University of Idaho

A Survivable Architecture for Real-Time Weather Responsive Systems

Technical Approach

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Project Overview

- Develop a prototype of a real-time weather-responsive traffic signal control system to improve the efficiency and safety of traffic signal operations during inclement weather
- The system receives weather information from the FHWA's Clarus system database, analyzes it, and makes necessary changes to signal timing parameters in response to inclement weather conditions.
- The system will operate and achieve its potential using current traffic controller and controller cabinet technologies. Minimal hardware, in addition to traffic controllers, are required.
- The system will be compatible with future applications within the connected-vehicle initiative.
- Software design addresses survivability concerns.

Potential Safety and Operational Benefits

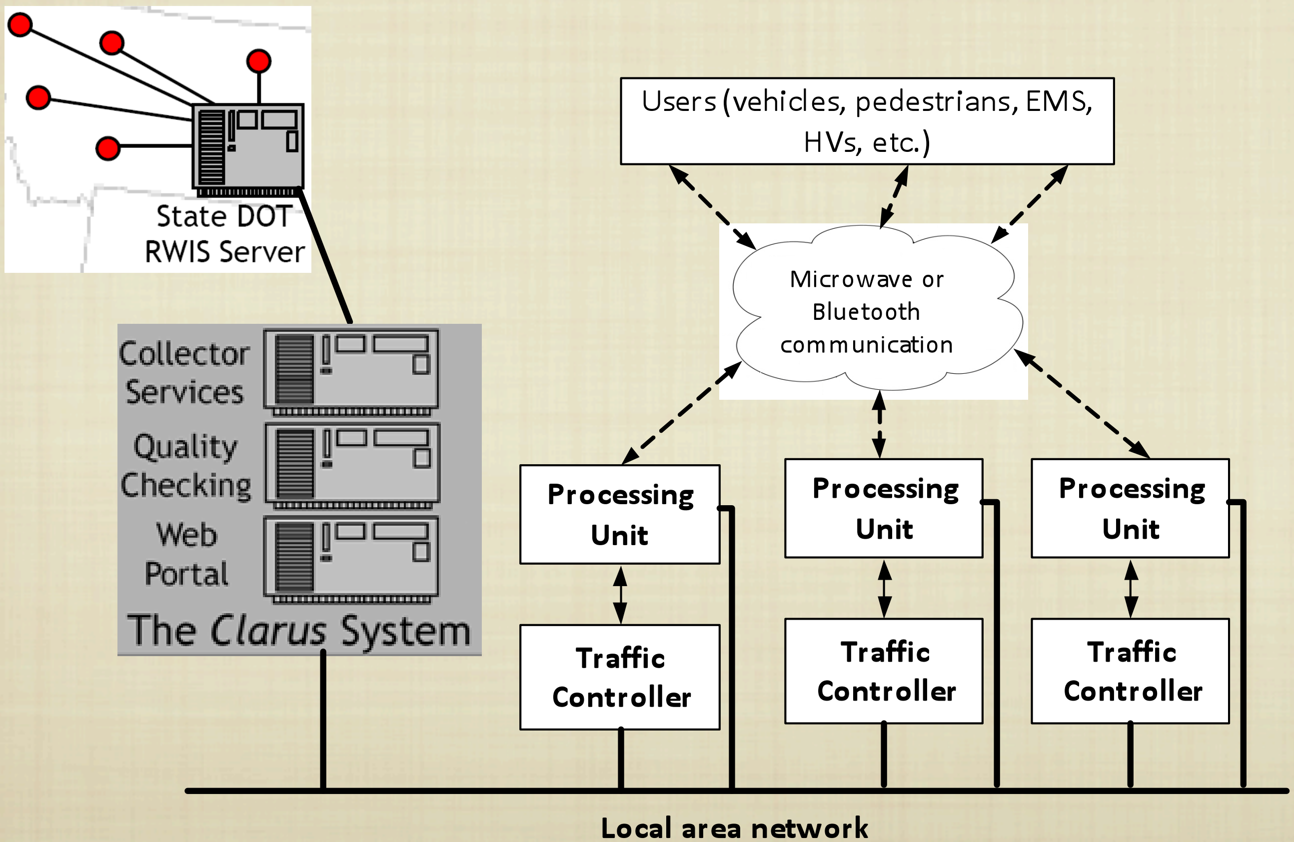
- Increase the value of yellow and all-red interval and coordination offset values for each weather condition
- Based on microscopic-simulation (VISSIM) and using surrogate safety measures:
  - 46% reduction in vehicles in dilemma zone
  - 34% reduction in conflicts
  - 19% increase in corridor throughput

Integrating Clarus data into RT-App.

