*-aware Software for Cyber Physical Systems

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Theme

- How can we build practical cyber physical systems of the future?
- 3 Critical (Foundational) Issues: must be addressed together
  - Robustness
  - Real-Time
  - Openness

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Foundational Principle

- Scientific and systematic approach for the impact of the physical on the cyber

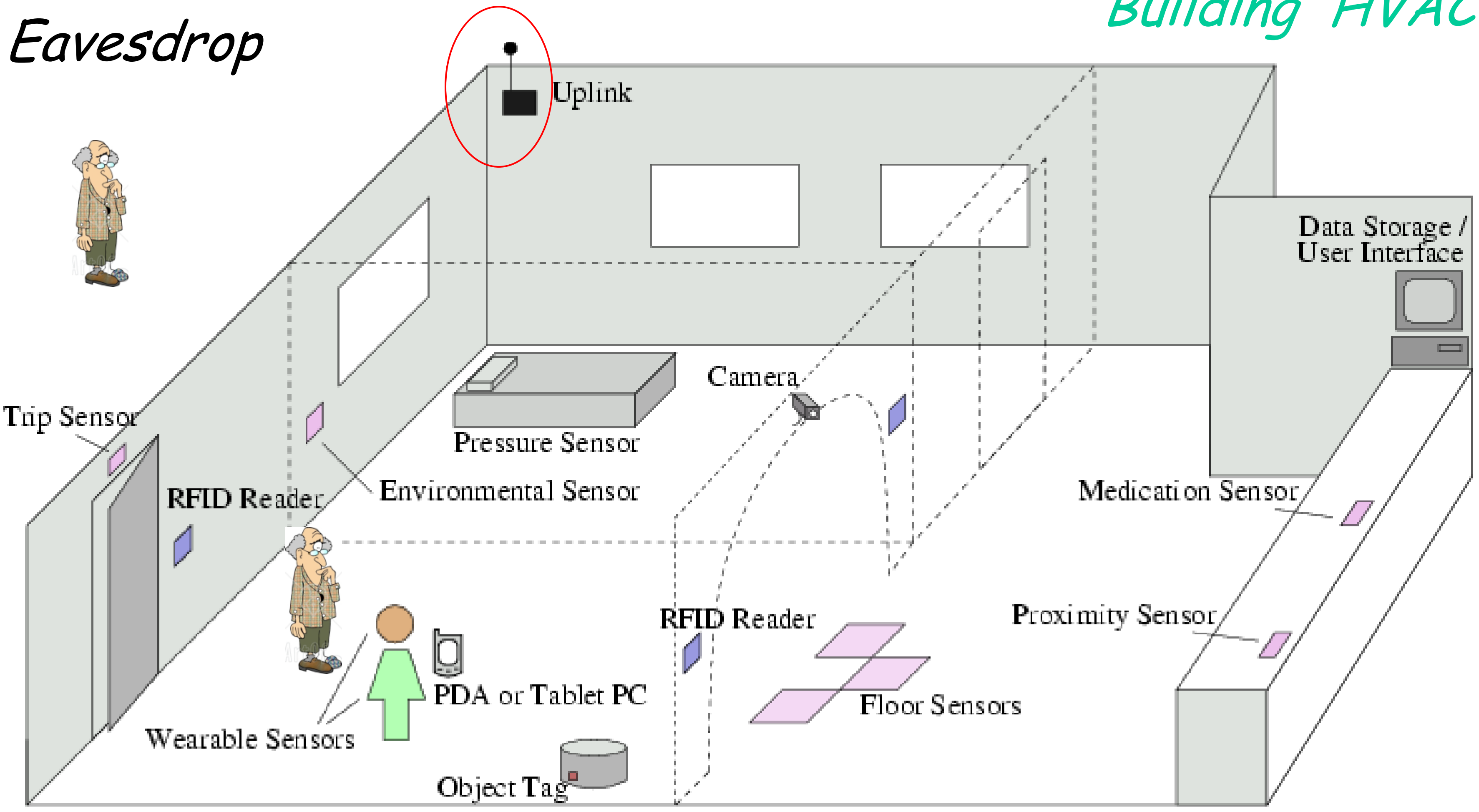
- Propose:
  - Physically-aware SW
  - Validate-aware SW
  - Privacy/security aware SW

Real-time aware

"Open" Smart Living Space

Eavesdrop

Building HVAC



Openness

- Typical embedded systems closed systems design not applicable

- Added value
- Systems interact with other systems
- Evolve over long time
- Physical system itself changes

- High levels of uncertainty: Guarantees

Outline

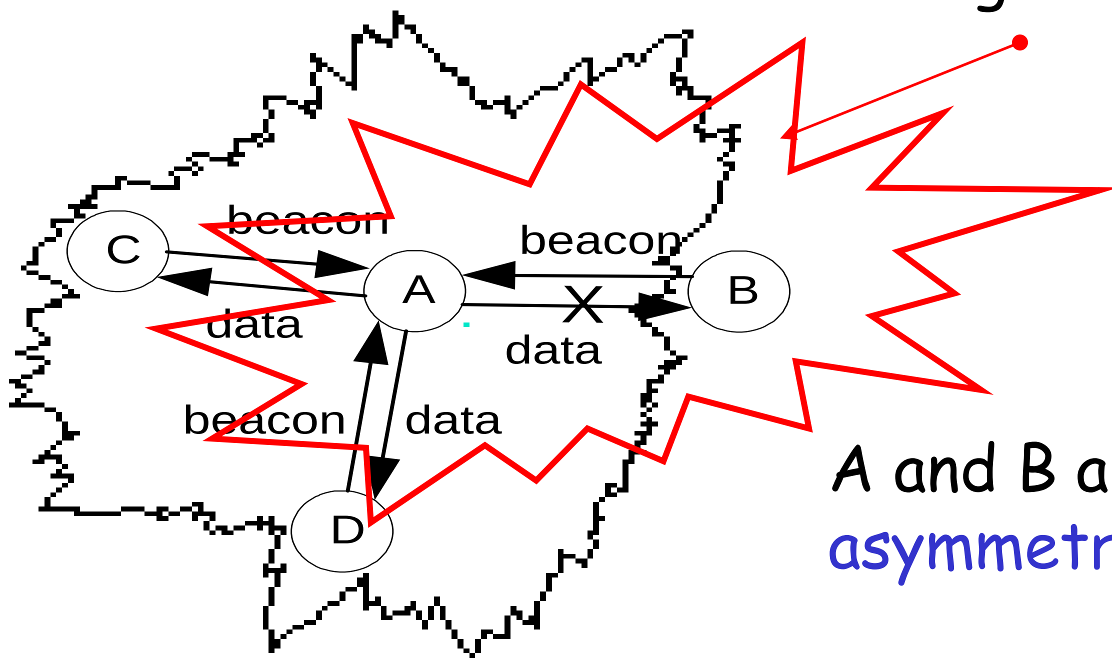
- Physically-aware software
- Validate-aware software
- Real-Time-aware software
- Privacy-aware software

Physically Aware: Impact of the Physical

- For Wireless Communications (things we know)
  - Noise
  - Bursts
  - Fading
  - Multi-path
  - Location (on ground)
  - Interference
  - Orientation of Antennas
  - Weather
  - Obstacles
  - Energy
  - Node failures

