Academic excellence for business and the professions

Probabilistic modelling of cyber threats in Cyber-physical systems

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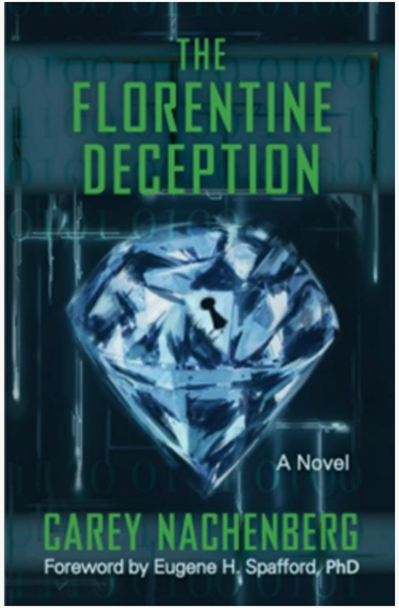
Separating Science Fantasy from Science facts



"If there's one disadvantage to spending more than a quarter of a century in security, it's that you become hypersensitised to ***mangled terminology and fantasy passed off as current science****"*

David Harley, Senior Research Fellow, ESET

Cyber Security Facts

- Computer systems, especially cyber-physical systems, are **complex**, and their complexity will only continue to increase.
- **Absolute cyber security is unattainable**.
- Cyber systems intended to be secure must **operate through attacks.**
- Protect the best you can, but realize that **perfect protection is impossible, so <u>resilience</u>** can only be achieved **through tolerating attacks**
  - This, in turn, **may require online detection and response**.
- **Assessment** of the “amount” of security that a particular approach to resilience provides **is essential**.
  - Even if assumptions are made that are ***difficult to justify***

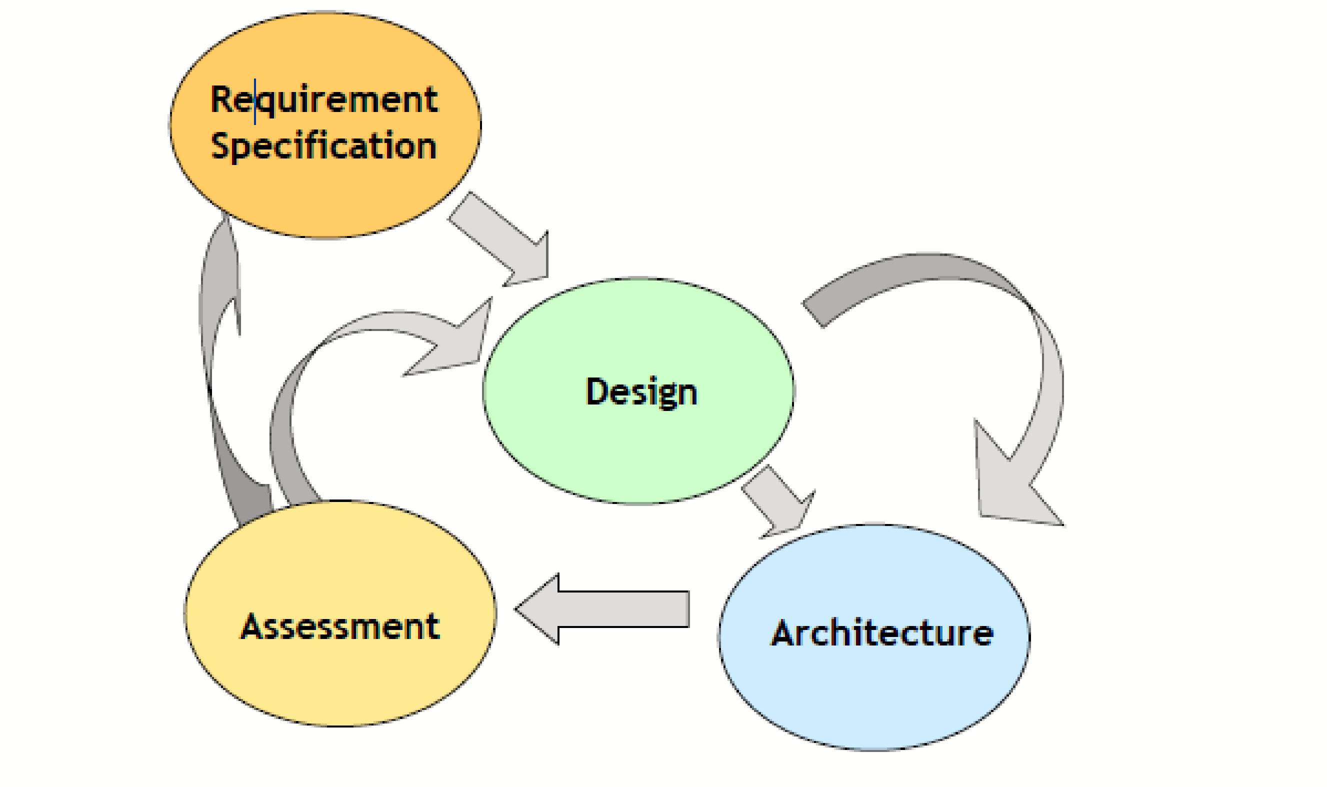
- **Perfect cyber security is science fantasy, and perfection is the <u>enemy</u> of good.**

