Progress in Robust Embedded System Architectures

http://www.ece.cmu.edu/roses

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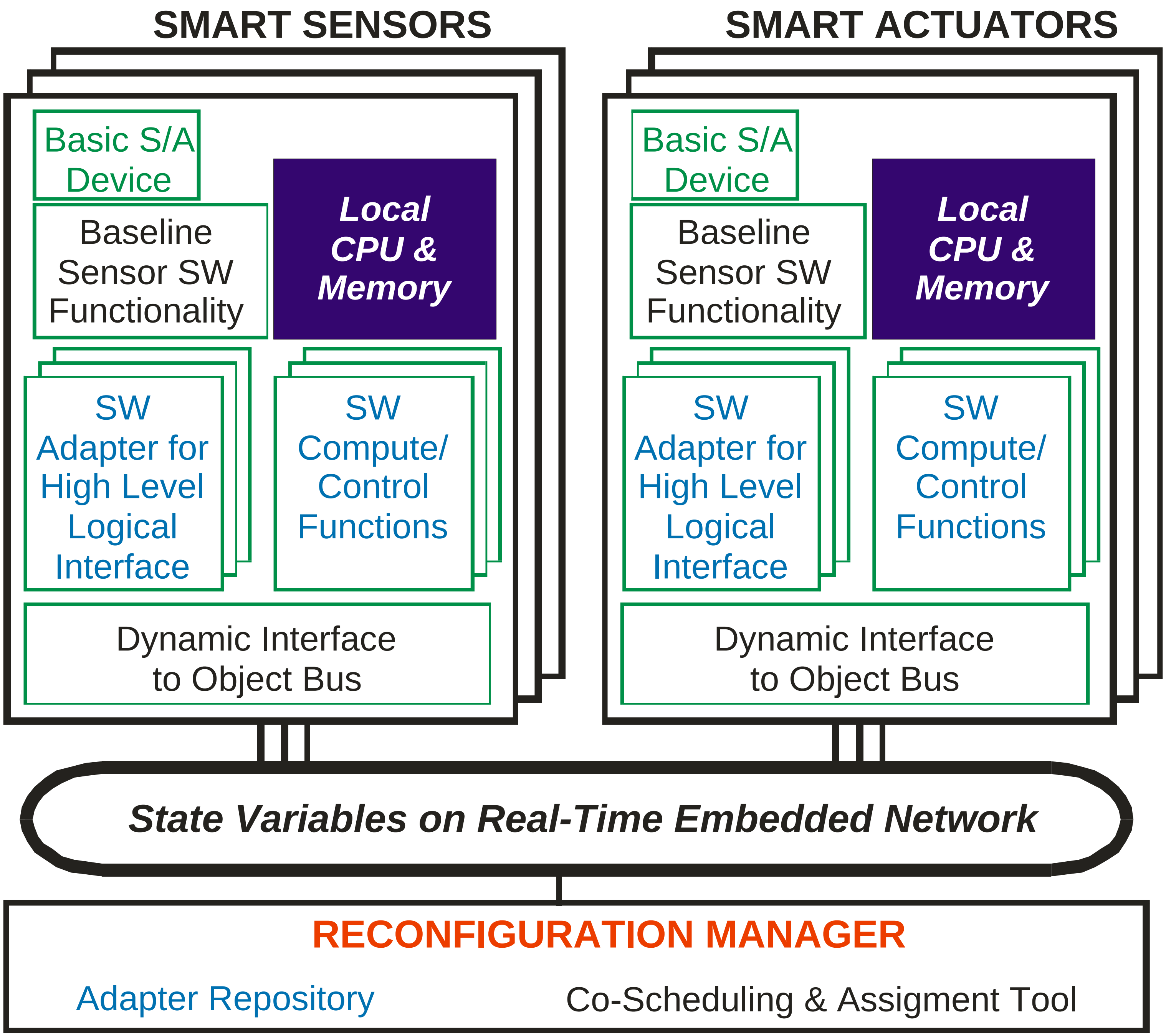
Outline

- **RoSES Strategic Vision**
  - Feasibility assessment
  - Key technical research areas
  - Technology transition to GM
- **Demo – Chris Martin**
  - **Including “workarounds” as a form of dependability**