Asymmetry

Irregular Range of A

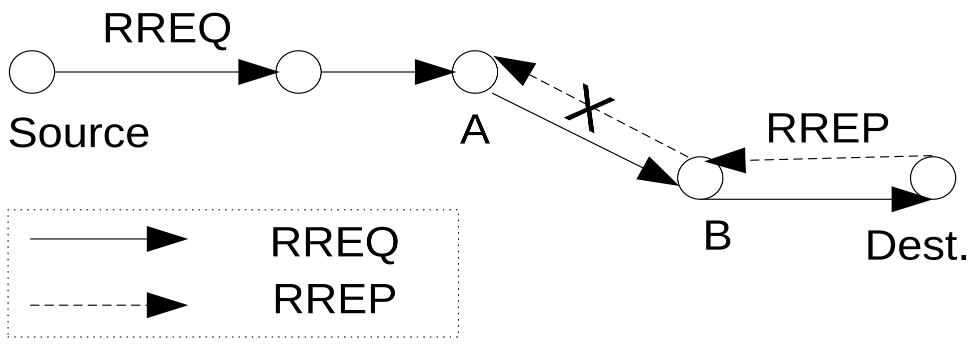


A and B are asymmetric

B, C, and D are the same distance from A.
Note that this pattern changes over time.