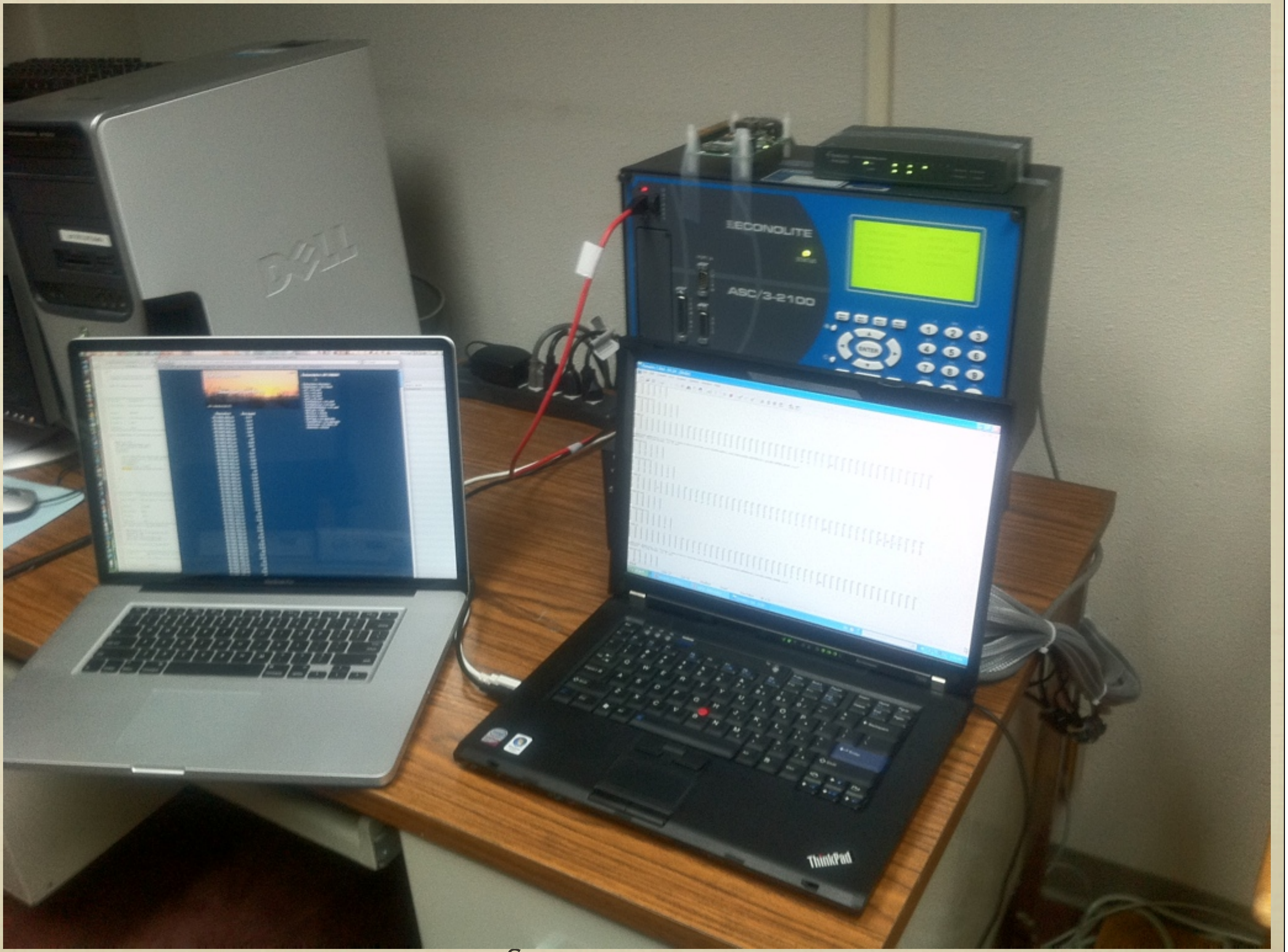
- Challenges
  - The Engineering Challenge
  - The Security Challenge
  - The Real-time Challenge
  - The Survivability Challenge (includes all “illities”)
- Apply the newest technology to a survivability architecture
  - Design Methodology based on *Design for Survivability*

Project Architecture

- A system operating in an unbounded environment
- Inheriting all problems from such environment

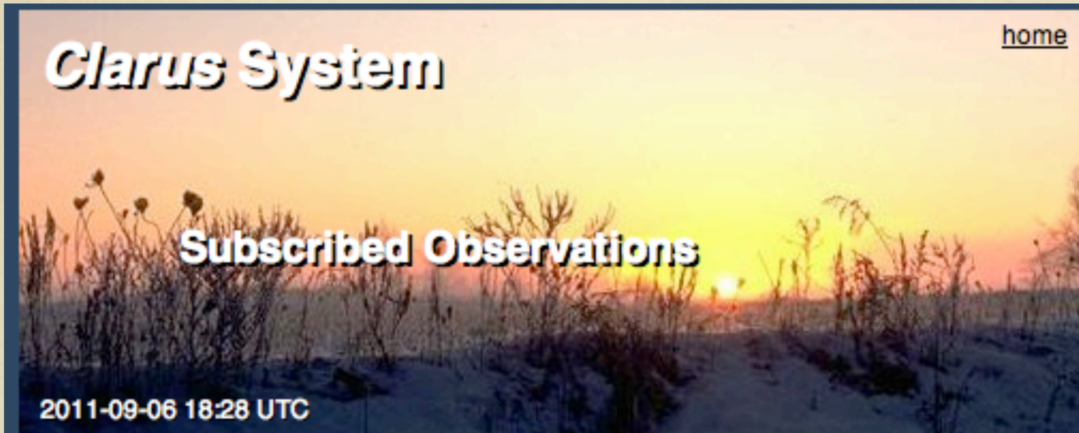


Prototype



Clarus...

