Embedded Software: Opportunities and Challenges

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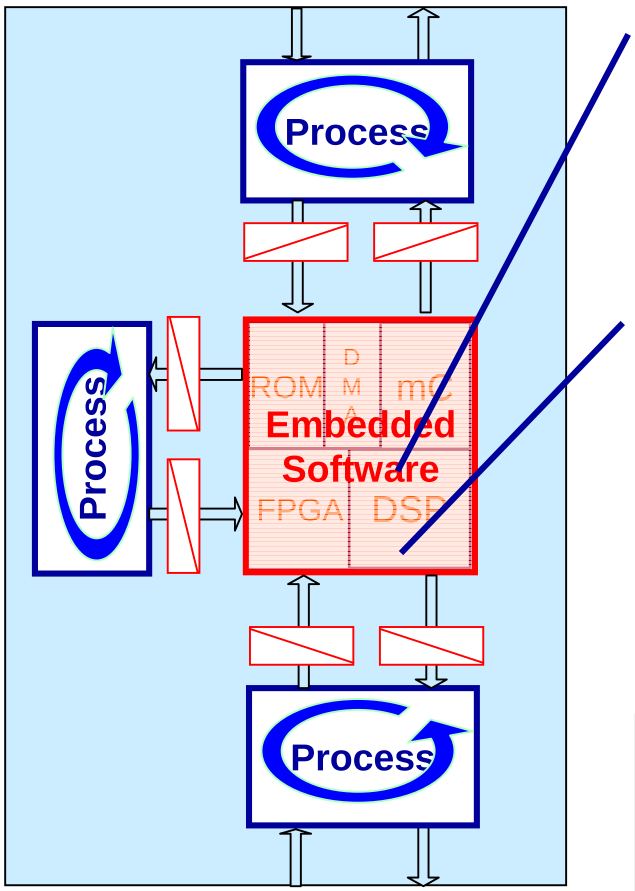
The Technology Challenge

Embedded systems: Information systems tightly integrated with physical processes



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

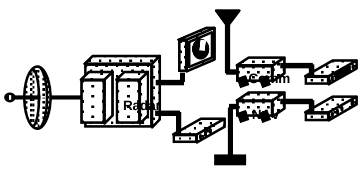
Root cause of problems is the emerging new role of embedded information systems:
- **Exploding integration role**
- **New functionalities that cannot be implemented otherwise**
- **Expected source of flexibility in systems**

Problem: **Lack of design technology aligned with the new role**

Problem for Whom?

- ***DoD (from avionics to micro-robots)***
  - *Essential source of superiority*
  - *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, conservative approach*

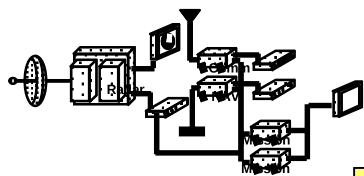
DoD Example: Avionics Systems



Independent Avionics 64 KB

DEDICATED SUBSYSTEMS

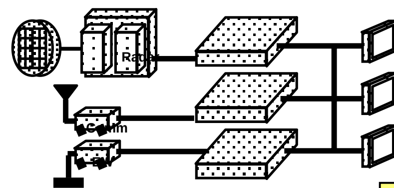
- •Digital Fire Control/NAV
- •PT-PT Wiring
- •Mechanically Controlled Sensors/FLT Controls/ Displays
- •Crew-Dominated Operation



Federated Avionics 1 MB

FEDERATED SUBSYSTEMS

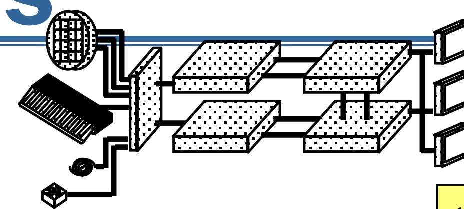
- •Functionally Integrated Data Processing
  - -NAV/WD/Air Data Sensors
  - -Flight Control
- •Beam Steering Sensors
- •Fly By Wire
- •Dedicated Digital Processing
- •Crew-Assisted Operations
  - - Weapon Delivery
  - - Automated TF/TA
  - - EW Response



Integrated Avionics 100 MB

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



Advanced Avionics 1 GB

SYSTEM of SYSTEMS

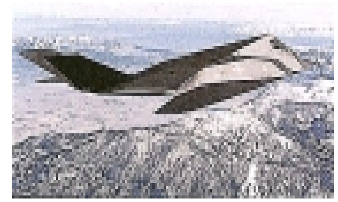
- •Platform Exploitation of Global Information
  - - Information Mining
  - - At-A-Distance Reconfiguration
- •Autonomous Vehicle Emphasis
  - - Air & Space
- •Air Crew/ Ground Crew Monitoring & Management
- •Automated Functions
  - - ATR (Multi-Sensor)
  - - Failure Prognostics
  - - Route/ Sensor/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