Routing

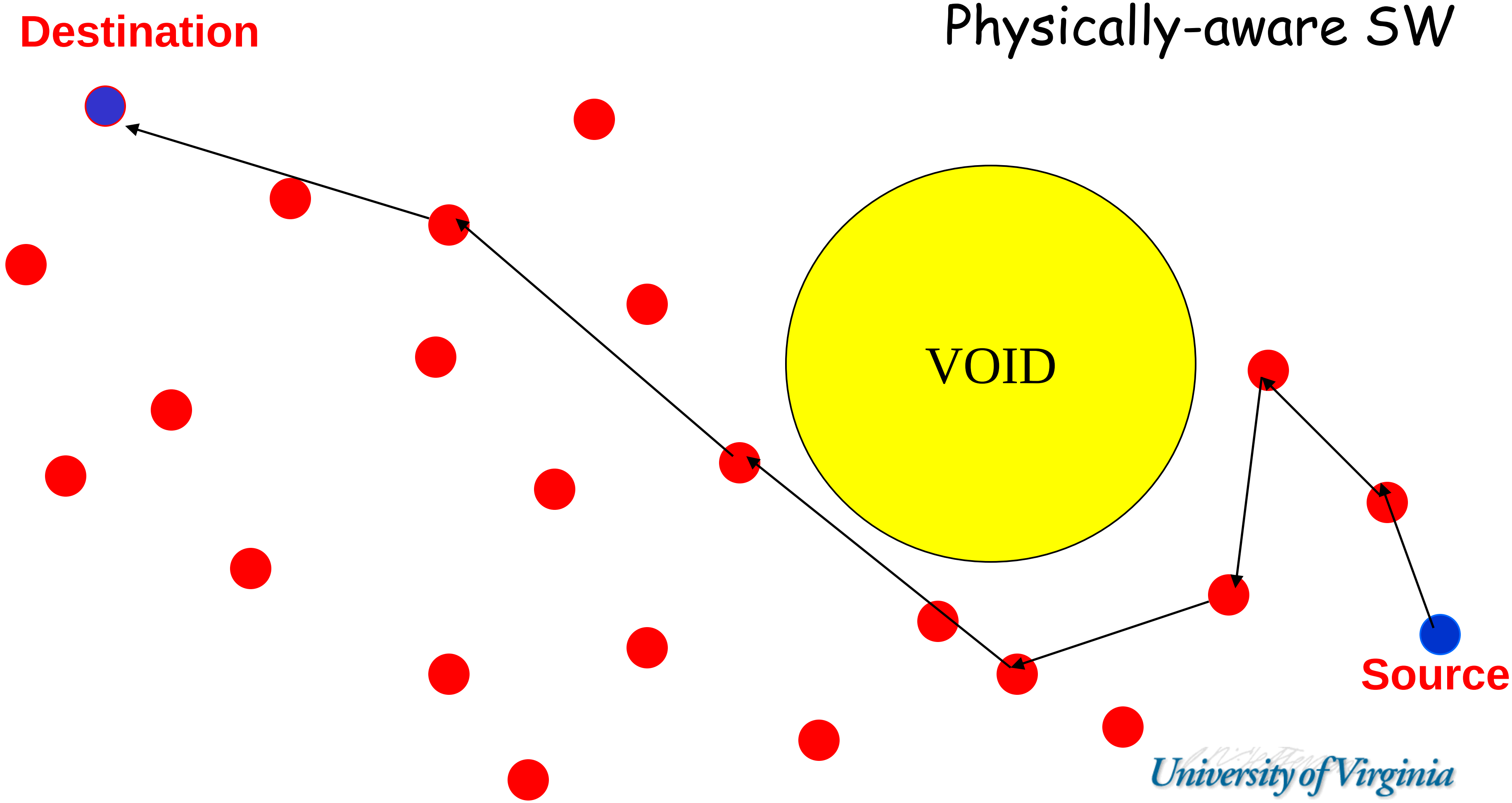
- DSR, LAR:
  - Path-Reversal technique



Impact on Path-Reversal Technique

Uncertainties -Voids

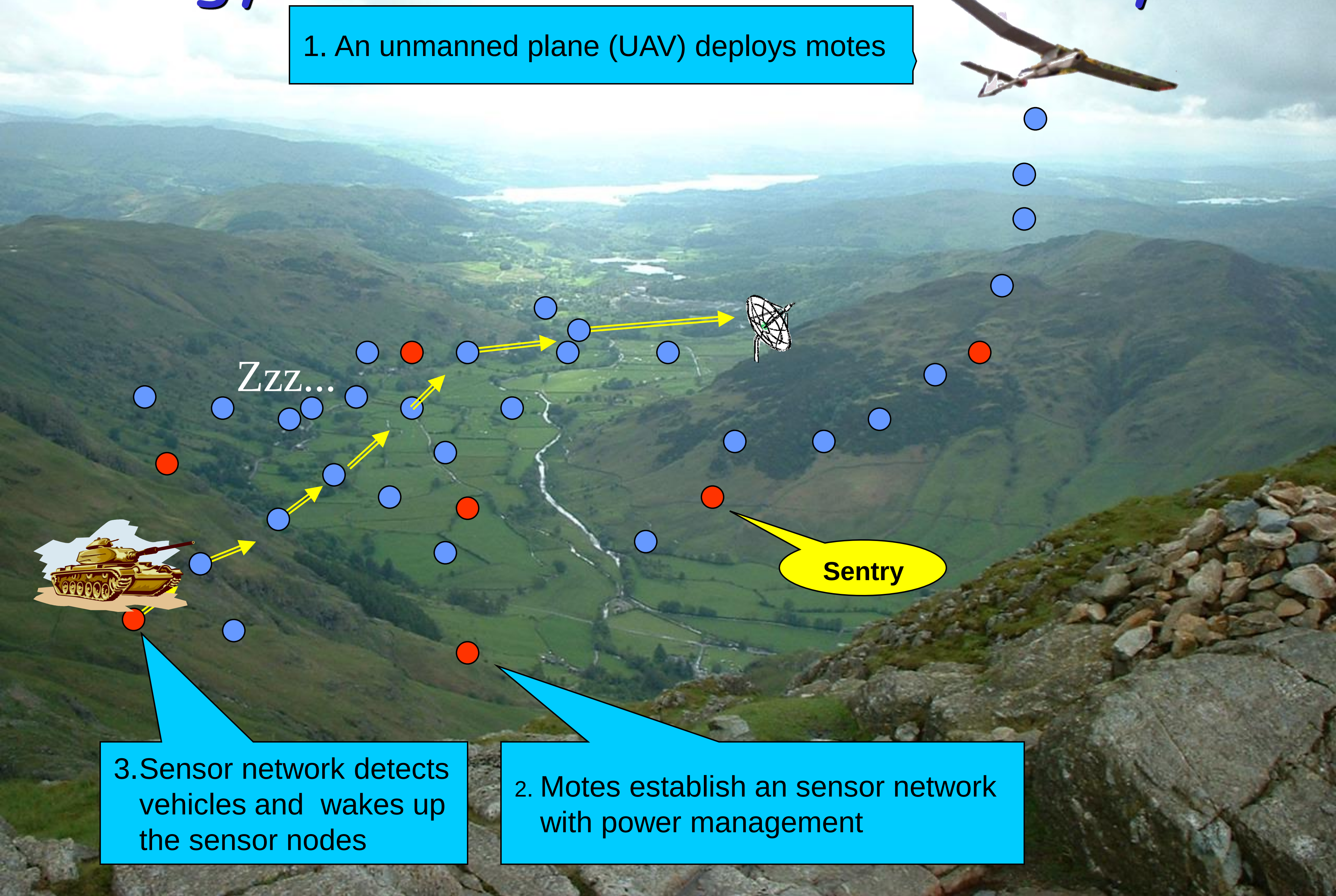
Left Hand Rule
Physically-aware SW



Cyber-Physical Dependencies

- Sensing
  - Sensor properties
  - Target Properties
  - Environmental interference

Energy Efficient Surveillance System



Tracking

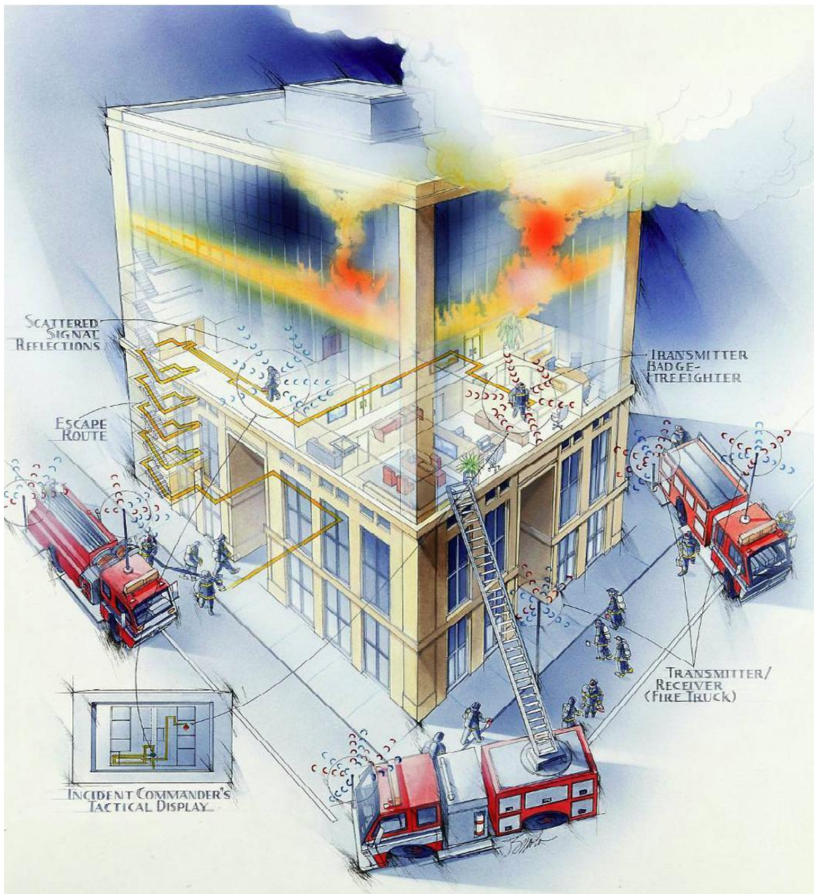
- Magnetic sensor takes 35 ms to stabilize
  - affects real-time analysis
  - affects sleep/wakeup logic
- Target itself might block messages needed for fusion algorithms
  - Tank blocks messages

Environmental Abstraction Layer (EAL)

Wireless Communication					Sensing and Actuation				
Interference	Burst Losses	Weak Links	Fading	…	Target Properties	Weather	Obstacles	Wake Up Delays	…

Not HW-SW co-design, but rather Cyber-Physical co-design

Validate Aware: Run Time Assurance (RTA)



- Safety Critical
- Long Lived
- Validated
- Re-validated

- Dynamics of Environmental Changes Influence Correctness

See Run Time Assurance paper in IPSN 2010.

RTA Goals

- Validate and Re-validate that system is still operational (at semantics level)
- Anticipatory RTA
  - Before problems arise
- Robust to evolutionary changes

Validate-aware software

RTA Solution

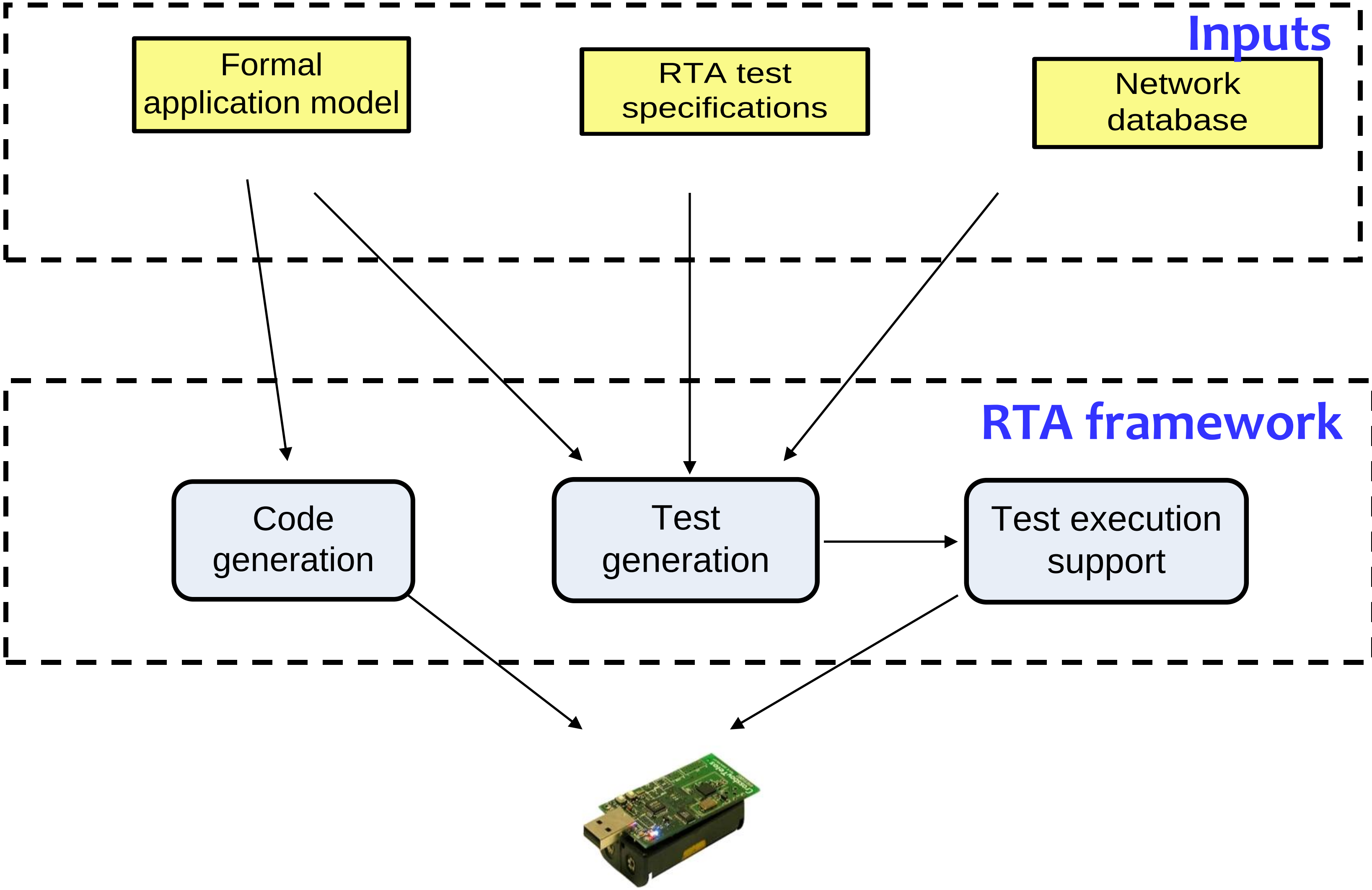
- Emulate sensor readings
- Reduce tests to focus on key functionality
- Overlap tests and system operation
- Evolve required tests