What is needed?

Assured Trustworthy System Operation in Hostile Environments

- **Trustworthy operation**
  - System does what it is supposed to do and nothing else.
  - Requirements are met – Reliability/Availability, Security, Safety (when applicable), Performance, etc.
- **Tolerate (to a degree) a hostile environment**
  - Accidental failures, Design flaws, malicious cyber attacks.
  - Consider the cyber, physical and social aspects
- **Provide assurance through assessment**
  - Provide justification (evidence, argument) that the system is ***fit for purpose***, remaining risks are acceptable for ***anticipated environment***
  - Compare design alternatives and choose the most resilient (trustworthy) system design.
    - This must be done *before* the system is deployed and ***continuously reviewed***.

Engineering for resilience



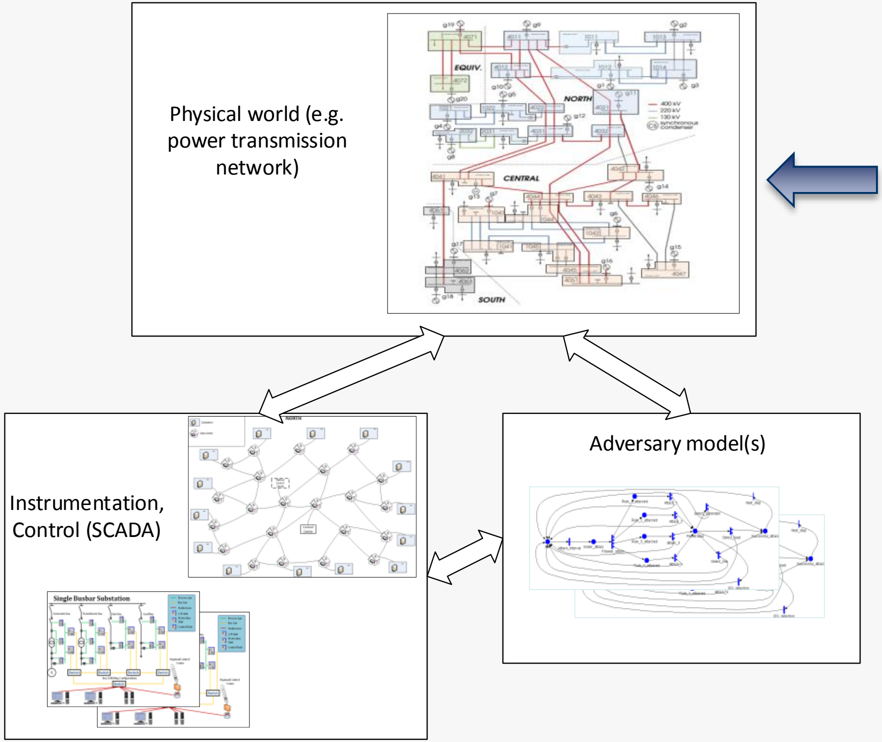
Sabbatical Leave: Oct 2016 – Sept 2017

- Visits of US with the financial support from UK GCHQ
  - Duke University (Prof Kishor Trivedi)
    - A recognized authority in solving ***Markov chains*** (CTMC) and semi-Markov processes. Invented Stochastic Petri Nets, etc.

  - University of Illinois at Urbana-Champaign (Prof Bill Sanders)
    - A recognized authority in ***model-based assessment*** (performance, reliability, security). Creator of the popular stochastic modelling tool, Mobius.

