approach
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Theme 1: Physicality

Embedded software: defines physical behavior of a complex nonlinear device

Embedded System: a physical process with dynamic, fault, noise, reliability, power, size characteristics
Embedded Software: designed to meet required physical characteristics

Primary challenge: How to design software to achieve required physical behavior?
Interactions, interactions,…

Controller Dynamics

- Digital Controller → D/A S/H → Power Amp. → Plant and Sensors → A/D

Embedded Software

- App-1 → Lib-1 → Kernel/Services/Hardware
- App-2 → Lib-2 → Kernel/Services/Hardware
- App-3 → Lib-3 → Kernel/Services/Hardware

- control law
- tolerated error, stability
- sampling rate
- limit-cycle oscillation
- loop delay
- noise

- HW/SW architecture
- Data types selection
- Scheduling policy,…
- Numeric accuracy
- Latency
- Jitter
Why Is this a Problem?

We have focused on functional composition...

**Composability**: Ability to link subsystems so that properties established at subsystem levels hold at the system level

But cross-cutting physical constraints weaken or destroy composability
Theme 2: Constraints and Change

Source of change: environment, requirements

Hard Problem: system-wide constraints accumulate in software

Effects of changes need to propagated by tracking constraints

Flexibility is essentially a SYSTEM-WIDE CONSTRAINT MANAGEMENT PROBLEM
Theme 3: Dealing With Dynamic Structures

A new category of systems:

Embedding +
Distribution +
Coordination

LARGE number of tightly integrated, spatially distributed physical and information system components with reconfigurable interconnection.

Why should we work on this?
• Tremendous progress in MEMS, photonics, communication technology: we need to build systems now from these.
• Identified applications with very high ROI: strong application pull
• Almost total lack of design theory technology: the problem is extremely hard.
Networked Embedded Systems: Examples

MEMS Actuators for Vortex Control (UCLA, CalTech)
- Number of nodes: $10^4$
- Loop frequency: 1 KHz
- Coordination frequency: 10Hz
- Geometric size: 30m

Pico Satellite Constellations (Aerospace Corporation)
- Number of nodes: $10^2 - 10^3$
- Loop frequency: 1-2 KHz
- Coordination frequency: 1Hz
- Geometric size: 1-1000km

Unified Processing Network For Avionics
- Processing nodes: > $3 \times 10^3$
- Link Bandwidth: 2GHz
- Aggregate Bandwidth: >$10^{12}$
- Industry Standard Protocol
**Need: Middleware for Coordination and Distribution**

**Model:** Locally and globally relevant information for global coordination

**Reasoner/Adapter:** Adaptation of local structure and parameters, coordination

**Controller:** Discrete or hybrid control of local physics

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**Distribution:**
- heterogeneous, simple components (10^2-10^5)
- changing interconnection topology
- **embedded synthesis** for dynamic distribution, reconfiguration

**Coordination:**
- global **coordination** of local interactions
- consistency of globally relevant information
- requirements are determined by locality of physics

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1. Software Enabled Control  
   FY99-03
2. Model-Based Integration of Embedded Software  
   FY00-04
3. Program Composition of Embedded Software  
   FY00-04
4. Networked Embedded Software Technology  
   FY01-05
One of the fundamentally new, tremendously expanding areas of computing.

(a) No matter which walk of life you choose, you end up writing software…
(b) No matter how great computer scientist you are - if you do embedded software – you will not get away without learning physics and engineering.

Answering the challenges requires nothing less than the re-integration of physical and information sciences.
Thematic Areas for ITO

- Embedded Systems
- High Confidence Systems and Software
- Internet Strategic Computing
- Human Computer Interfaces
- Augmented Cognition
- Information Substrates
- Dynamical Systems
- Computational Substrates
- Biological, Quantum, Mems, Smart Fabric
- High-Speed Networking, Pervasive, Heterogeneous Computing

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