Generic RoSES System Architecture



RoSES Strategic Vision:

- **Goal:**

  Develop theory, techniques, & key tools for robust distributed embedded systems

- **Grand Hypothesis:**

  Graceful degradation will provide cost-effective dependability

- **Approach:**
  - Understand problem & demonstrate feasibility
    - Prototypes for key points to explore issues
  - Resolve key research issues
    - Structure approach to spin off capabilities over time
  - Transition knowledge to industry
    - Work with GM Software Architecture team for mutual benefit

Overview: Problem Understanding

- **Run-time infrastructure**
  - Why can’t we just buy this stuff?

- **Configuration management**
  - Is this really just a known software partitioning problem?

- **Architectural definition & patterns**
  - Getting past having to ignore the man behind the curtain

Run Time Infrastructure

- **Why can't we just buy one?** (Meredith Beveridge)
  - Many are just paper – look at real tools
  - Corba is too "fat"
  - Jini looked attractive …
    and sort of worked …
    but had significant shortcomings

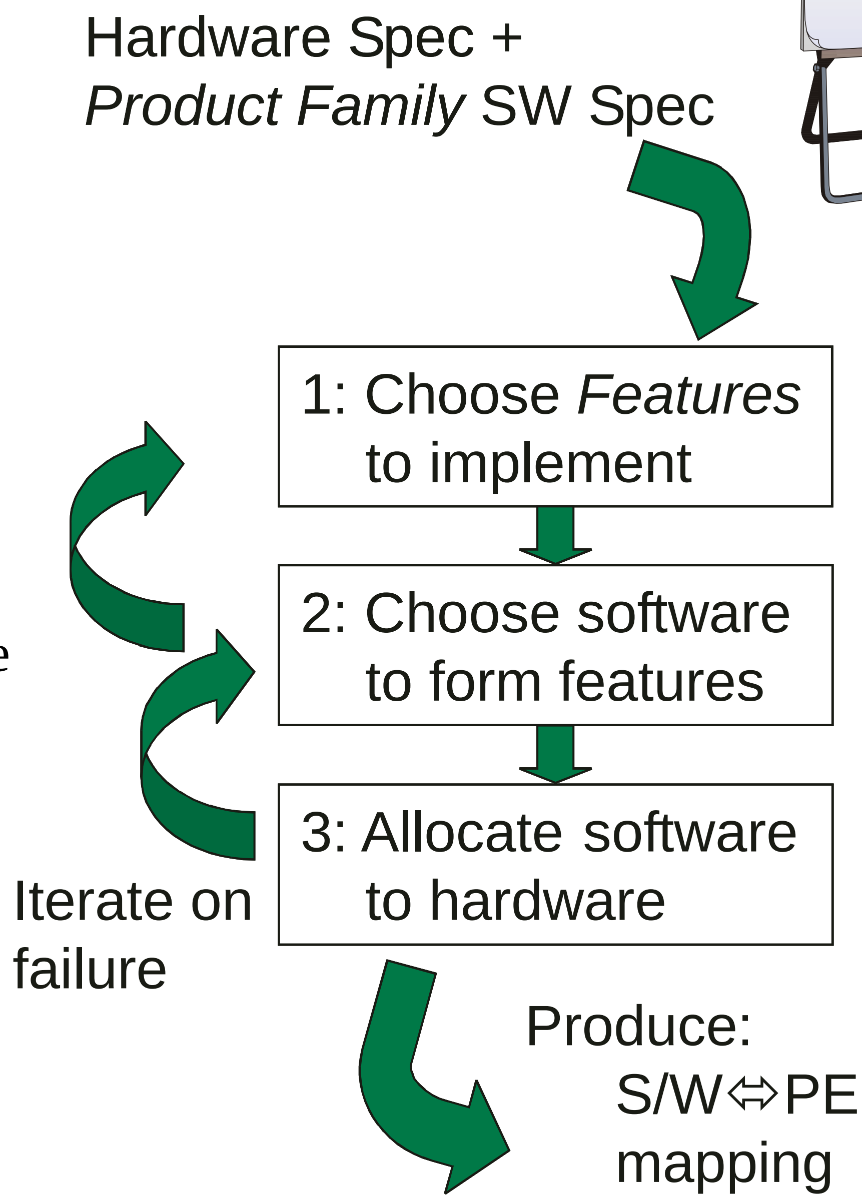
- **Getting something that will really work** (Yang Wang)
  - Key requirements based on Jini and other experiences
  - What can we learn from other research middleware?
  - How compatible can we be with desktop middleware?
    - Differ where it is important to do so
    - Remain compatible wherever possible
  - Support key needs for graceful degradation