  - Johns Hopkins University (Prof Yair Amir)
    - A recognized authority in distributed systems, especially in ***protocol for reliable communication*** (reliable multicast, Byzantine agreement protocols, etc.) Created popular tools for reliable communication such as Spread and Spines overlay.

Duke University: Efficient solution for complex hybrid models



For several years now with my group we have worked with a model of NORDIC – 32, a power transmission network, extended with instrumentation, compliant with IEC 61850.

I reported on this work in previous visits to DESSERT (in 2014).

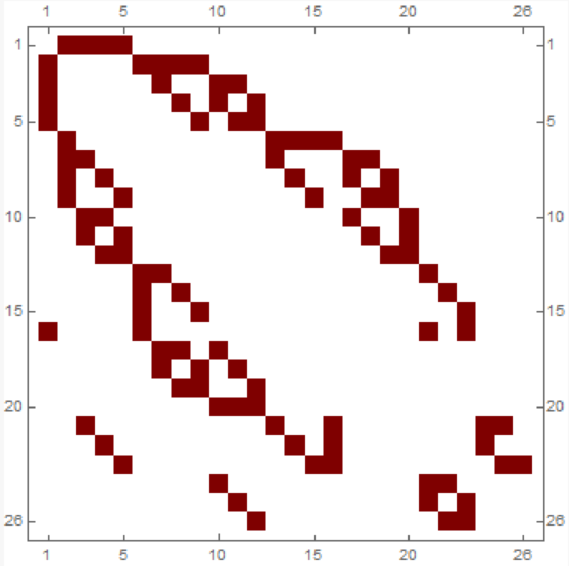
- A complex hybrid model (probabilistic and deterministic) including models of Adversary attacking the assets of transmission network.

Efficient solution for complex *hybrid* models

- Looked at various extensions of Petri nets (e.g. fluid Petri nets) to deal with *continuous* state space.
- Looked at ways of speeding up simulations:
  - It turned out that deterministic models (power-flows calculations including the optimal load shedding, ***optimal power-flow*** (OPF)) take more than 90% of simulation time;
  - Caching the OPF results led to ***dramatic reduction of simulation time***
- Looked at ***truncation of the state space*** (really very large without truncation, $\sim 2^{1500}$)
  - Limiting the number of simultaneous accidental failures
  - The effect of deterministic models was captured.
    - a set of elements might be ***switched off*** (disconnected elements ***cannot fail*** until reconnected again)
    - Transition probability matrix affected by switching-off of components.

Efficient solution (2)

- Currently we are working on a numeric ***transient availability solution*** of NORDIC-32 power sub-system.
- Below is an illustration from a ***feasibility study***.



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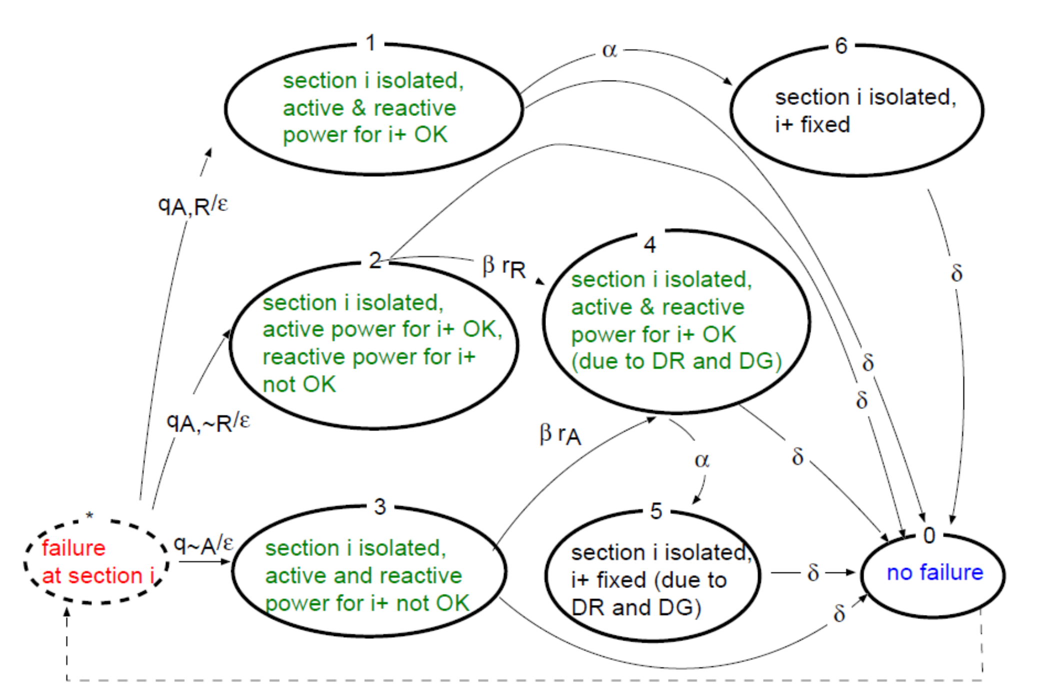
Efficient solution (3)