- Utilizing local sensor data to do what?



Observations	Size (bytes)
20110906_1815.csv	420
20110906_1800.csv	5,515
20110906_1745.csv	5,515
20110906_1730.csv	5,515
20110906_1715.csv	5,515
20110906_1700.csv	5,515
20110906_1645.csv	5,515
20110906_1630.csv	5,515
20110906_1615.csv	5,515
20110906_1600.csv	5,515
20110906_1545.csv	5,515

Subscription: 2011082501

Subscription Information:
DateCreated = 2011-08-25
Lat1 = not used
Lon1 = not used
Lat2 = not used
Lon2 = not used
PointRadiusLat = not used
PointRadiusLon = not used
PointRadiusRadius = not used
ObsType = 0 (all)
MinValue = -Infinity
MaxValue = Infinity
RunFlags = not applicable
PassNotPass = not applicable
Contributors = ID_State_TD
StationIds = Shirrod

Clarus Subscription Data

- Access Clarus data files from the web

http://www.clarus-system.com/SubShowObs.jsp?subId=2011082501&file=20110906_2200.csv

http://www.clarus-system.com/SubShowObs.jsp?subId=2011082501&file=20110906_2200.csv

Google

Axel UI Research Finances Misc. Clarus Conferences Music Kitty Hawk MANET TV Find Motorcycle


```
ObsTypeID,ObsTypeName,ClarusSensorID,ClarusSensorIndex,ClarusStationID,ClarusSiteID,Category,ClarusContribID,Contributor,StationCode,Timestamp,Latitude,Longitude,Elevat
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END OF RECORDS -- 2011082501:20110906_2200.csv
```

Highly Critical (Essential) Clarus Data

essPrecipSituation	Describes the weather situation in terms of precipitation, integer values indicate situation
essPrecipYesNo	Indicates whether or not moisture is detected by the sensor: (1) precip; (2) noPrecip; (3) error
essPrecipRate	The rainfall, or water equivalent of snow, rate
essRoadwaySnowpackDepth	The current depth of packed snow on the roadway surface
essAirTemperature	The dry-bulb temperature; instantaneous
essVisibilitySituation	integer value, describes the travel environment in terms of visibility
essVisibility	Surface visibility (distance)
essSurfaceStatus	integer value, a value indicating the pavement surface status

Highly Critical (Essential) Clarus Data

essSurfaceTemperature	The current pavement surface temperature
windSensorGustSpeed	The maximum wind gust recorded by the wind sensor during the 10 minutes preceding the observation
essSnowfallAccumRate	The snowfall accumulation rate
essIceThickness	Indicates the thickness of the ice on surface
essPrecipitationStartTime	The time at which the most recent precipitation event began
essPrecipitationEndTime	The time at which the most recently completed precipitation event ended
essMobileFriction	Indicates measured coefficient of friction

Potentially Useful Data

windSensorAvgSpeed	A two-minute average of the windspeed
essPrecipitationOneHour	The total water equivalent precipitation over the one hour preceding the observation
essSurfaceIceOrWaterDepth	The current thickness of ice or depth of water on the surface of the roadway
essSurfaceBlackIceSignal	integer, A value indicating if Black Ice is detected by the sensor
essPavementTemperature	The current pavement temperature 2-10 cm below the pavement temperature.
pavementSensorTemperatureDepth	The depth at which the pavement temperature is detected

What could possibly go wrong?