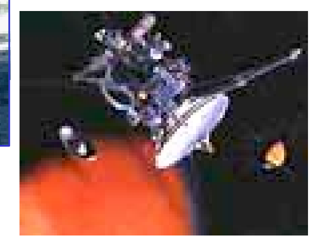
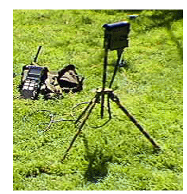
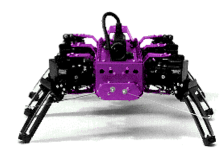
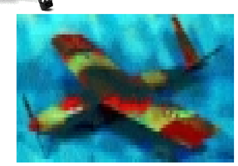
1958 **1950's - 60's** **1970's - 80's** **1990's - 00's** **2000 →**

Source: AFRL

Technology Themes

- **Software and Physics**
  - Establish composability in SW for physical characteristics; System/software co-design and co-simulation environments; New methods for system/code composition
- **Embracing Change**
  - Adaptive Component Technology; Adaptable composition frameworks; QoS middleware for embedded systems
- **Dealing with Dynamic Structures**
  - Property prediction without assuming static structures; Monitoring, controlling and diagnosing variable structure systems.

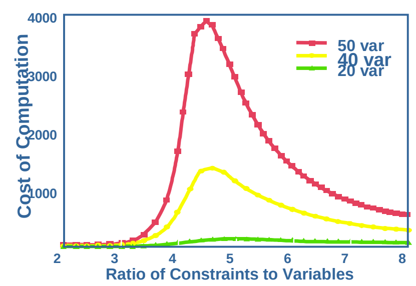


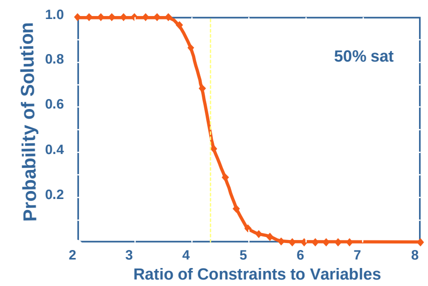






Why Can We Make a Difference?

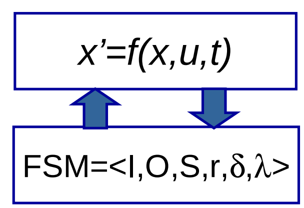
New, critical insights in fundamentals:

Phase transitions have been found in computational requirements for solving fundamental "intractable" problems.



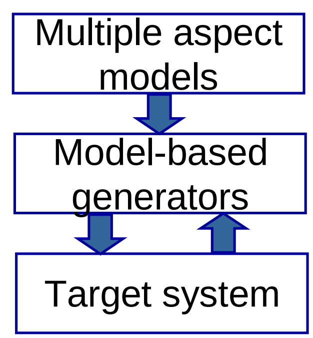


Emerging theory of hybrid systems provides a new mathematical foundation for the design and verification of embedded systems



- Model checking
- Compositional synthesis
- Simulation

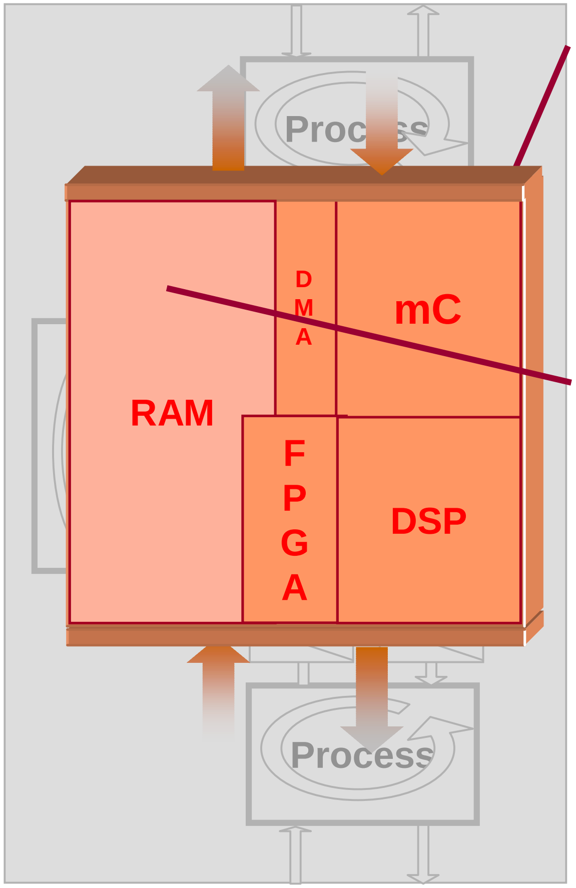
Revolutionary changes in software creation: Model-based generators, aspect languages, DSL-s offer new foundation for design automation and adaptation.