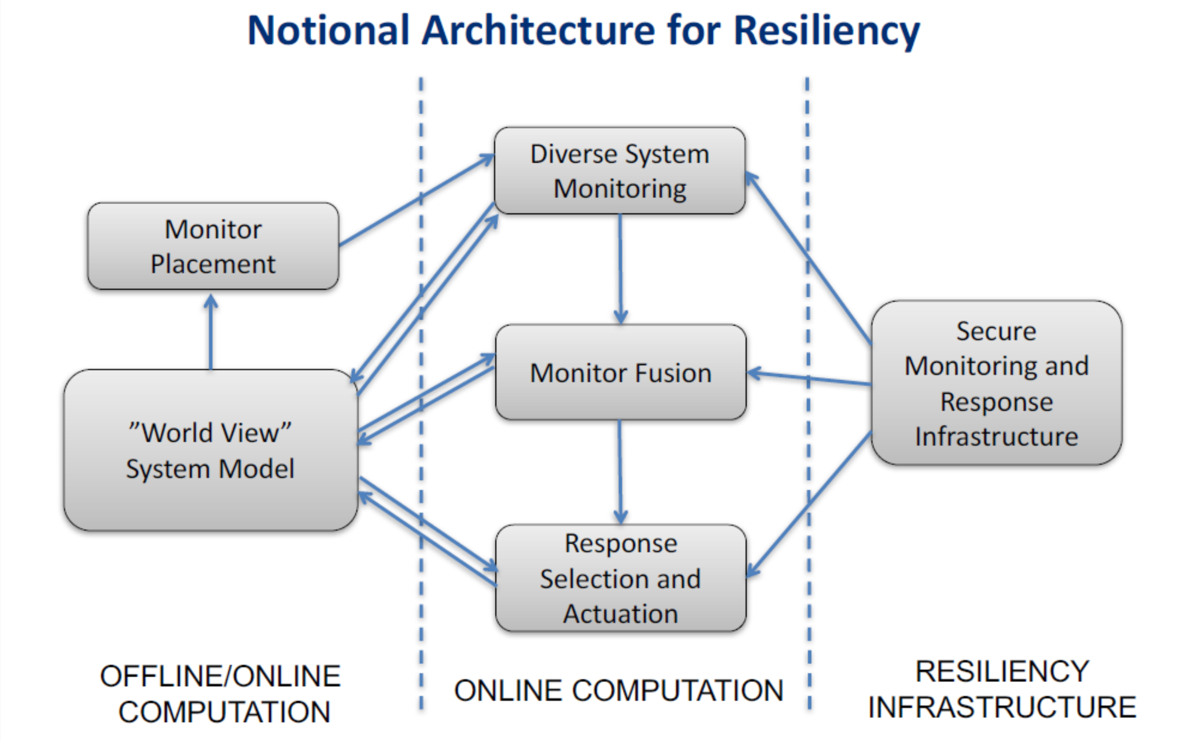
- Transient solution seems feasible if the state space is truncated to 3 or even 4 ***simultaneous failures***
  - These many simultaneous failures have never been observed in our simulations of NORDIC-32 (many elements could be switched-off though)
  - Probability of exceeding the threshold of simultaneous failures can be calculated
- Transient solution will tell us:
  - Whether ***steady-state is achievable*** within a given horizon (e.g. a year or 10 years)
  - Solution is expected to be much faster than simulation
    - Markov Decision Processes (MDP) and other artificial intelligence (AI) techniques become feasible for ***sensitivity analysis*** on model parameters.
    - ***Conservative parameterization*** of an Adversary model becomes feasible.