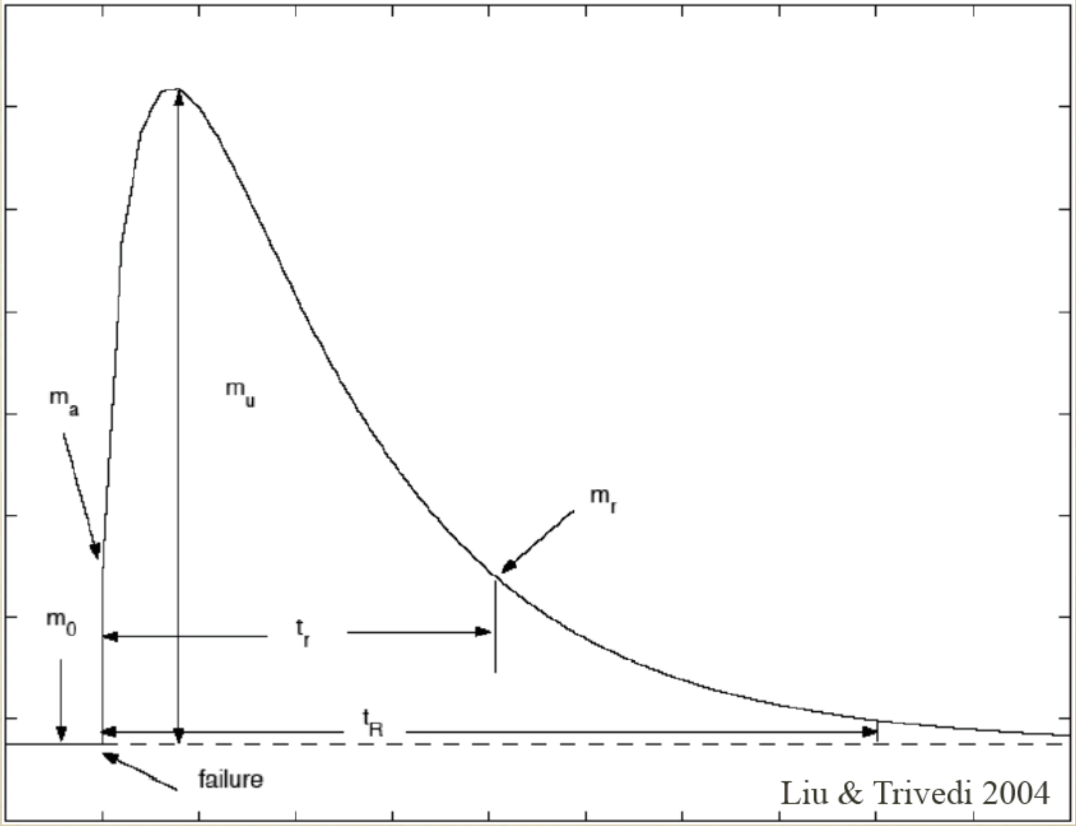
- What assumptions should one place on a system?
  - Anything is possible!
    - and it <u>will</u> happen!
  - Malicious act will occur sooner or later
  - It is hard or impossible to predict the behavior of an attack

Unique Opportunity

- What is unique about this project?
  - The application domain is part of a Critical Infrastructure
  - The project is just small enough to demonstrate a survivability architecture
    - The code is relatively small
    - The execution is relatively deterministic
    - The run-time support is relatively mature

What is Survivability

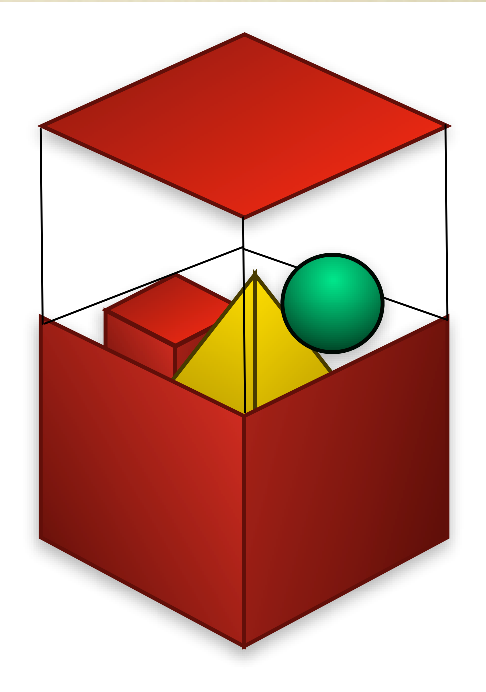
- Closely related Terms
  - Intrusion Tolerance
  - Resilience
- Relationship to
  - Fault-tolerance
  - Security