(work starting Spring 2002)

RoSES

Configuration Management

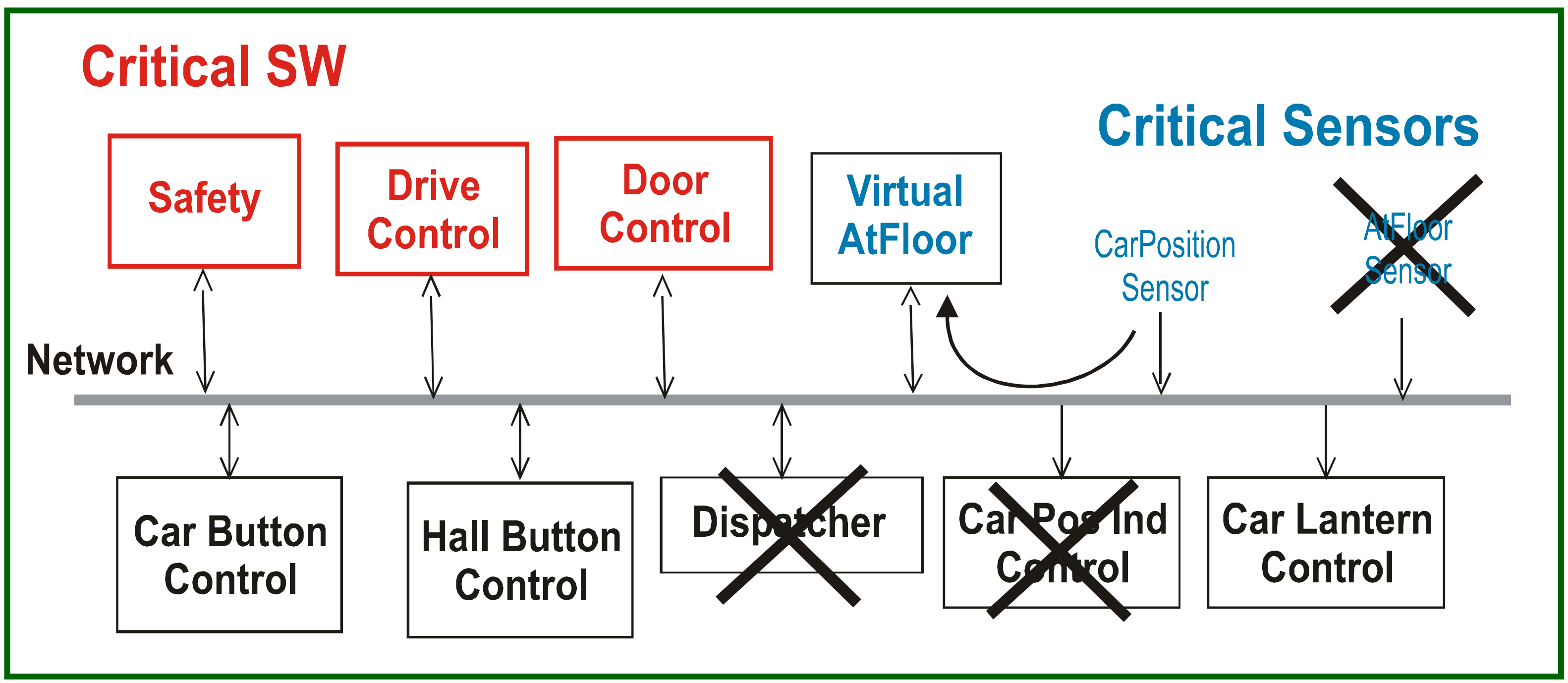
- **How do we track fine-grain distributed components?**
  (Bill Nace)
  - Which software component goes where in the system?
  - Given a fixed set of hardware, optimize system functionality
    - In general, not all possible software will fit on hardware
    - Various feature classes contain overlapping functionality
  - Progress
    - Good heuristics for quick solution
    - Representation & method successful on pilot problem
    - Working on a larger problem



Architectural Definition & Patterns

- **Robust architectural patterns** (Charles Shelton)
  - Are there generic approaches to attain robustness?
  - Can we evaluate "robustness"?