- Formal modeling
- Verification tools
- Automated code synthesis

Theme 1:
Software and Physics

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

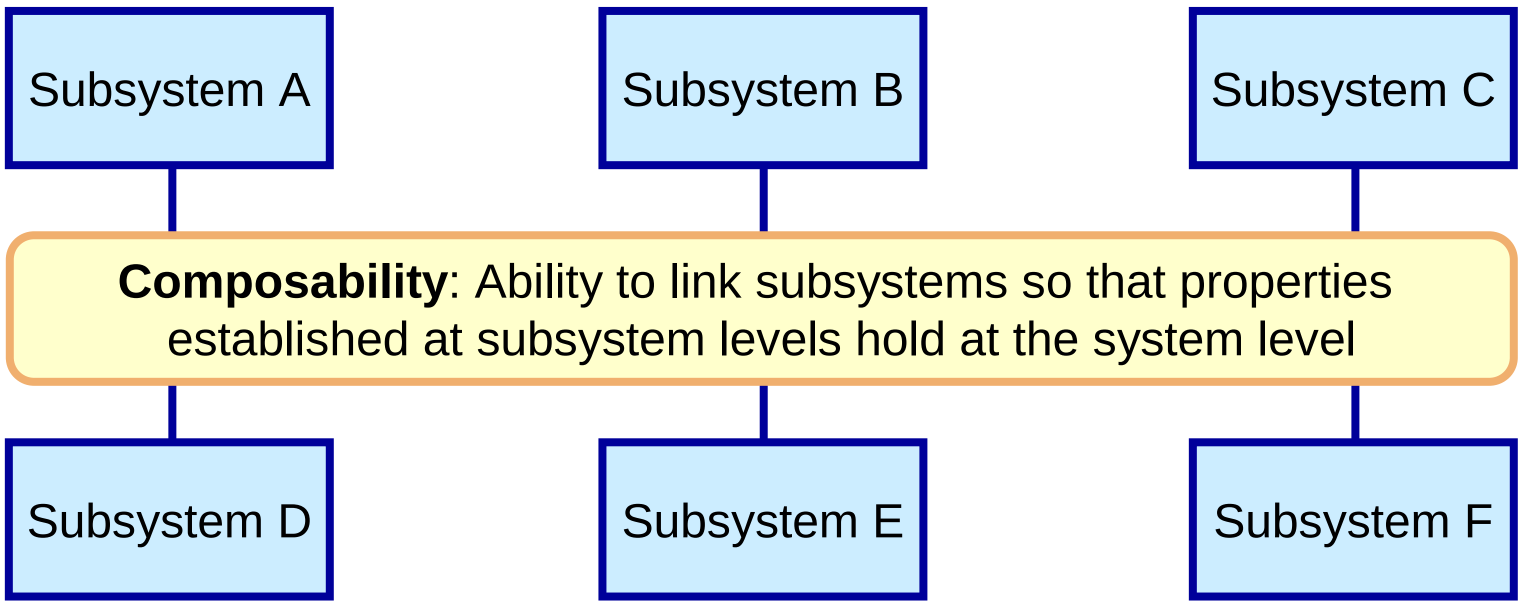
Hard Design Problem:

- Both continuous and discrete attributes (a lot)
- Every module has impact on many attributes (throughput, latency, jitter, power dissipation,..)
- Modules contend for shared resources
- Very large-scale, continuous-discrete, multi-attribute, densely-connected optimization problem

Primary challenge: Cost-cutting physical constraints destroy composability

Why Is this a Problem?

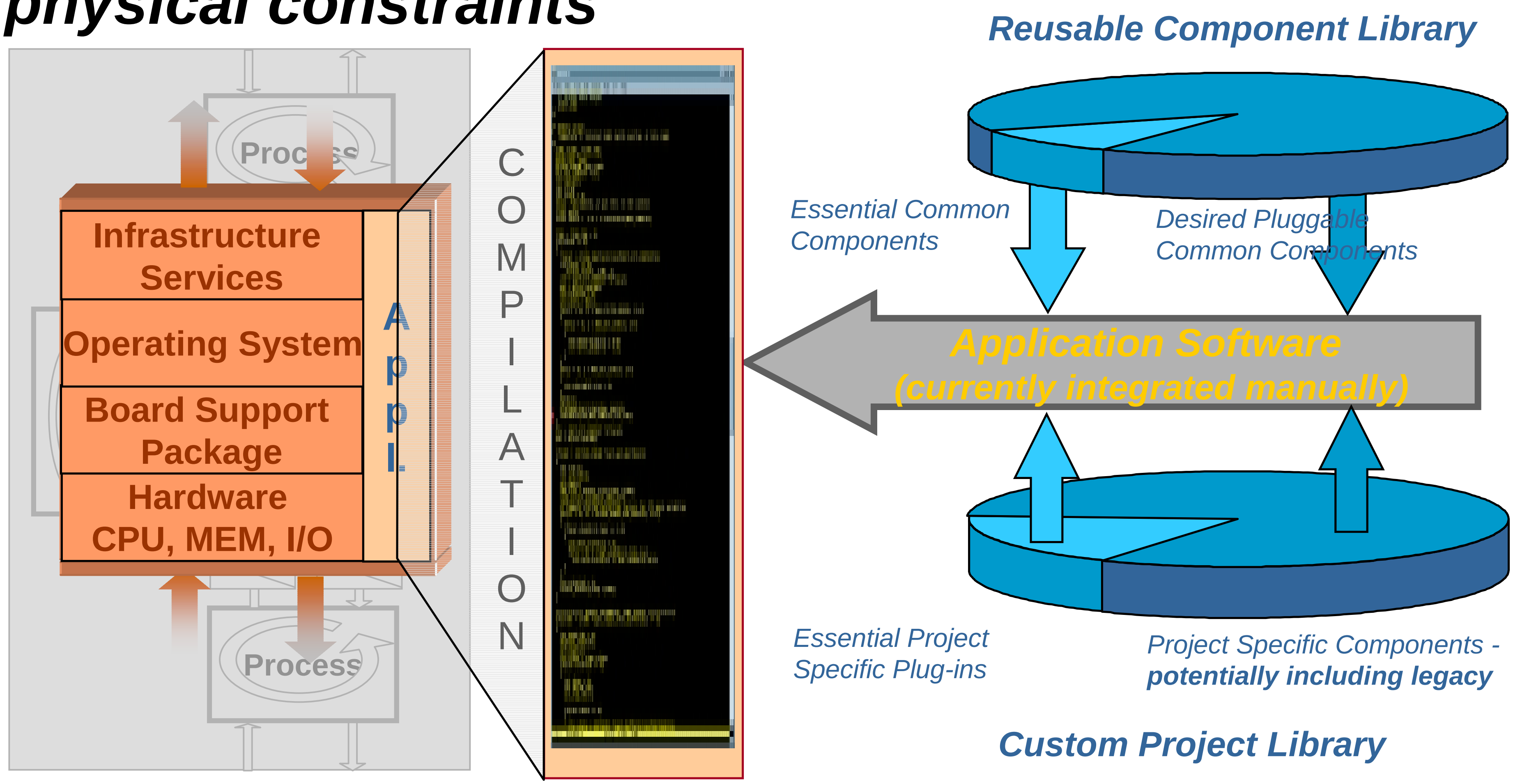
We have focused on functional composition...