Liu & Trivedi 2004

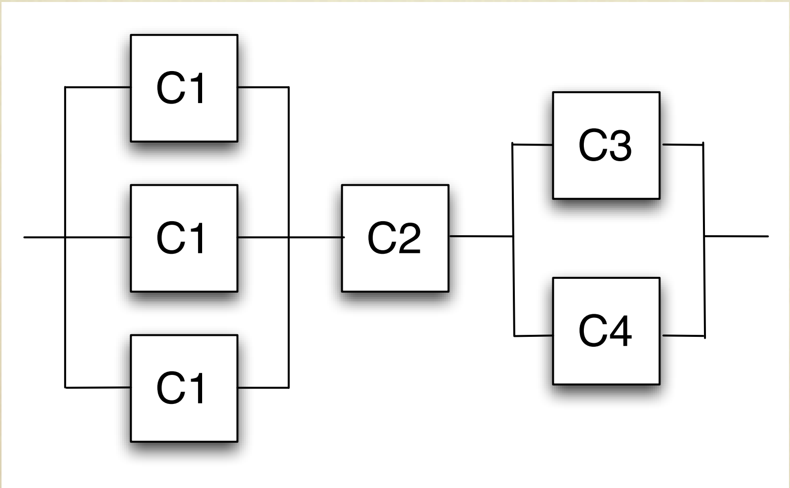
Design for Survivability

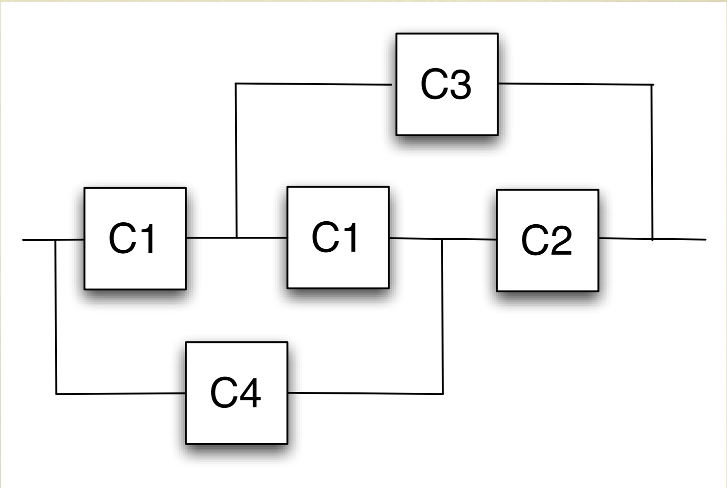
- When Systems become too complex
  - Design by Integration of Survivability mechanisms
  - Build-in *not* add-on
  - Design for Survivability has surfaced in different contexts



Design for Analyzability

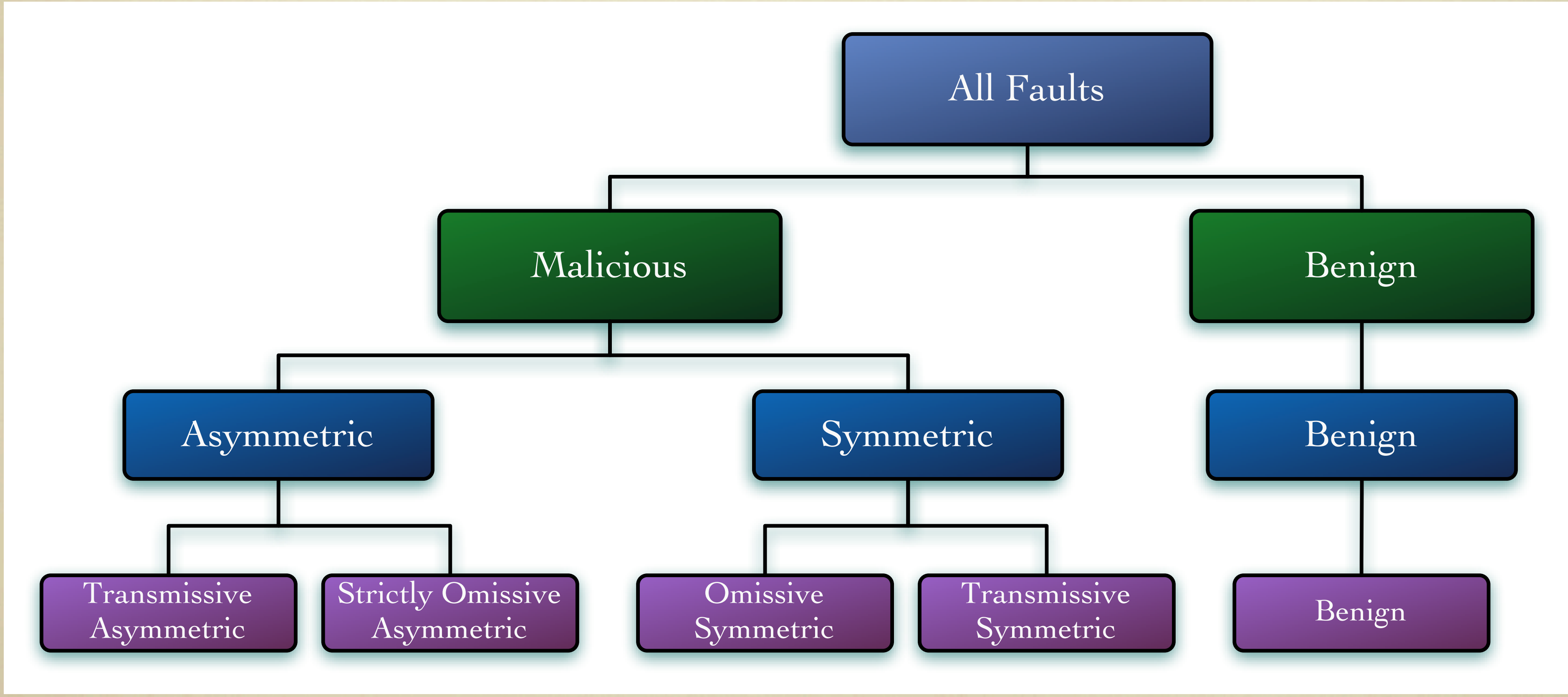
- Not a new concept
- e.g., Series-Parallel RBD
  - Not all systems are Series-Parallel!