  - Progress:
    - Using realistic elevator example to demonstrate methodology
    - First results for quantifying robustness
  - Plan: work with GM architecture team



Overview: Resolve Key Research Issues

- **Project focus areas:**
  - Can we use UML or do we have to invent something?
  - Embedded to people interface
  - Embedded to enterprise interface

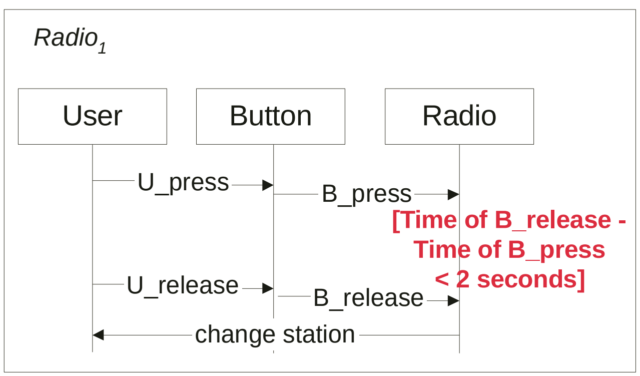
- **Long-term items:**
  - Formal representation & quantification
  - Appropriate robustness approaches
  - NP-hard issues in specification & evaluation

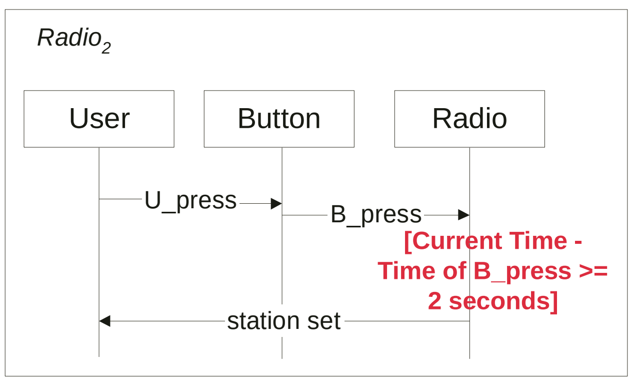
Fundamental Suitability of UML

Can UML handle real embedded systems?

- Spring 2001: class to build realistic systems
- Uncovered several problems; several solutions invented

- Compiler theory helps with stitching scenarios (Beth Latronico)
- Statechart clustering helps with global modes (Elissa Newman)
- SW architecture different than for desktops (Owen Cheng)





(Beth Latronico)

SD → message duration **response** SD | ε

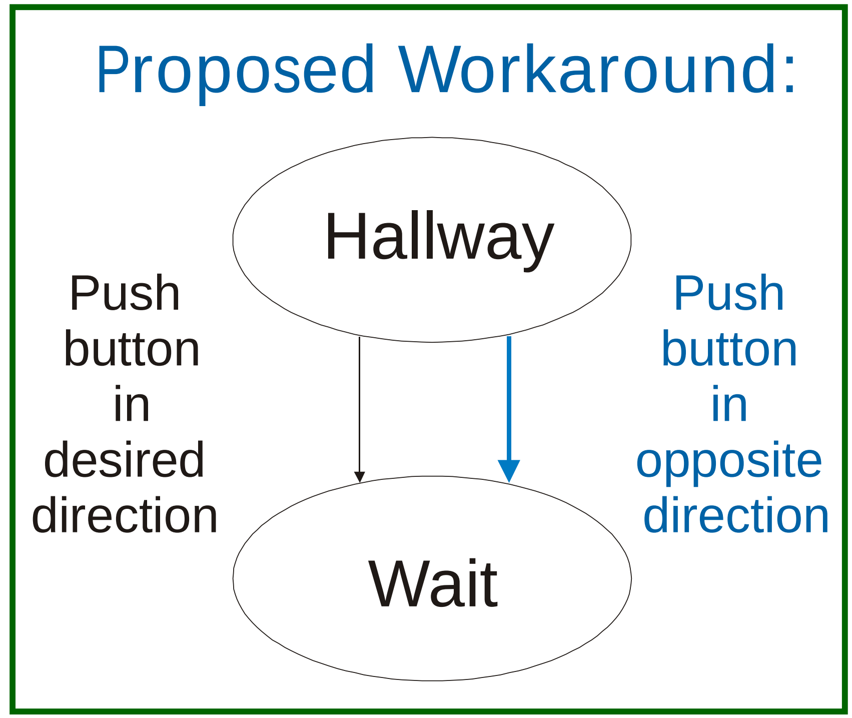
message duration **response** →
α B_release **change_station**
| β **station_set**