Other ideas from interacting with Duke

- Survivability analysis
  - Eliminates the need to define ***intensity*** of cyber attacks
  - Focus on how a power system behaves ***post successful attack.***
- Interestingly, the Duke solution depends on an ***aggregated model***, of the state of the power system
  - Own work on "risk communication models" applies.
  - Kishor suggested that we add ***transient analysis*** to our work to get additional insight.

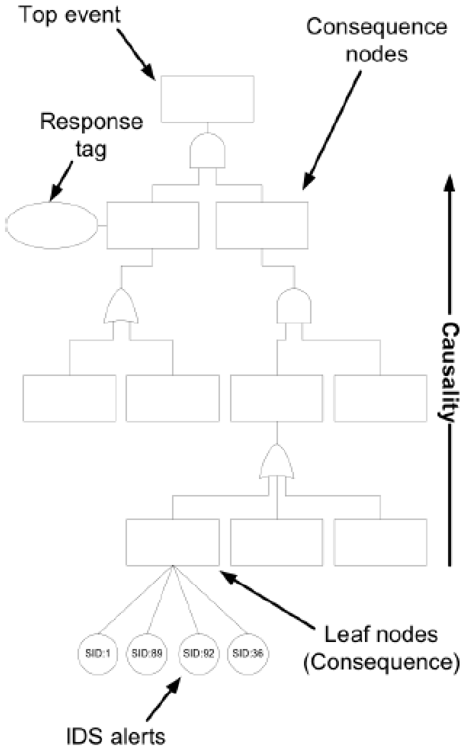


University of Illinois at Urbana Champaign (UIUC)

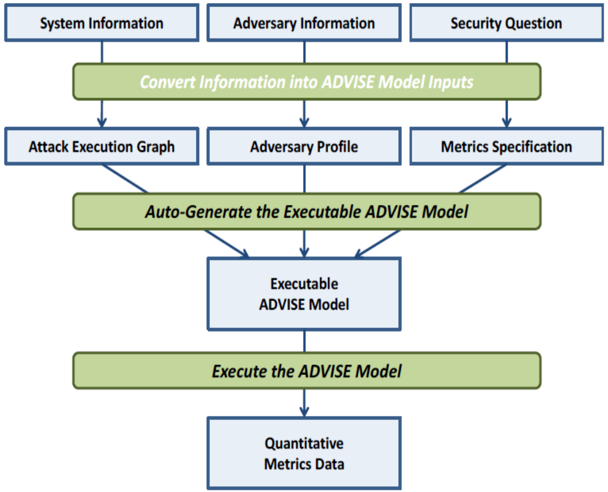


UIUC (2): Rapid Response Engine (RRE)

- **RRE: a real-time automatic, scalable, adaptive and cost-sensitive intrusion response system**
  - Accounts for planned adversarial behavior
  - Accounts for uncertainties in IDS alerts
- Models adversary behavior and responses using **Attack-Response Tree** (ART)
- Employs a game-theoretic response strategy against adversaries in a two-player Stackelberg game
- Developed distributed and hierarchical prototype implementation