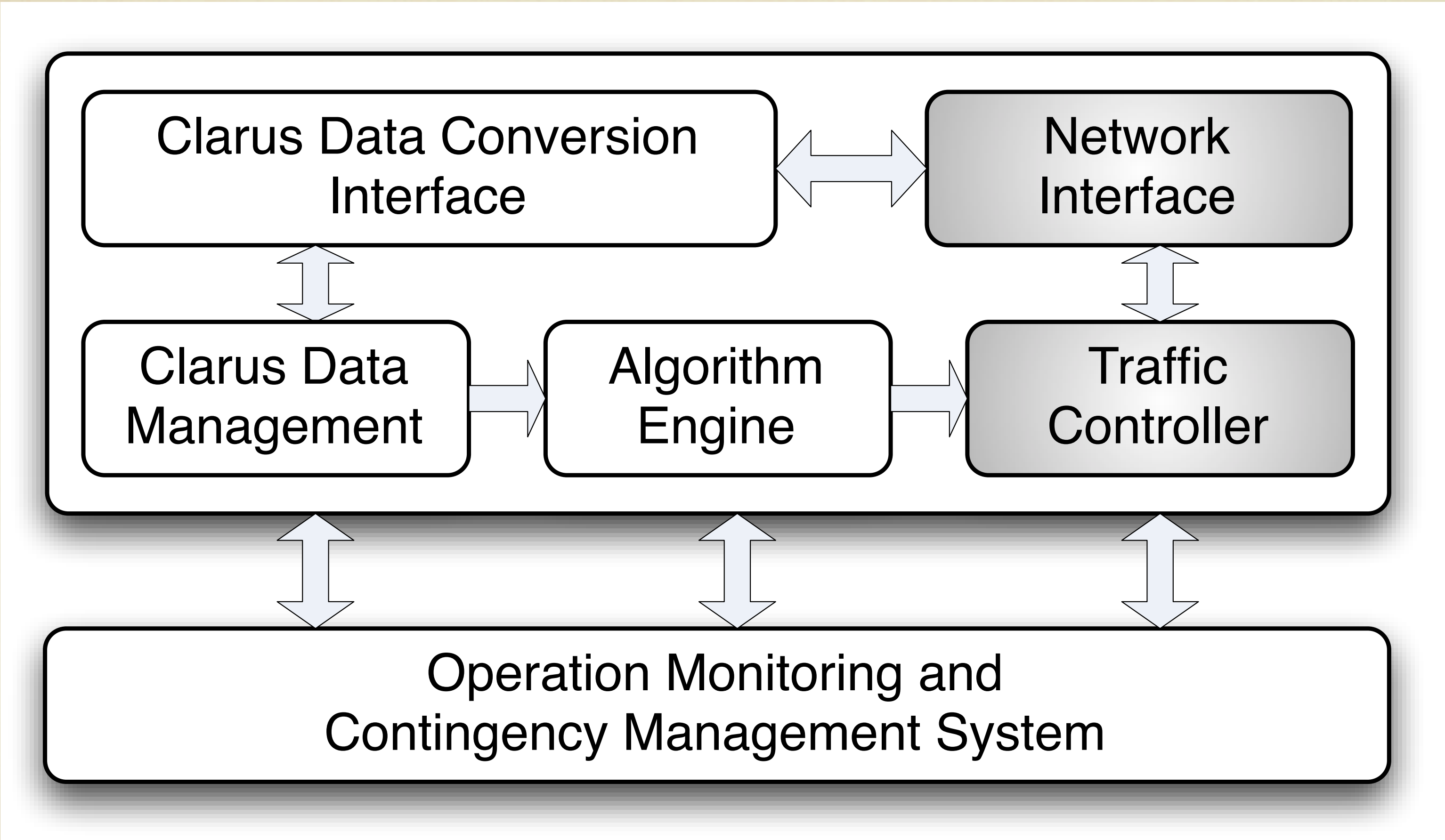
Fault Models:

The world in which we live/operate



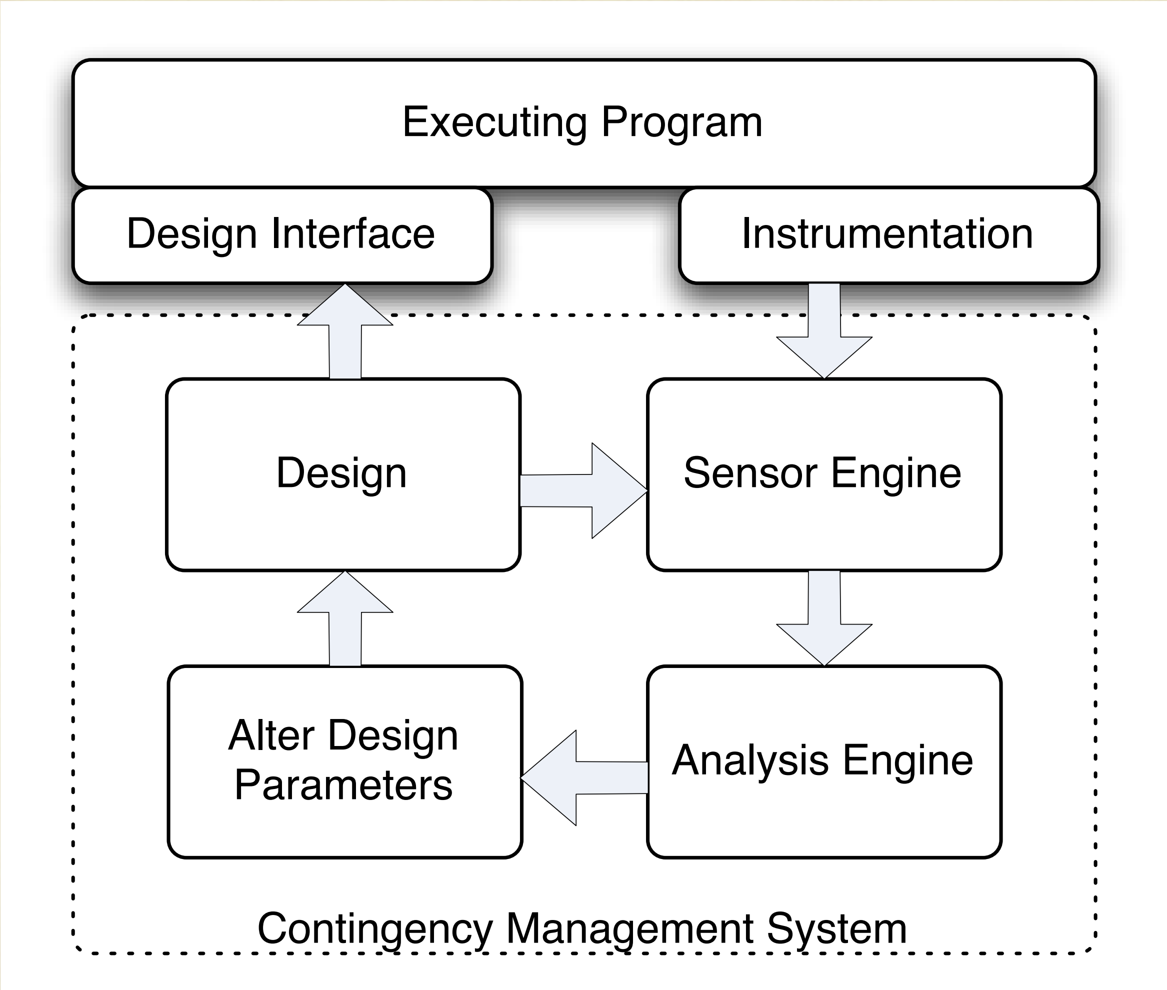
Software Architecture

- Overview



Design Methodology

- Measurement-based design and operation



Our view of a System

- Different “machines”
  - Operations
  - Functions
  - Modules
- Epoch
  - defined by transitions

Profiles

- Frequency Spectrum
  - count of invocations
  - probability of invocation
  - defined for an epoch
  - defined for operations, functions and modules
  - does not say anything about dependencies!