Embedded To People Interface

- **People can help with robustness(!)** (Chris Martin)
  - Concept of "workaround" is important, but neglected
  - Minor user flexibility can improve system-level robustness

  - Most real systems have several ways to accomplish goals
  - They can be represented as paths through UML scenarios

  - Min-cut graph algorithm can expose robustness bottlenecks
  - Elevator system results demonstrate feasibility



Embedded To Enterprise Interface

- **What happens when Embedded meets Enterprise?**

  (Priya Narasimhan & Phil Koopman)

- **From Jini experience we know to expect incompatibilities**
  - Event-driven *vs.* periodic
  - Transactional *vs.* continuous control
  - Rollback/retry *vs.* maintaining control stability

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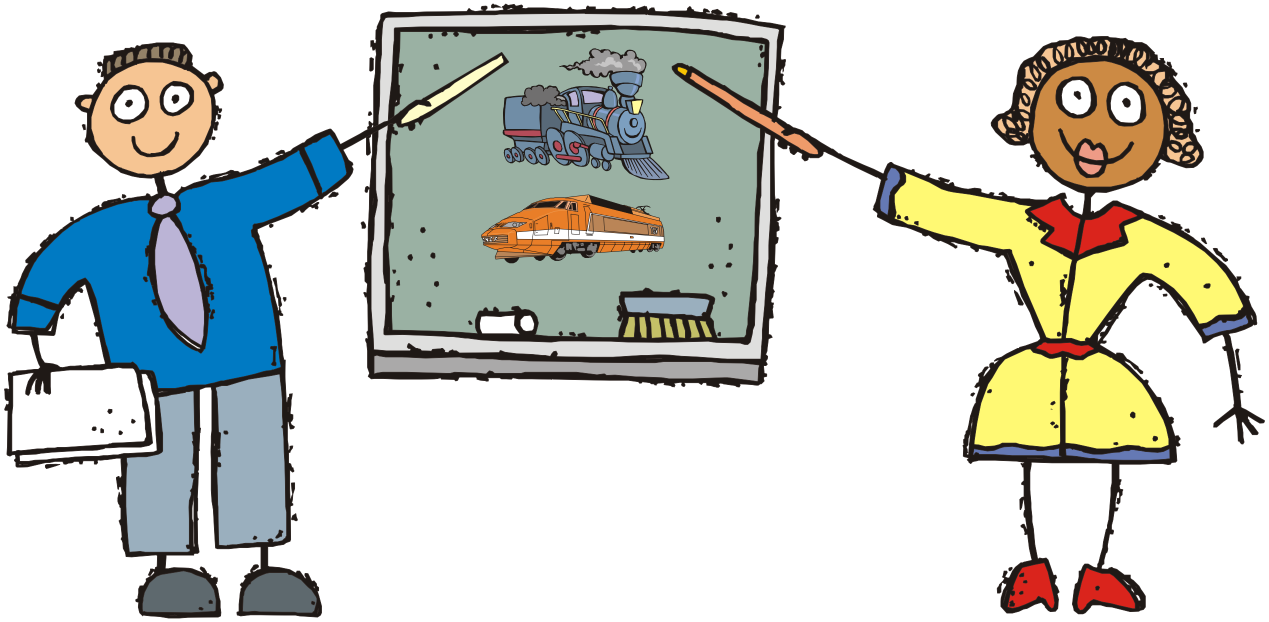