Current Solutions

- Prior deployment analysis
  - Testing
  - Debugging
- Post mortem analysis
  - Debugging
- Monitoring low-level components of the system
  - System health monitoring

Necessary, but not sufficient

RTA Framework



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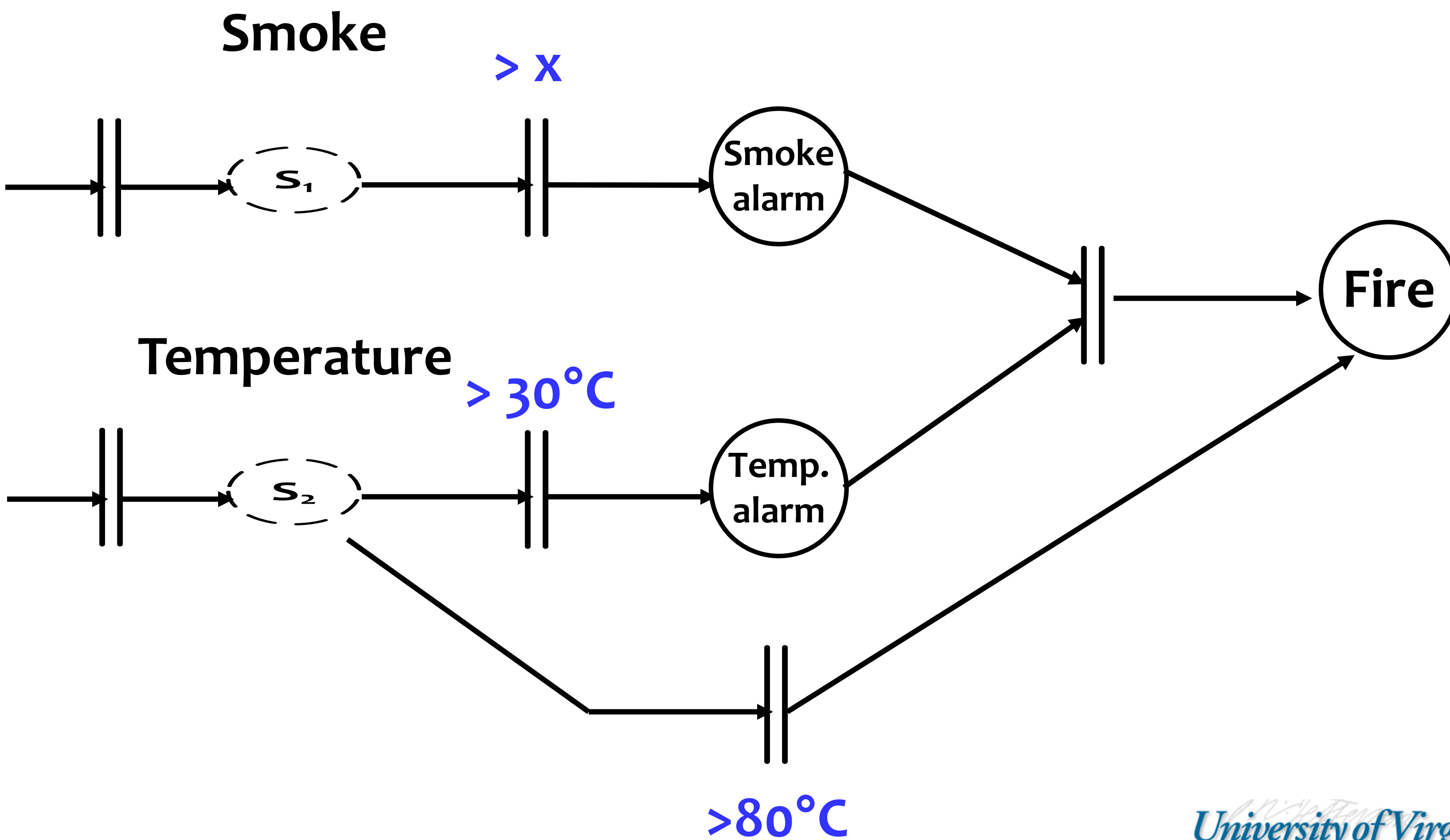
Model-based Specification

Sensor Network Event Description Language (*SNEDL*)