Profiles

- Module Profiles of Costates

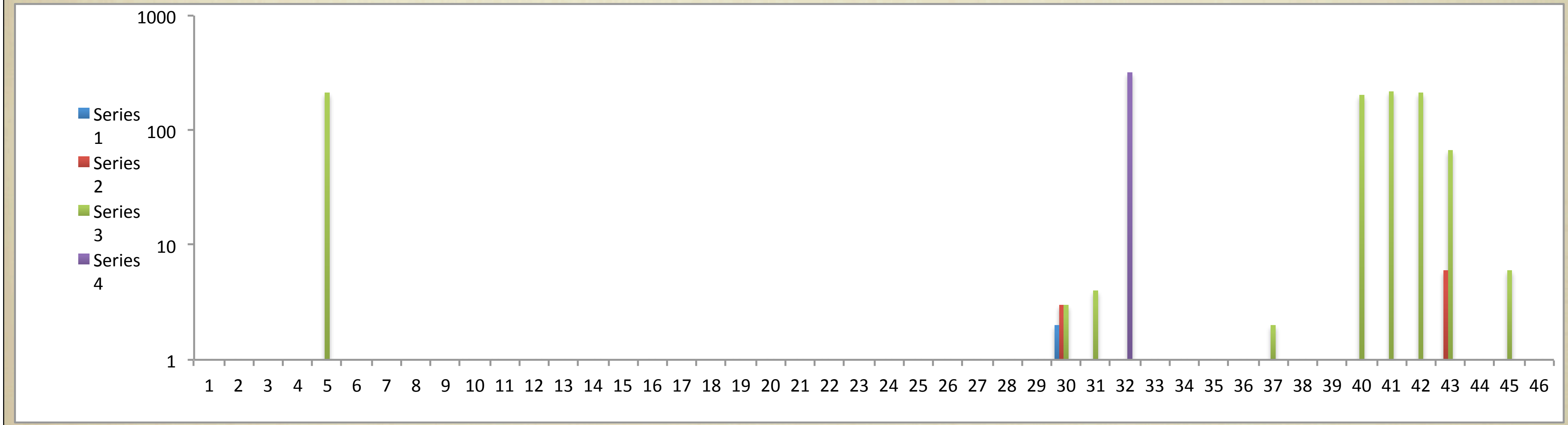


Figure 4: Sample Profiles

Dependencies

- Relationship between Operations, Functionalities, and Modules

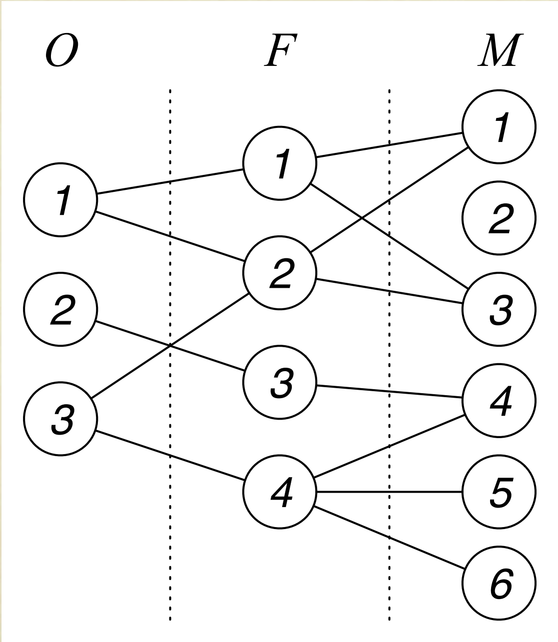
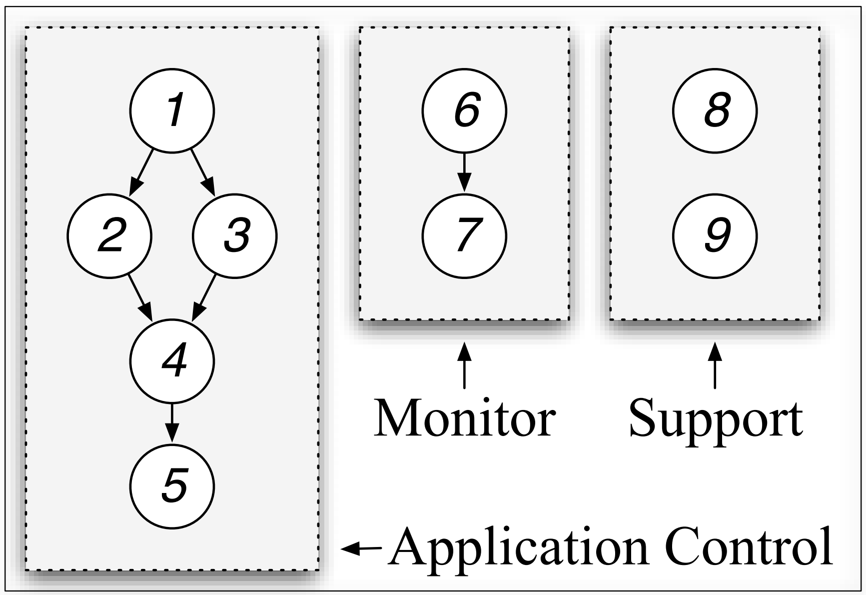


Figure 2: Mappings in ($O \times F \times M$)

Dependencies cont.

- Operations $G^O = (O,<)$
- Functionalities $G^F = (F,<)$
- Modules $G^M = (M,<)$

Operations & Costates

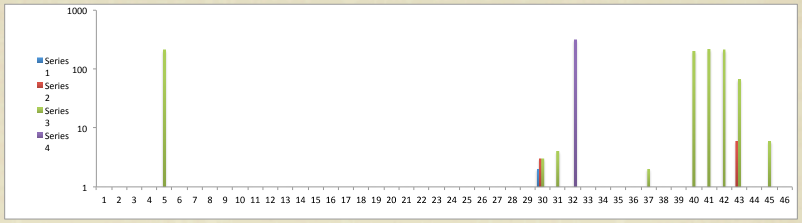


1 Get Clarus data
2 Receive data from LCS
3 Receive data from Clarus
4 Analyze Clarus data
5 Adjust controller
6 Monitor analysis
7 Monitor adaptive reconfiguration
8 Time synchronization
9 Support routines

Figure 3: Costates and Operations

Certificate executions

- Certified profiles
  - based on profiles
  - costate profiles reduce non-determinism



For each costate: If we consider m sequences of n epochs each, we can define a costate centroid $\overline{\mathbf{u}} =< \overline{u}_1, \overline{u}_2, ..., \overline{u}_{|O|} >$ where

$$\overline{u}_i = \frac{1}{m} \sum_{j=1}^{m} \hat{u}_i^j$$

and the distance from $\hat{\mathbf{u}}^k$ from centroid $\overline{\mathbf{u}}$ is given by

$$d_k = \sum_{i=1}^{n} (\overline{u}_i - \hat{u}_i^k)^2$$

Conclusions

- Unique opportunity to apply new Design Methodology
  - Real-time Control Application
  - Utilize Design for Survivability
  - Allows for integration of key features necessary for CI
  - Derivation of real-time self-monitoring via Instrumentation
- Future potential
  - Apply the concept to other applications

System Demonstration

Questions