- **Class in Spring 2002 to build one and see what happens**

Formal Representation & Quantification

- **What is system architecture?** (Shelton)
  - Multiple viewpoints onto a single system
    - Hardware + software + communications + control
    - Human interface + upgrades + safety/security + validation + run-time infrastructure + fault management + …
  - Patterns for different architectural styles
    - General tradeoffs inherent to each style

- **Can there really be a "safety architecture"?** (Latronico)

- **What is graceful degradation?** (*everyone*)
  - For that matter, in a partially disabled system, what does "working" mean?
  - Perhaps it is related to vulnerability to mission failure (Martin)

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Appropriate Robustness Approaches

- **Can we characterize the robustness tradeoff space?**
  - Brute force replication
    - Expensive – many more components in system
    - Not entirely effective for software
  - Failover modes
    - Design intensive, but known to work
    - Can we create more systematic ways to do this?
  - Reconfiguration (current emphasis)
    - Can work together with product family configuration management (Nace)
    - Whether it is even feasible is a research topic (*yes, so far*)
  - Heterogeneous redundancy
    - If two sensors/actuators are almost the same, can they be interchanged?
    - Few existing techniques, although analytic redundancy fits here
    - People can use systems differently (people are "system components" too) (Martin)

NP-Hard Issues In Specification & Evaluation

- **Many hard problems encountered as we go**
  - Allocating software to components (Nace)
  - System specification
    - Product family architecture specification (Shelton)
    - Specification of utility for different features & feature sets
  - Evaluation
    - When is a system really "working" when it is partially disabled? (Martin)
    - Safety/certification of component-based systems (Latronico)
  - Implementation
    - Software runtime infrastructure (Wang)
    - Real time scheduling for distributed networked system
    - Security of embedded+enterprise combined system
    - What baseline set of components gives most reconfiguration flexibility?
  - . . .

RoSES

Overview: Transition Knowledge To Industry

- **Work with GM architecture team**
  - Trips both ways
  - Students create representative vehicle subsets for research
  - GM benefits from experience gained in RoSES implementation

- **Teaching**
  - Stream of CMU grads. trained in robust embedded system design
    - Soon to include robust enterprise systems as well
  - Opportunity for GM-based course projects
    - 6-12 months advanced planning required
    - Topic area must be carefully selected

Related Work – Embedded Protocols

- **CRC error detection effectiveness** (Chakravarty)
  - Train Communication Protocol design review
  - Found that error codes could be much more effective
    - Error codes optimized for long messages
    - But embedded networks have short messages – different design tradeoff point

- **FlexRay & TTP protocols** (Koopman)
  - Were already being evaluated for another customer
  - Expertise available when GM joined FlexRay consortium

RoSES Publications In 2001

- ***2001 Workshop on Reliability in Embedded Systems***
  - Nace – Component allocation framework
  - Shelton – Architectural principles
  - Martin & Latronico – User workarounds
- ***2001 UML Conference***
  - Latronico – sequence diagrams as a formal language
- ***IBM Ubiquitous Computing Workshop***
  - Nace – Internet meets embedded systems (invited)
- **Theses:**
  - Beveridge – Jini meets CAN (also invited paper at ***WORDS 2002***)
  - Martin – User workarounds + graph analysis
  - Chakravarty – Optimal embedded network error detection

Conclusions

- **Results coming in on understanding the problem area**
  - Run-time infrastructure
  - Configuration management (PhD thesis next year)
  - Architectural definition & patterns (PhD thesis in about 2 years)
- **Progress on key technology areas**
  - UML isn't dead (yet) – but will require augmentation
  - Embedded to people interface is an emergent opportunity
  - Embedded to enterprise interface (Spring 2002 course)
- **Pieces of long-term issues being solved as we go**
  - Formal representation & quantification
  - Appropriate robustness approaches
  - NP-hard issues in specification & evaluation
- **Participation with GM SW architecture team**