But cross-cutting physical constraints weaken or destroy composability

Current Technology:
Functional Composition

Functional composition does not addresses physical constraints



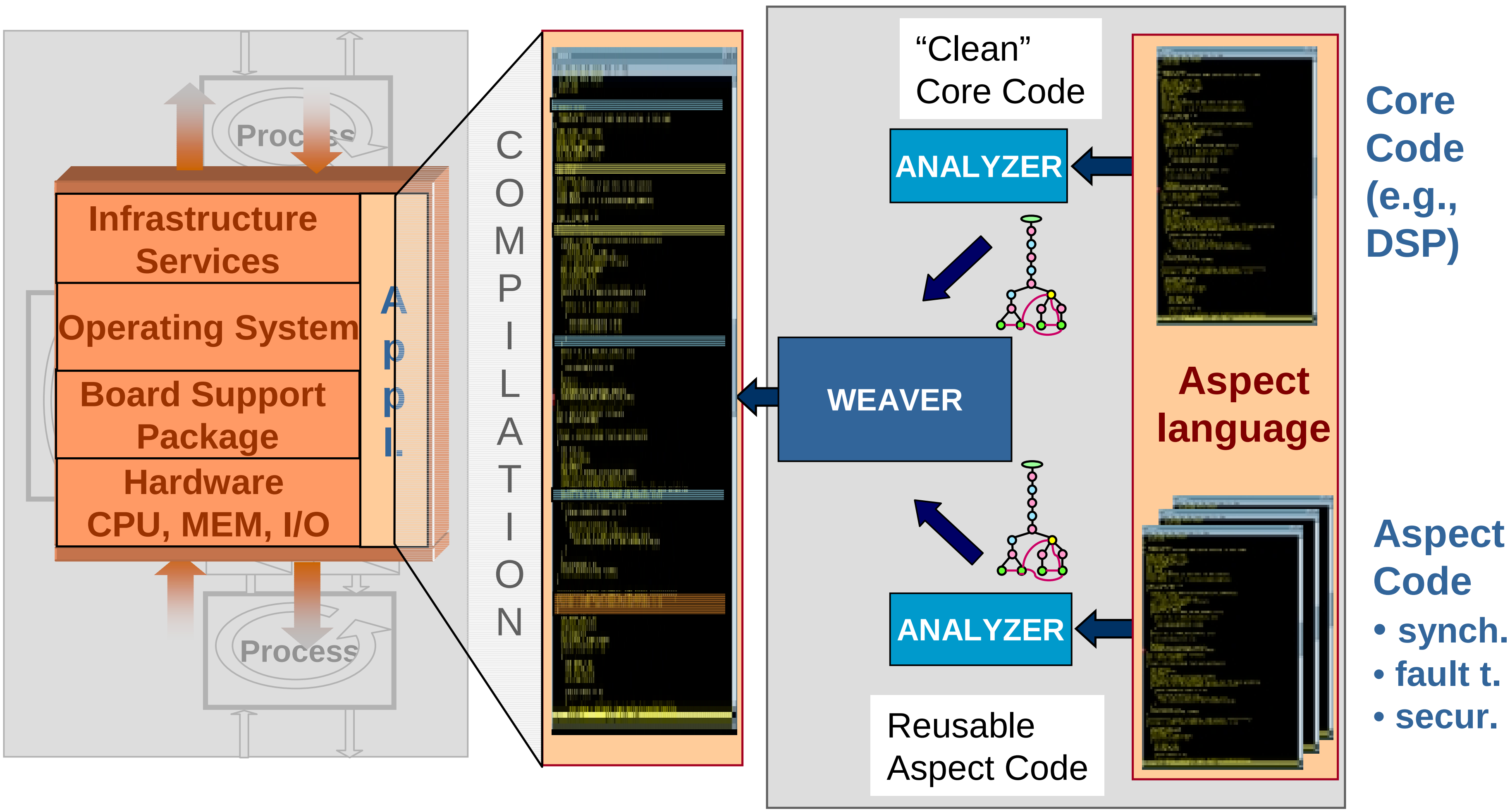
Goal: Design Automation Tools for Embedded Systems