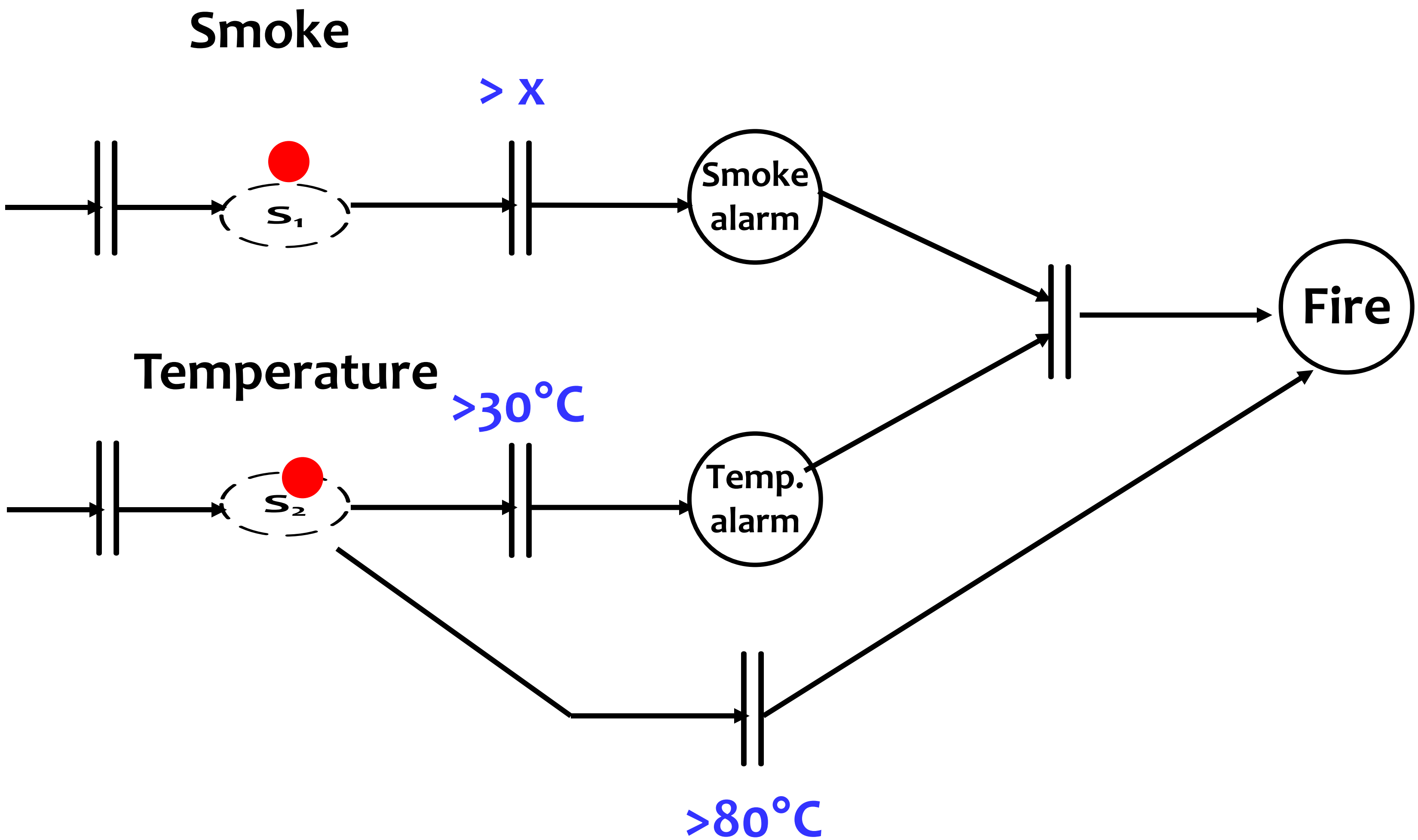
Test Specification

//Declare the basic elements of the language
Time T1;
Region R1, R2;
Event FireEvent;

//Define the elements (time and place)
T1=07:00:00, */1/2010; //first day of month
R1={Room1};
R2={Room2};

FireEvent = Fire @ T1;

Token Flow



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Code Generation

- Code is automatically generated from the formal model
- Advantages of the token – flow model:
  - efficiently supports self-testing at run time
  - it is easy to monitor execution states and collect running traces
  - we can easily distinguish between real and test events

Validate-aware SW

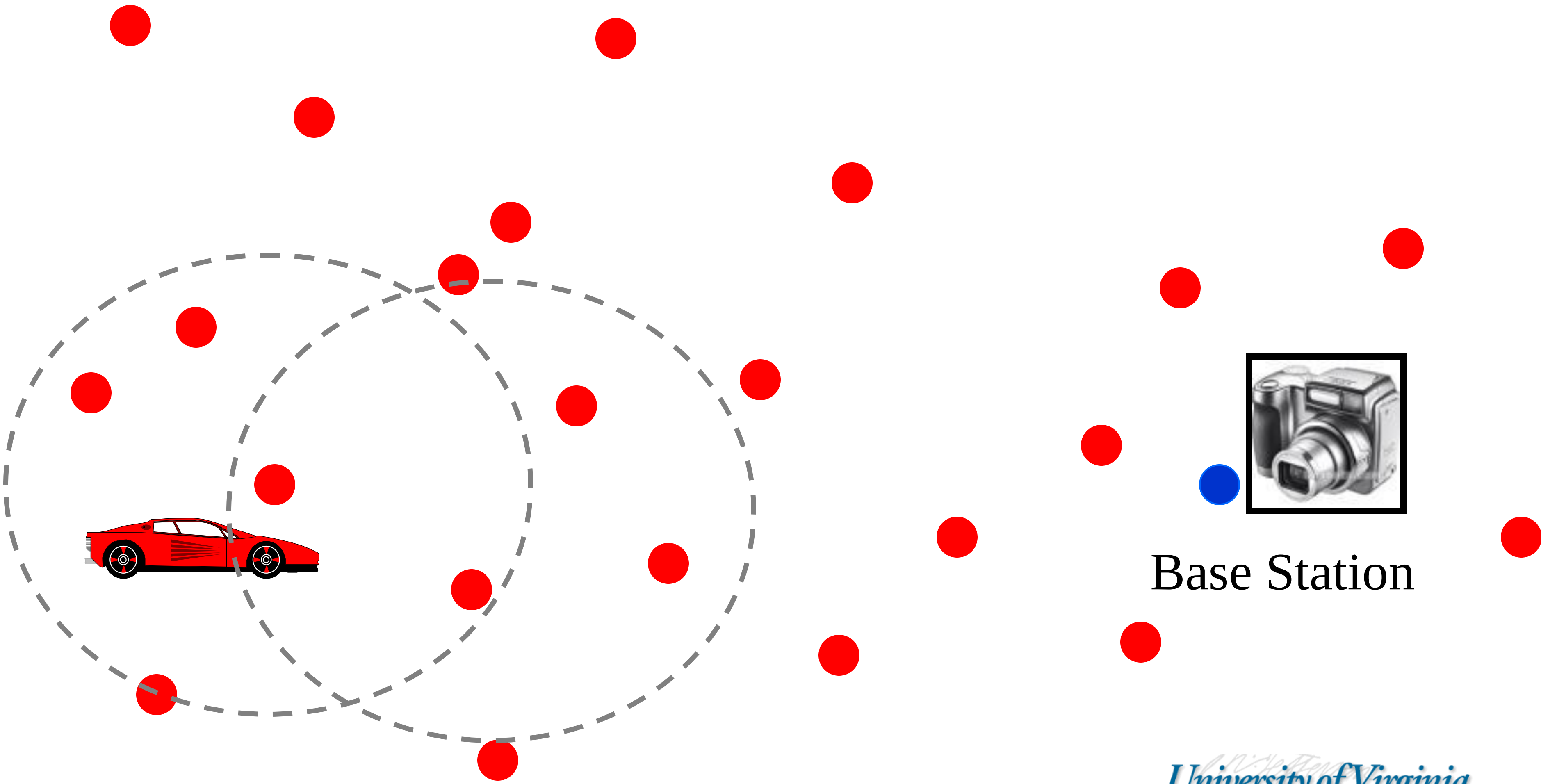
- High level spec on "function"
- Runtime SW that targets demonstrating "validation"
- SW design for ease of validation
- Framework – to load, run, display tests
- System: Be aware of validation mode

Real-Time Aware

- Hard deadlines
- Hard deadlines and safety critical
- Soft deadlines
- Time based QoS