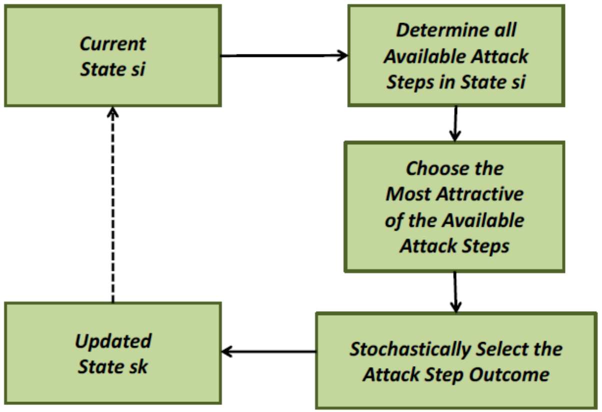


UIUC (3): ADVISE

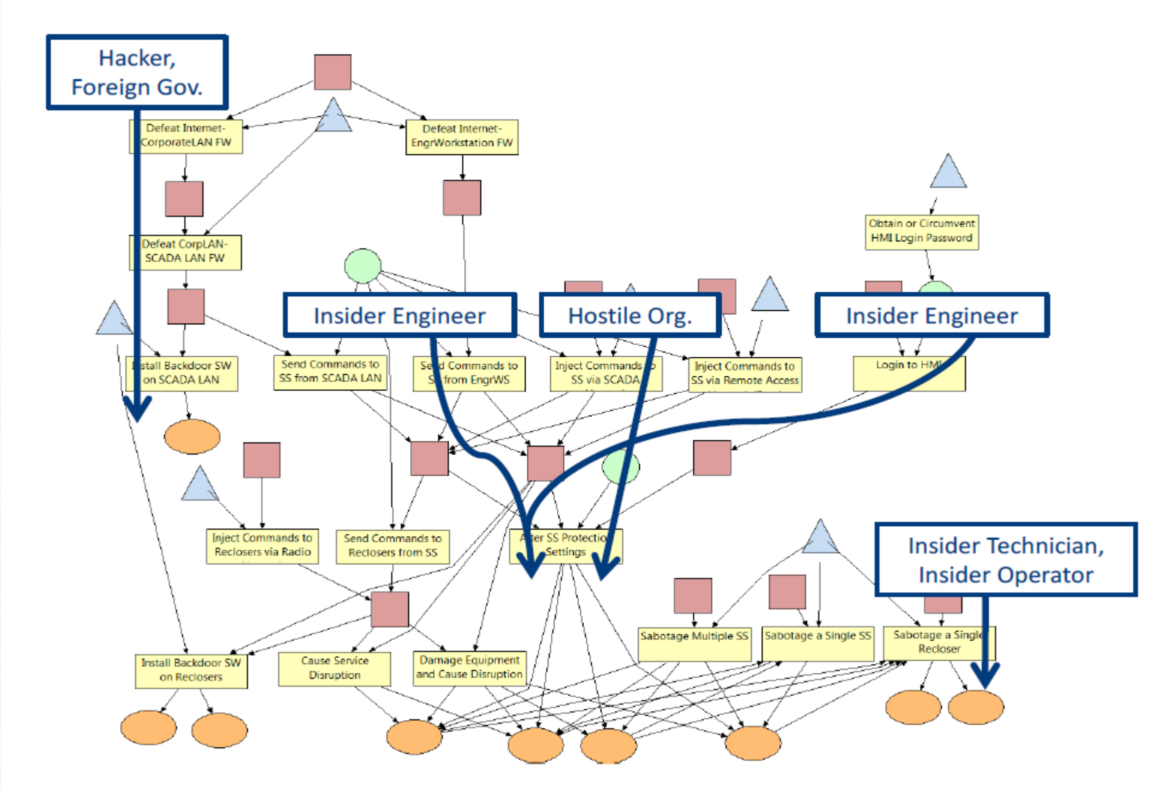


Model Execution: the Attack Decision Cycle

- The adversary selects the most attractive available attack step based on his attack preferences.
- State transitions are determined by the outcome of the attack step chosen by the adversary.



UIUC (4): ADVISE META



ADVISE META contains an ***attack ontology*** using Attack Execution Graphs (AEG).

For a given communication network all AEG are generated automatically by the tool.

Impact of actions (as in MDP) is defined by the Modeller.

City’s collaboration with UIUC

- *Contributions* to ADVISE META ontology
  - Models of attacks that we have worked with in NORDIC-32
  - Models of attacks that we have identified as interesting, e.g. on special purpose software such as SE/WAMS.
- *Integration* of ADVISE META with NORDIC-32
  - NORDIC – 32 model of power system (simulation of using the numeric solver) will compute the ***impact*** of actions taken by an adversary.
  - Initial agreement reached on this with Bill Sanders and Ken Keefe, the chief developer of Mobius (ADVISE META)
- Access to the *test bed* of industrial control systems (power system simulators and real equipment) available at UIUC.

Interaction with Johns Hopkins

- I delivered a 1-day seminar on modelling the effect of cyber attacks on reliability of a 2-channel software system
  - I am to deliver a lecture on this tomorrow, the 19th of May.
- My work is relevant to their work on ***intrusion tolerant architectures*** built with a Byzantine agreement protocol.
- Agreed to work together and validate the sufficient conditions for Byzantine protocol to be guaranteed to work correctly.

- The colleagues briefed me on their own work on a "resilient SCADA", which is currently under development. Their plan is to use the resilient communication (based on spines overlays).
  - They plan to release the resilient SCADA as open source.
  - Might be of interest here at KhAI, too.

Thank you

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