- **Compose model-based design frameworks:**
  - Use existing CAD, EDA, CASE and systems Engineering frameworks as seeds
  - Add customizable design views and notations
  - Provide multi-resolution simulation
  - Add automated analysis and system/software synthesis

- **Capabilities:**
  - Co-evolve **integrated** physical and information system **MODELS**
  - **Synthesize/customize** software and system components **directly from models**
  - Establish **composability for physical behavior**

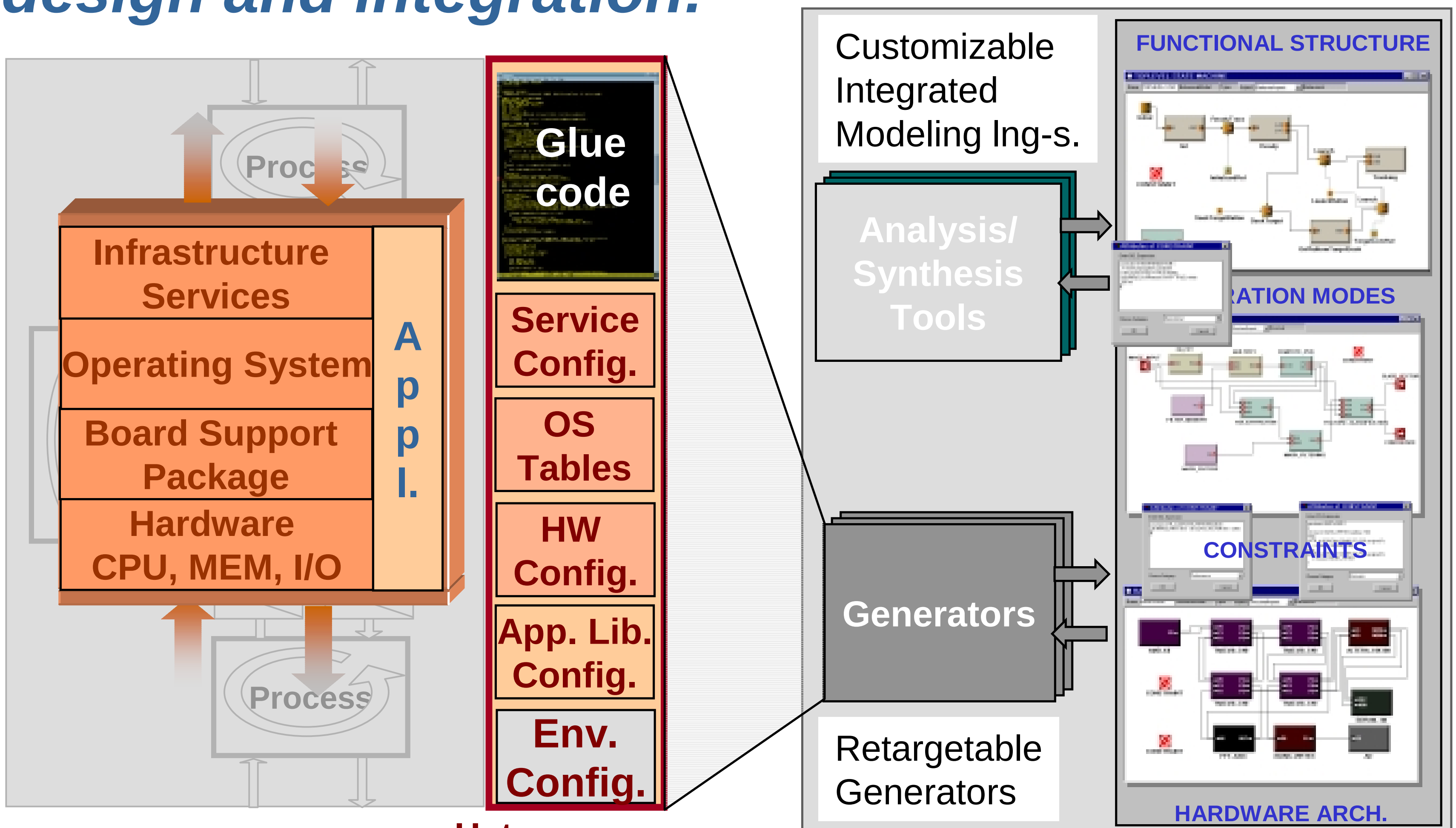
ITO: Program Composition for Embedded Systems (PCES)

Aspect languages will change programming:



ITO: Model-Based Integration of Embedded Software (MoBIES)