- Dynamically changing platform (HW and SW)

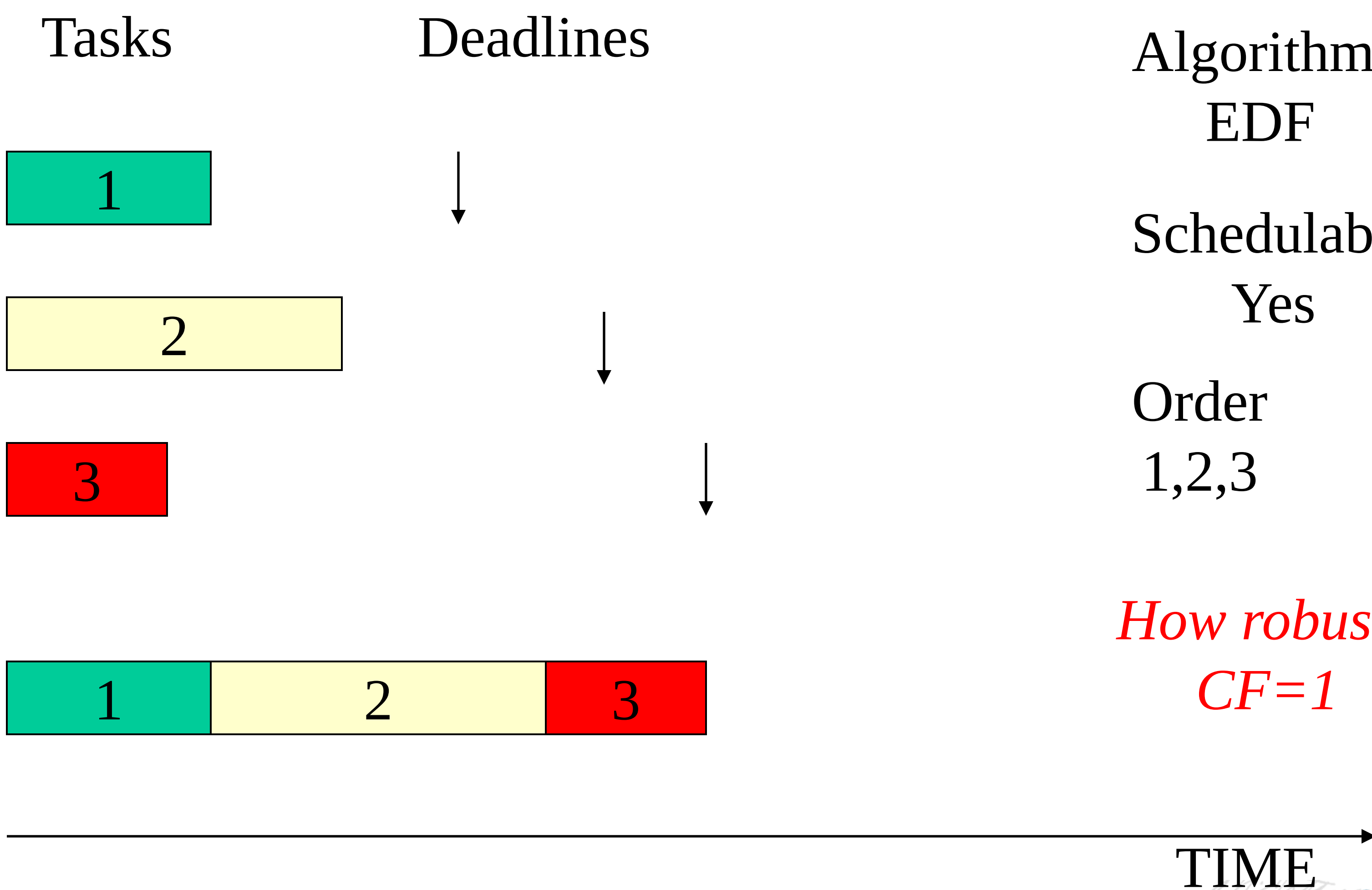
Example: Group Management (Tracking)



Deadlines

- If we have enough late messages within groups we can lose the track
  - Not straightforward deadline
  - Tied to redundancy, speed of target
- If messages don't make it to base station in hard deadline we miss activating "IR camera"
- If we don't act by Deadline D truck carrying bomb explodes – safety critical

Real-Time Scheduling



Algorithm
EDF

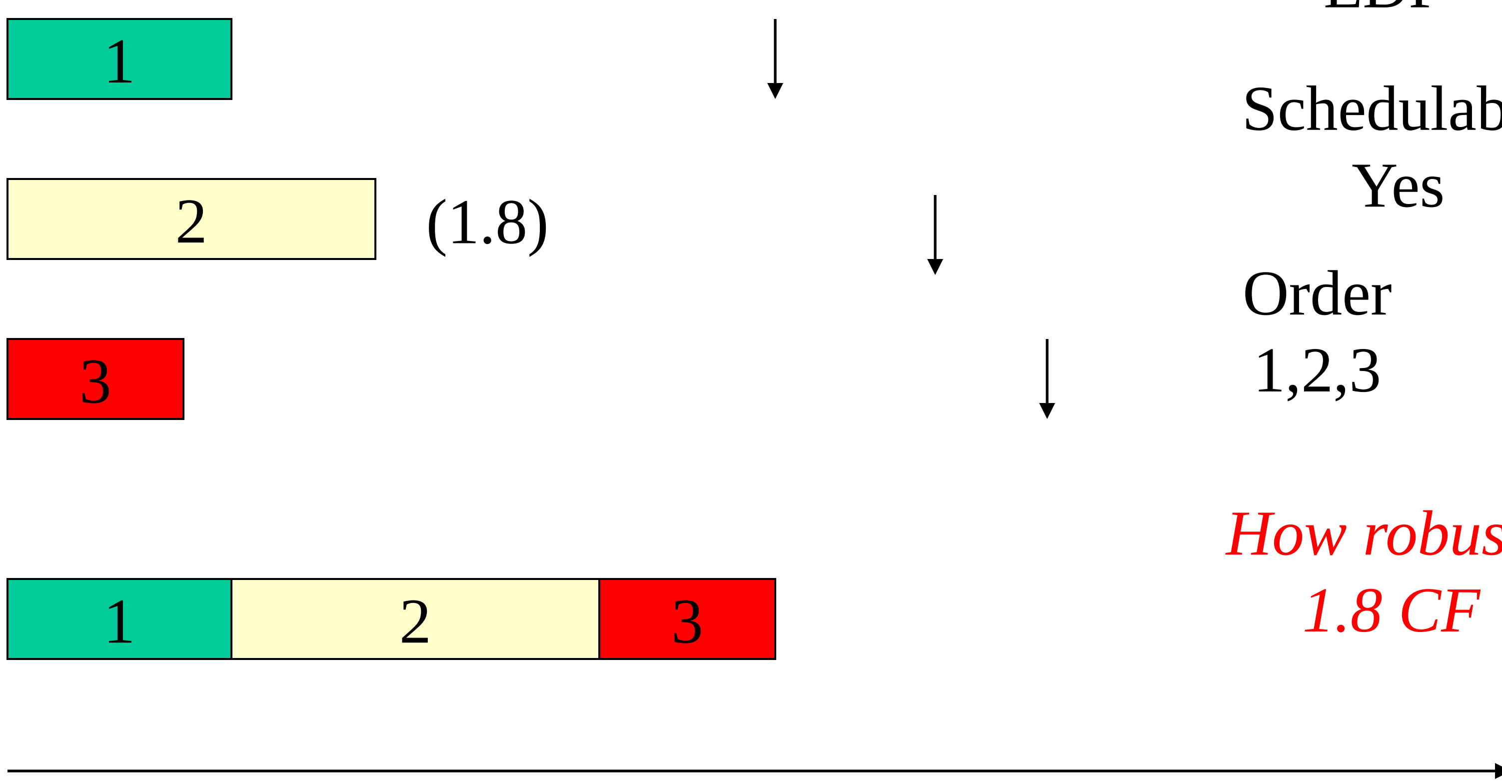
Schedulable
Yes

Order
1,2,3

How robust?
CF=1

Robust RT Scheduling For Real World CPS

Tasks Deadlines



TIME

Algorithm
EDF

Schedulable
Yes

Order
1,2,3

How robust?
1.8 CF

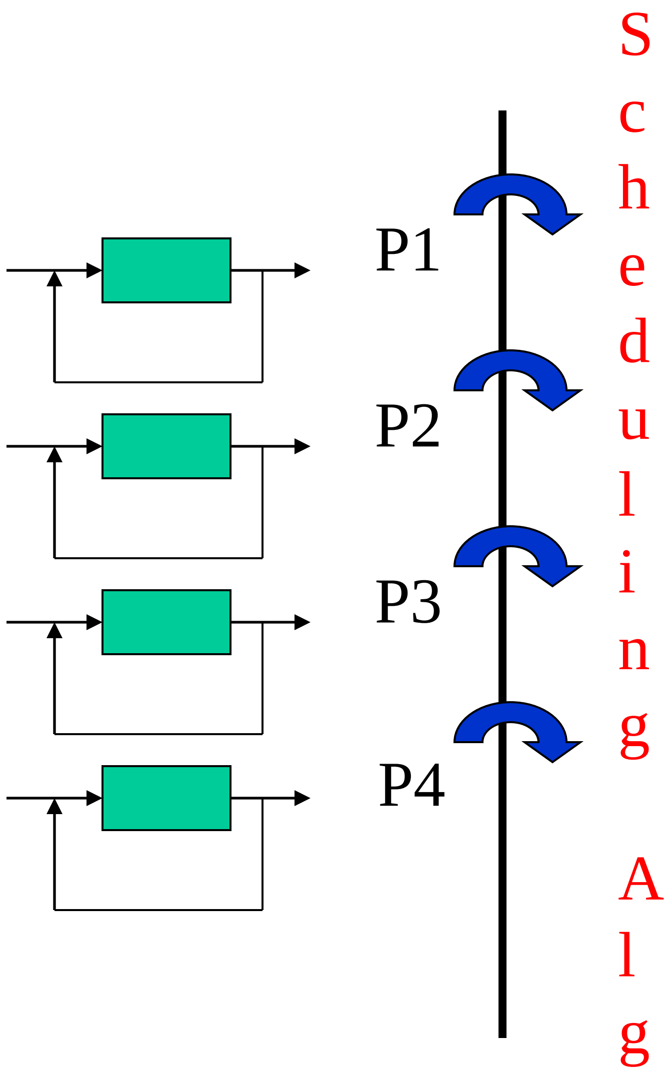
Real-Time Technology

- Three possible approaches
  - Velocity Monotonic
  - Exact Characterization

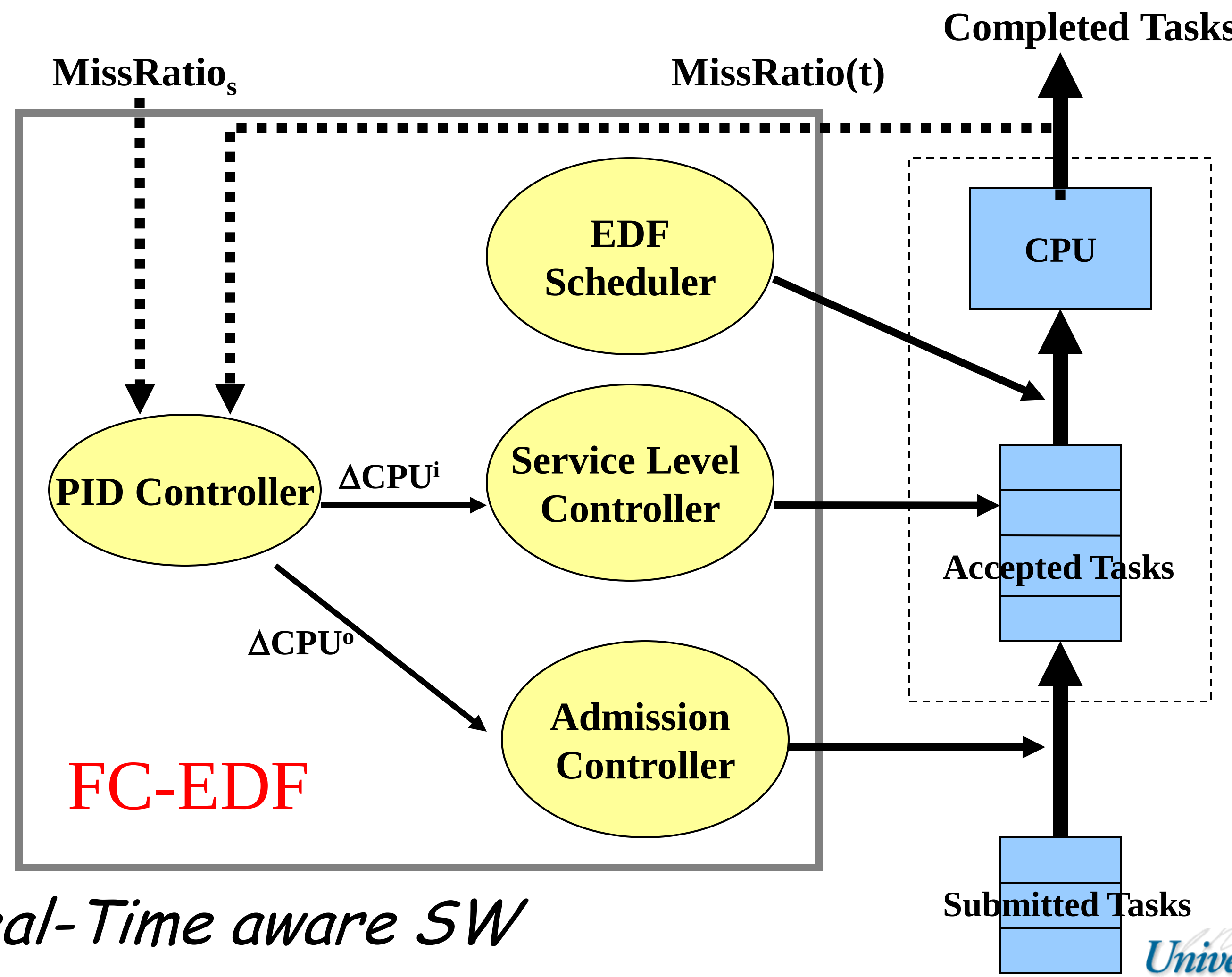
  - SW-based Control Theory

Feedback Control

- Front-End
  - feedback loops based on real world control
  - generate timing requirements/rates
  - generally fixed
  - handed to scheduling algorithm