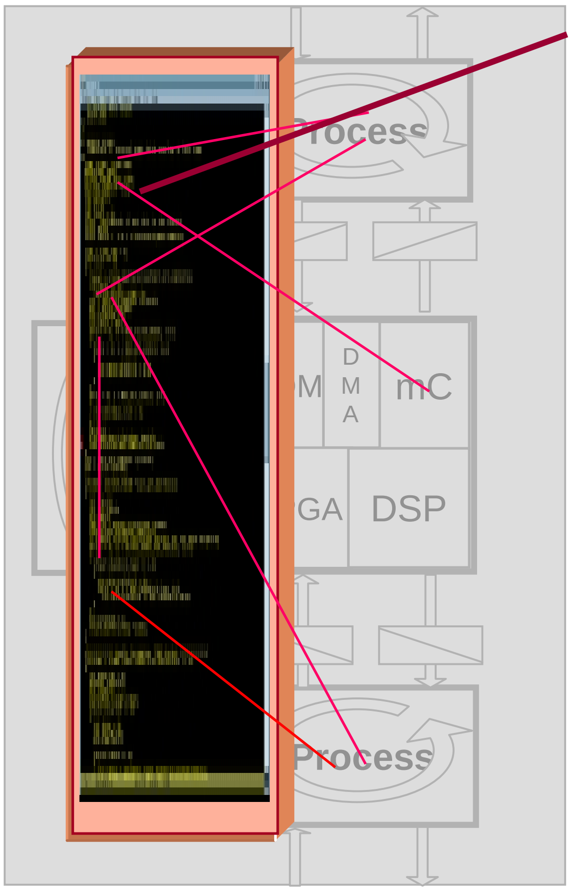
Model-based integration will change system design and integration:



Heterogeneous Customization Interface

Theme 2: Embracing Change

Source of change: environment, requirements



Hard Problem: **Due to its integration role, system-wide constraints accumulate in software:**
- **Process properties - algorithms, speed, data types**
- **Algorithms, speed, data types - resource needs**
- **Shared resources - speed, jitter,..**

..scattered all over the software.

Condition for managing change:
- **Constraints need to be explicitly represented**
- **Effects of changes need to propagated by tracking constraints**

Flexibility is essentially a
SYSTEM-WIDE CONSTRAINT MANAGEMENT PROBLEM

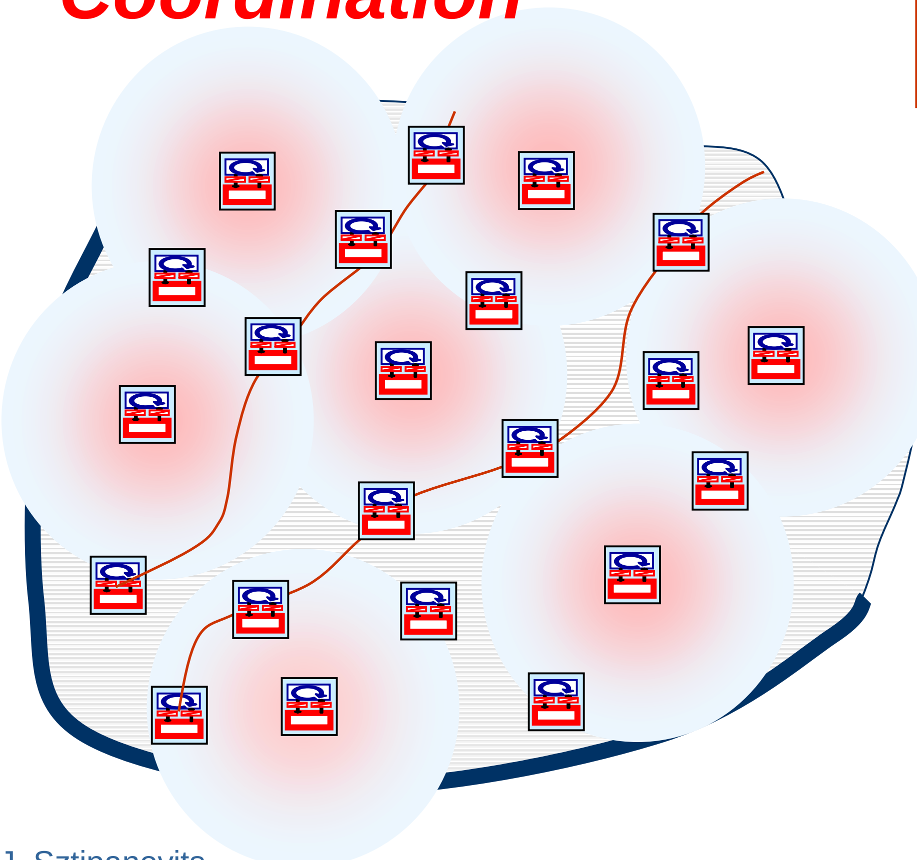
Goal: Adaptive Component Technology for Embedded SW

- **Builds on object component technology (CORBA, COM) but provides:**
  - Internal mechanisms to respond to changes
  - Physically and computationally "self-aware" components
- **Capabilities:**
  - Insulates software from hardware with small performance penalty
  - Increases tolerance to unexpected changes
  - Optimizes performance
  - Increases tolerance to faults

Theme 3: Dealing With Dynamic Structures

A new category of systems:

Embedding +
Distribution +
Coordination

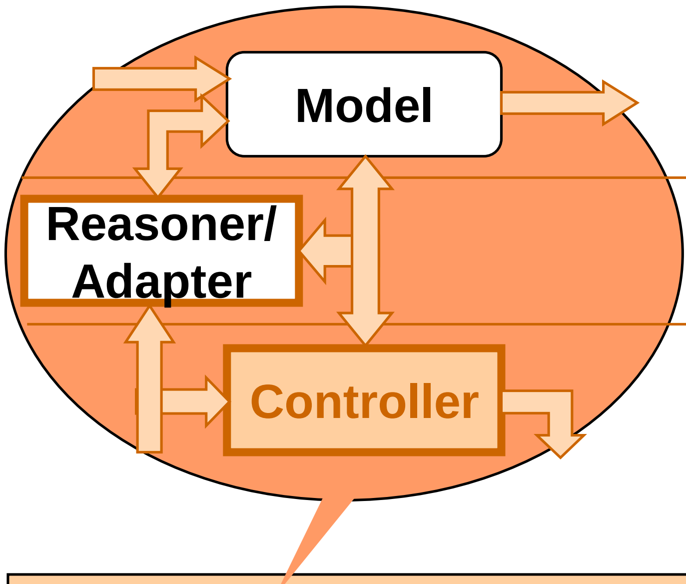


LARGE number of tightly integrated, spaciously and temporarily distributed physical/information system components with reconfigurable interconnection.

Why should we work on this?
The wave is coming:

- 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.**

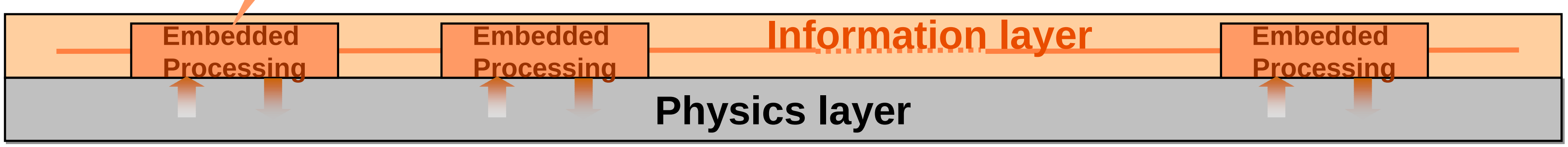
Problem Abstraction



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



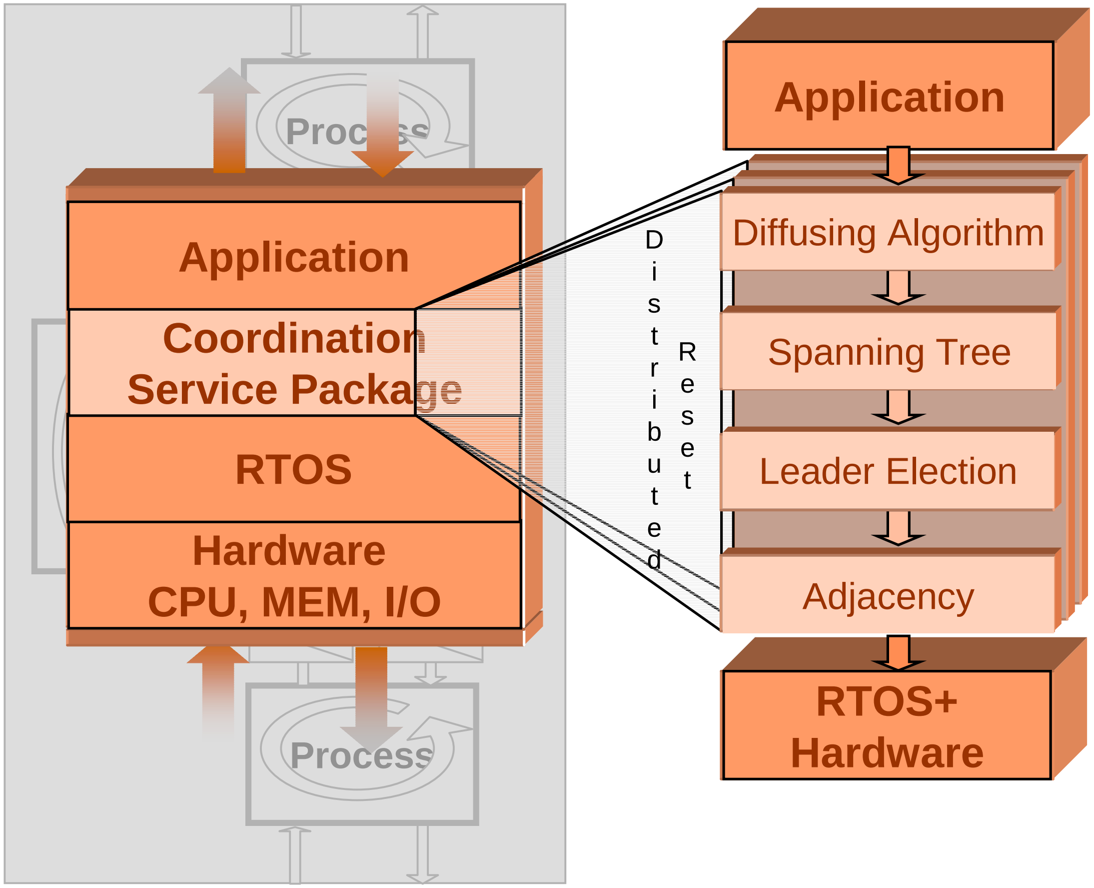
Distribution:

- 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

Goal: Services for Coordination



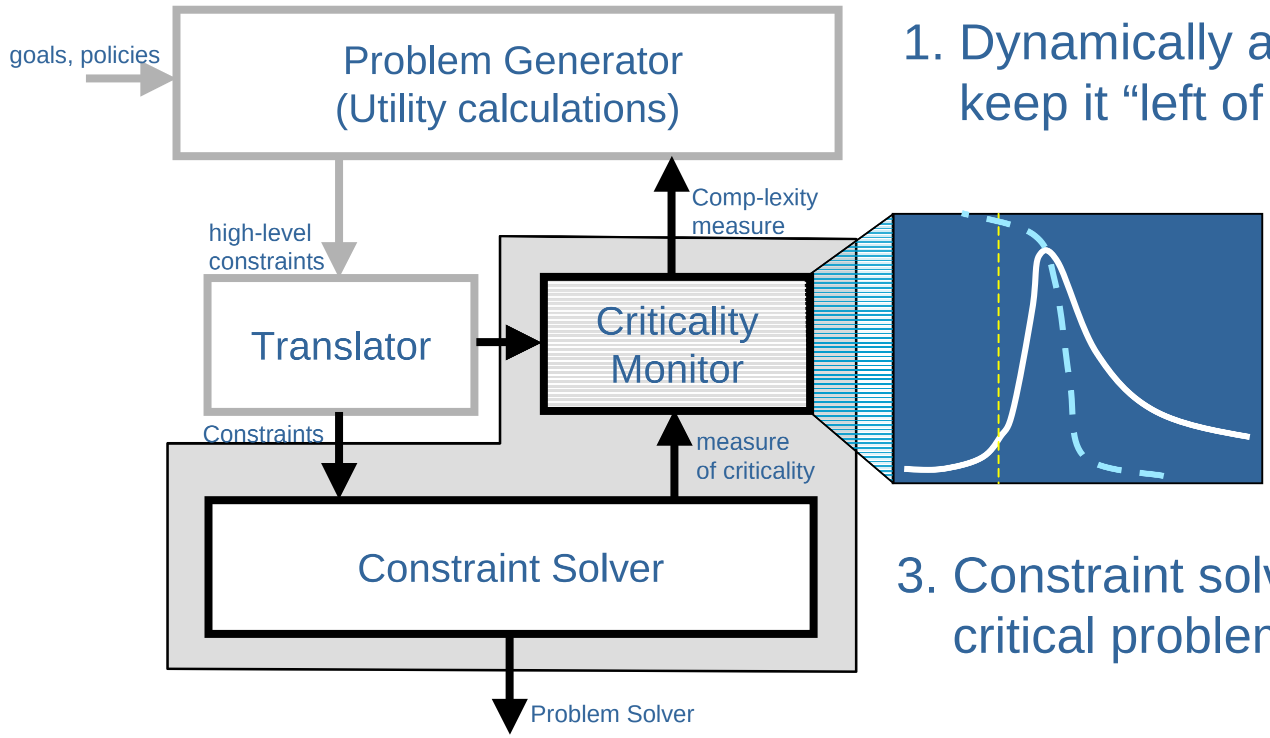
- Applications determine the type of services required
- Physical characteristics of the system determine dynamics, accuracy and required fault behavior of services
- Services are built in layers with rich interdependence
- Algorithms used in components depend on the distributed computation model

Hard Problems: Hybrid self-stabilization, customizable design, predictable dynamics, time bounded synthesis, automated composition.

Approach to Synthesis Services

Approach: Transition-aware, sub critical problem solver

Challenge: Problem statistics, order parameter.



1. Dynamically adjust the problem to keep it "left of the phase transition".
2. Criticality monitor gives assessment of problem complexity using simple analysis methods.
3. Constraint solver rapidly solves sub-critical problem instances.

What Are We Doing?

Software and Physics

- System/Software co-[design,simulation, analysis]--
- New methods for system/code composition----------
- Frameworks and middleware for embedded SW---
- Hybrid optimization,analysis-----------------------------

Embracing Change

- Adaptive components for embedded systems-------
- Methods for controlling flexibility------------------------
- Adaptable frameworks and QoS middleware-------
- Programming methods to achieve flexibility----------

Networked Embedded Systems

- Predicting global properties from local component descriptions without assuming static structures---
- Monitoring, controlling and diagnosing of variable structure hybrid systems----------------------------------
- Dynamic composition frameworks and middleware for networked embedded systems---------------------
- Controlling physical, chemical and biological properties via embedded information processing---

Relevant existing programs: (MoBIES, PCES, SEC)

- Coordinate efforts
- Leverage to increase common technology base
- Primary impact on Themes 1-2

New-start program:

- **Networked Embedded Systems Technology (NEST)**

Planned program:

- Adaptive and Reflective Middleware Systems

Conclusion

- **Embedded Software is an important area for DARPA due to the exploding integration role of information technology across military platforms.**
- **Existing and planned programs establish a new re-integration of physical and information sciences. This will make a huge difference in our ability to:**
  - **Design software for achieving physical behavior,**
  - **Make software able to absorb change in physical systems,**
  - **Build, integrate physical systems dynamically from spaciously and temporarily distributed components.**
- **To do this means changing culture. DARPA's focused investment is critical to catalyze and accelerate this process.**