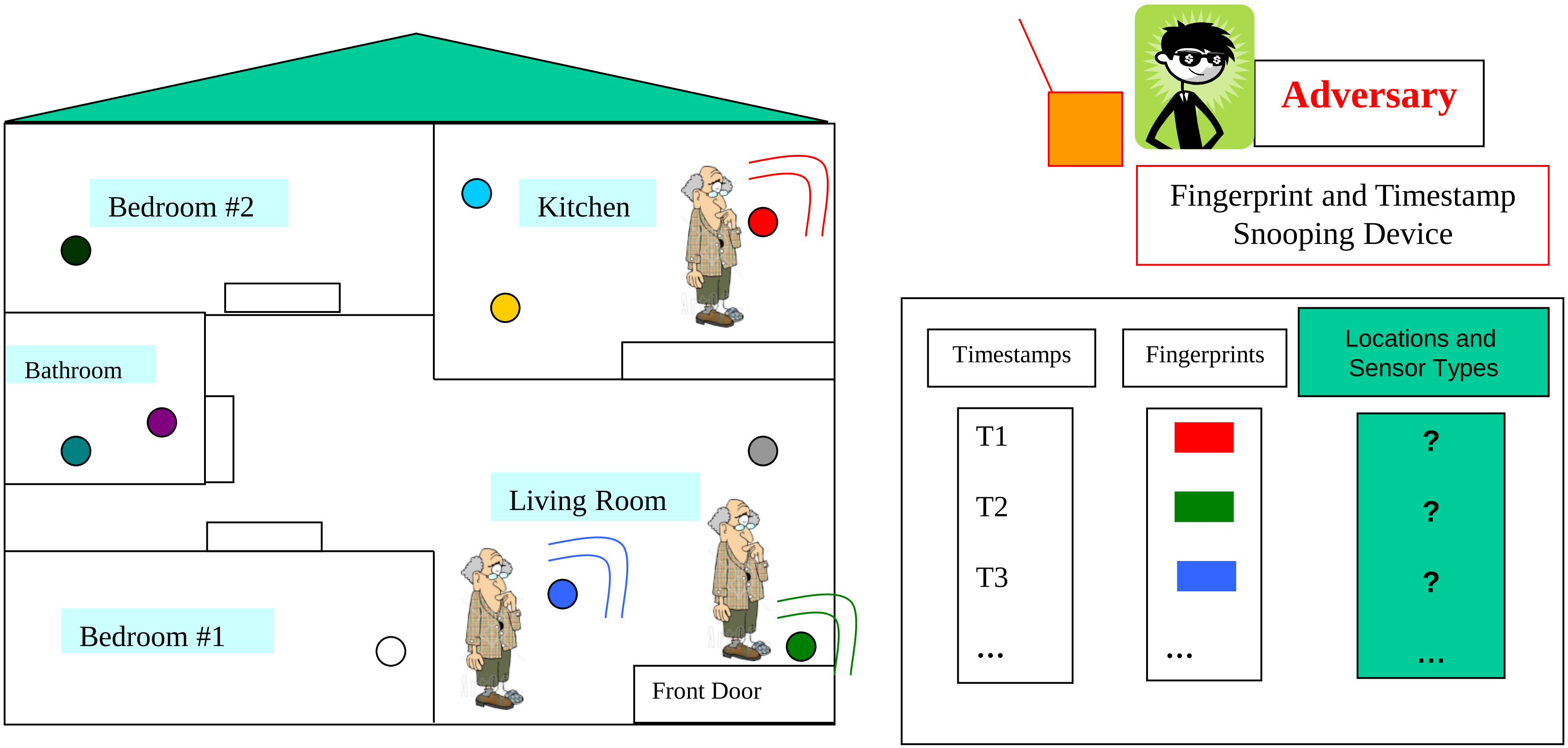


FC-EDF Scheduling



Real-Time aware SW

Privacy-aware: Fingerprint And Timing-based Snoop attack



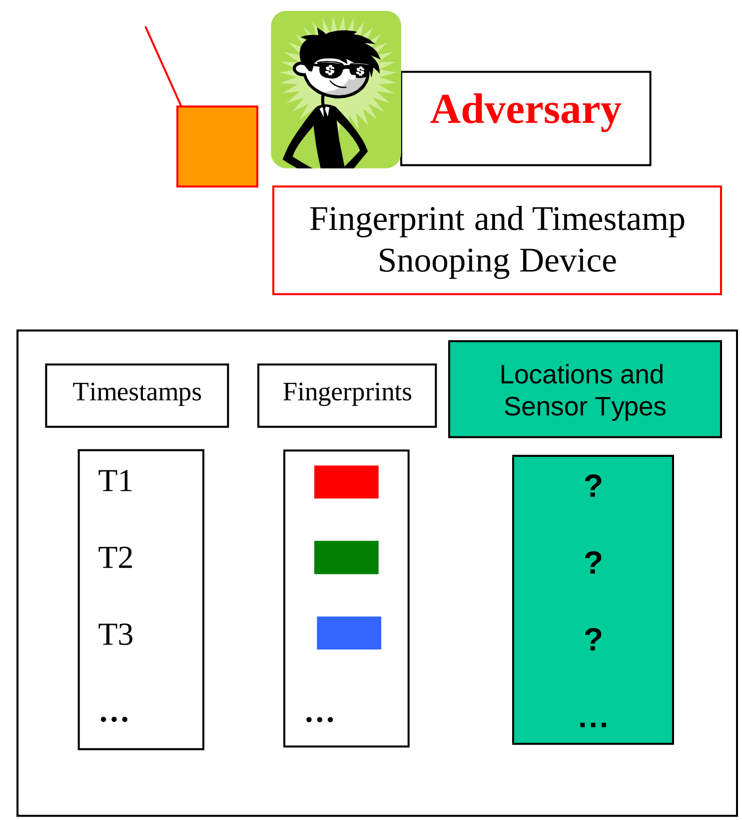
V. Srinivasan, J. Stankovic, K. Whitehouse, Protecting Your Daily In-Home Activity Information fron a Wireless Snooping Attack, Ubicomp, 2007.

Performance

- 8 homes - different floor plans
  - Each home had 12 to 22 sensors
- 1 week deployments
- 1, 2, 3 person homes
- Violate Privacy - Techniques Created
  - 80-95% accuracy of AR via 4 Tier Inference
- FATS solutions
  - Reduces accuracy of AR to 0-15%

ADL

- **ADLs inferred:**
  - Sleeping, Home Occupancy
  - Bathroom and Kitchen Visits
  - Bathroom Activities: Showering, Toileting, Washing
  - Kitchen Activities: Cooking
- High level medical information inference possible
- HIPAA requires healthcare providers to protect this information



Solutions

- Periodic
- Delay messages
- Add extra cloaking messages
- Eliminate electronic fingerprint
  - Potentiometer
- Etc.

Privacy-aware software

Summary

- Robustness – to deal with uncertainties: (major environment and system evolution)
- Real-Time – for dynamic and open systems
- Openness – great value, but difficult

- Physically-aware
- Validate-aware
- Real-Time-aware
- Privacy/security-aware

**aware*
CPS-aware

- Diversity – coverage of assumptions

- EAL